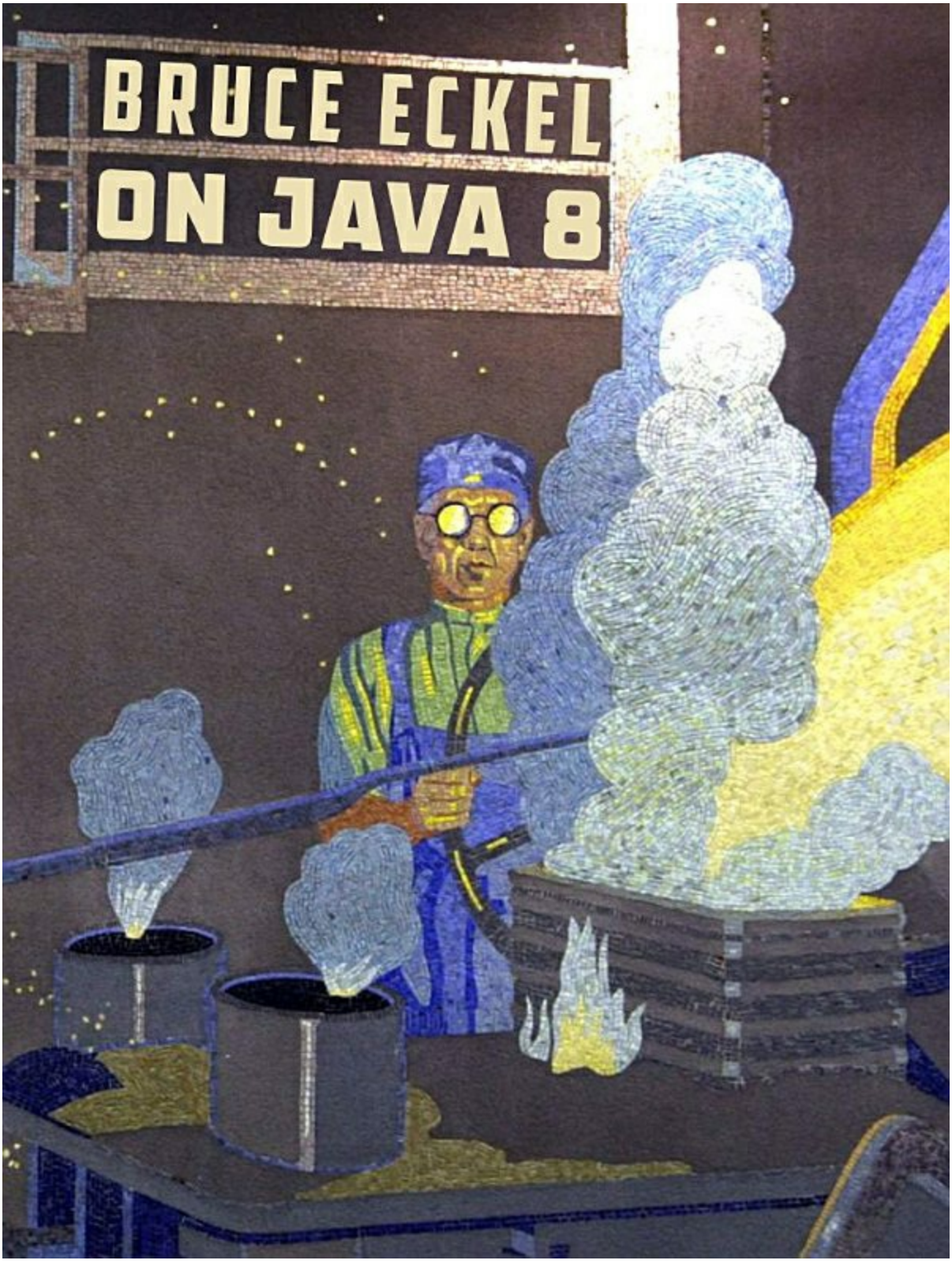

On Java 8

Bruce Eckel

MindView LLC

2017

On Java 8

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This book is available for purchase at www.OnJava8.com,

where you'll also find supporting materials.

This book was created as an eBook for tablets and computers. That is, it was not first created for print and then converted. It is an eBook first—all layout and formatting is designed to optimize your viewing experience on the various eBook reading platforms and systems.

Cover design by Daniel Will-Harris, www.Will-Harris.com

Preface

This book teaches the most modern form

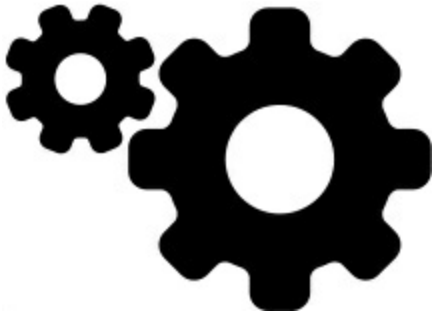
of Java programming using the features

in the 8th version of that language.

My previous Java book, *Thinking in Java, 4th Edition* (Prentice Hall 2006), is still useful for programming in Java 5, the version of the language used for Android programming. But especially with the advent of Java 8, the language has changed significantly enough that new Java code feels and reads differently. This justified the two-year effort of creating a new book.

On Java 8 is designed for someone with a basic foundation in programming. For beginners, web sites like Code.org and Khan Academy can provide at least some of that background, along with the *Thinking in C* seminar freely available at the OnJava8 Site. Services like YouTube, blogs and StackOverflow have made finding answers ridiculously easy compared to just a few years ago when we relied on print media. Combine these with perseverance, and you can use this book as your first programming text. It's also intended for professional programmers who want to expand their knowledge.

I am grateful for all the benefits from *Thinking in Java*, mostly in the form of speaking engagements all over the world. It has proved



invaluable in creating connections with people and companies for my Reinventing Business project. One of the reasons I finally wrote this book is to support my *Reinventing Business* research, and it seems the next logical step is to actually create a so-called *Teal Organization*. I hope this book can become a kind of crowdfunding for that project.

Goals

Each chapter teaches a concept, or a group of associated concepts, without relying on features that haven't yet been introduced. That way you can digest each piece in the context of your current knowledge before moving on.

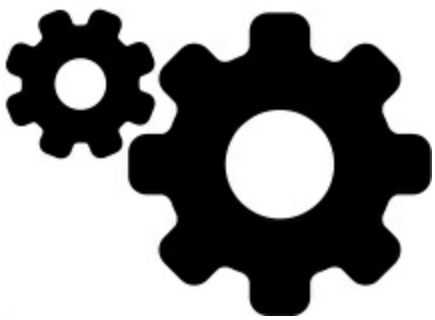
My goals in this book are to:

1. Present the material one step at a time so you can easily incorporate each idea before moving on, and to carefully sequence the presentation of features so you're exposed to a topic before

you see it in use. This isn't always possible; in those situations, a brief introductory description is given.

2. Use examples that are as simple and short as possible. This sometimes prevents me from tackling "real world" problems, but I've found that beginners are usually happier when they can understand every detail of an example rather than being impressed by the scope of the problem it solves. For this I might receive criticism for using "toy examples," but I'm willing to accept that in favor of producing something pedagogically useful.

3. Give you what I think is important for you to understand about the language, rather than everything I know. I believe there is an information importance hierarchy, and there are some facts that 95 percent of programmers will never need to know—details that just confuse people and increase their perception of the complexity of the language. If *you* must think about it, it will also confuse the reader/maintainer of that code, so I advocate



choosing a simpler approach.

4. Provide you with a solid foundation so you understand the issues well enough to move on to more difficult coursework and books.

Language Design

Errors

Every language has design errors. New programmers experience deep uncertainty and frustration when they must wade through features and guess at what they should use and what they shouldn't. It's embarrassing to admit mistakes, but this bad beginner experience is a lot worse than the discomfort of acknowledging you were wrong about something. Alas, every failed language/library design experiment is forever embedded in the Java distribution.

The Nobel laureate economist Joseph Stiglitz has a philosophy of life that applies here, called *The Theory of Escalating Commitment*:

"The cost of continuing mistakes is borne
by others, while the cost of admitting
mistakes is borne by yourself."

If you've read my past writings, you'll know that when I find design errors in a language, I tend to point them out. Java has developed a particularly avid following, folks who treat the language more like a

country of origin and less like a programming tool. Because I've written about Java, they assume I am a fellow patriot. When I criticize the errors I find, it tends to have two effects:

1. Initially, a lot of "my-country-right-or-wrong" furor, which typically dies down to isolated pockets. Eventually—this can take years—the error is acknowledged and seen as just part of the history of Java.
2. More importantly, new programmers don't go through the struggle of wondering why "they" did it this way, especially the self-doubt that comes from finding something that just doesn't seem right and naturally assuming *I must be doing it wrong or I just don't get it*. Worse, those who teach the language often go right along with the misconceptions rather than delving in and analyzing the issue. By understanding the language design errors, new programmers can understand that something was a mistake, and move ahead.

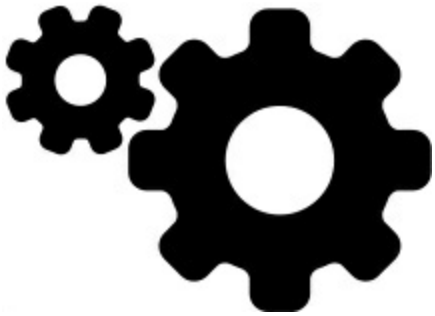
Understanding language and library design errors is essential because of the impact they have on programmer productivity. Some companies and teams choose to avoid certain features because, while seductive on the surface, those features can block your progress when you least

expect it. Design errors also inform the creation and adoption of new languages. It's fun to explore what can be done with a language, but design errors tell you what *can't* be done with that language.

For many years, I honestly felt a lack of care from the Java designers regarding their users. Some of these errors seemed so blatant, so poorly thought-out, that it appeared the designers had some other motivation in mind instead of serving their users. There was a lot of notoriety around the Java language for a long time, and perhaps that's where the seduction was. This seeming lack of respect for programmers is the major reason I moved away from Java and didn't want anything to do with it for such a long time.

When I did start looking into Java again, something about Java 8 felt very different, as if a fundamental shift had occurred in the designers' attitude about the language and its users. Many features and libraries that had been warts on the language were fixed after years of ignoring user complaints. New features felt very different, as if there were new folks on board who were extremely interested in programmer experience. These features were—finally—working to make the language better rather than just quickly adding ideas without delving into their implications. And some of the new features are downright

elegant (or at least, as elegant as possible given Java constraints). I can



only guess that some person or people have departed the language group and this has changed the perspective.

Because of this new focus by the language developers—and I don't think I'm imagining it—writing this book has been dramatically better than past experiences. Java 8 contains fundamental and important improvements. Alas, because of Java's rigid backwards-compatibility promise, these improvements required great effort so it's unlikely we'll see anything this dramatic again (I hope I'm wrong about this). Nonetheless, I applaud those who have turned the ship as much as they have and set the language on a better course. For the first time I can ever recall, I found myself saying "I love that!" about some of the Java code I've been able to write in Java 8.

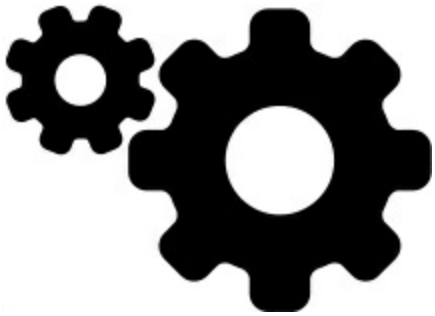
Ultimately, the timing for this book seems good, because Java 8 introduces important features that strongly affect the way code is written, while—so far—Java 9 seems to focus on the understory of the

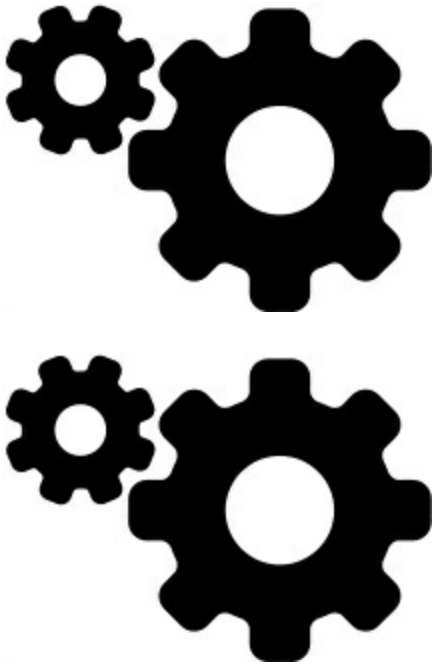
language, bringing important infrastructure features but not those that affect the kind of coding focused on in this book. However, because it's an eBook, if I discover something I think requires an update or an addition, I can push the new version to existing customers.

Tested Examples

The code examples in this book compile with Java 8 and the Gradle build tool. All the examples are in a freely-accessible Github repository.

Without a built-in test framework with tests that run every time you do a build of your system, you have no way of knowing whether your code is reliable. To accomplish this in the book, I created a test system to display and validate the output of most examples. The output from running an example is attached, as a block comment, at the end of examples that produce output. In some cases only the first few lines are shown, or first and last lines. Embedded output improves the





reading and learning experience, and provides yet another way to verify the correctness of the examples.

Popularity

Java’s popularity has significant implications. If you learn it, getting a job will probably be easier. There are a lot more training materials, courses, and other learning resources available. If you’re starting a company and you choose to work in Java, it’s much easier to find programmers, and that’s a compelling argument.

Short-term thinking is almost always a bad idea. Don’t use Java if you really don’t like it—using it just to get a job is an unhappy life choice. As a company, think hard before choosing Java just because you can hire people. There might be another language that makes fewer

employees far more productive for your particular need.

But if you do enjoy it, if Java *does* call to you, then welcome. I hope this book will enrich your programming experience.

Android Programmers

I've made this book as "Java 8 as possible," so if you want to program for Android devices, you must study Java 5, which I cover in *Thinking in Java, 4th edition*. At the time of publishing of *On Java 8*, *Thinking in Java, 4th Edition* has become a free download, available through www.OnJava8.com. *Thinking in Java, 4th Edition* is available in print from Prentice-Hall. In addition, there are many other resources that specialize in Android programming.

This is Only an eBook

On Java 8 is only available as an eBook, and only via www.OnJava8.com. Any other source or delivery mechanism is illegitimate. There is no print version.

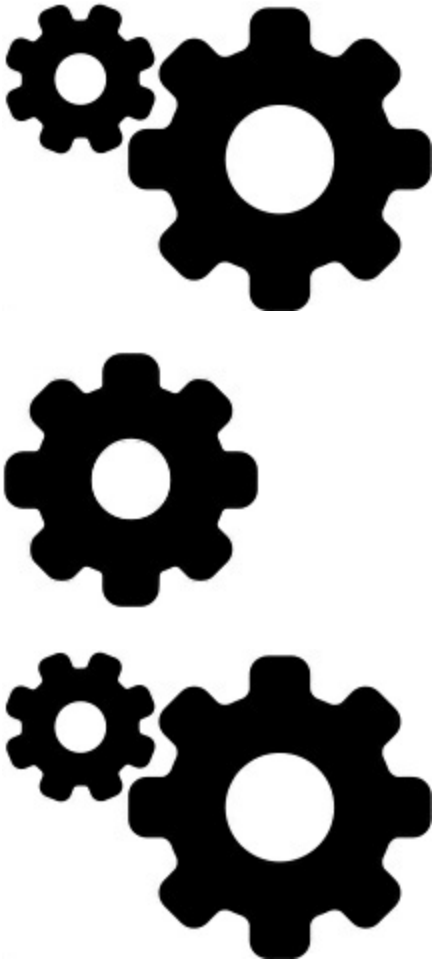
This book is far too large to publish as a single print volume, and my intent has always been to only publish it as an eBook. Color syntax highlighting for code listings is, alone, worth the cost of admission. Searchability, font resizing or text-to-voice for the vision-impaired, the fact you can always keep it with you—there are so many benefits to eBooks it's hard to name them all.

Anyone buying this book needs a computer to run the programs and write code, and the eBook reads nicely on a computer (I was also surprised to discover that it even reads tolerably well on a phone). However, the best reading experience is on a tablet computer. Tablets are inexpensive enough that you can now buy one for less than you'd pay for an equivalent print version of this book. It's much easier to read a tablet in bed (for example) than trying to manage the pages of a physical book, especially one this big. When working at your computer, you don't have to hold the pages open when using a tablet at your side. It might feel different at first, but I think you'll find the benefits far outweigh the discomfort of adapting.

I've done the research, and Google Play Books works on, and provides a very nice reading experience, every platform, including Linux and iOS devices. As an experiment, I've decided to try publishing

exclusively through Google Books.

Note: *At the time of this writing, reading the book through the*



Google Play Books web browser app was—although tolerable—the least satisfying viewing experience. I strongly advocate using a tablet computer instead.

Colophon

This book was written with Pandoc-flavored Markdown, and produced into ePub version 3 format using Pandoc.

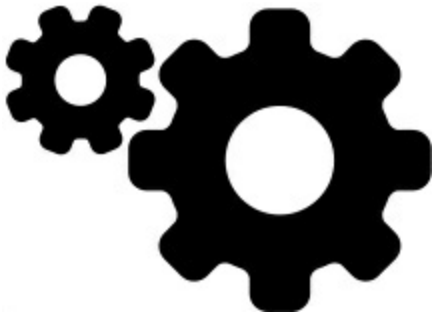
The body font is Georgia and the headline font is Verdana. The code font is Ubuntu Mono, because it is especially compact and allows more characters on a line without wrapping. I chose to place the code inline (rather than make listings into images, as I've seen some books do) because it was important to me that the reader be able to resize the font of the code listings when they resize the body font (otherwise, really, what's the point?).

The build process for the book was automated, as well as the process to extract, compile and test the code examples. All automation was achieved through fairly extensive programs I wrote in Python 3.

Cover Design

The cover of *On Java 8* is from a mosaic created through the *Works Progress Administration* (WPA, a huge project during the US Great Depression from 1935-1943 which put millions of out-of-work-people back to work). It also reminds me of the illustrations from *The Wizard of Oz* series of books. My friend and designer, Daniel Will-Harris (www.will-harris.com) and I just liked the image.

Thanks



Thanks to Eric Evans (author of *Domain-Driven Design*) for suggesting the book title, and to everyone else in the conference newsgroups for their help in finding the title.

Thanks to James Ward for starting me with the Gradle build tool for this book, and for his help and friendship over the years. Thanks to Ben Muschko for his work polishing the build files, and Hans Dockter for giving Ben the time.

Jeremy Cerise and Bill Frasure came to the developer retreat for the book and followed up with valuable help.

Thanks to all who have taken the time and effort to come to my conferences, workshops, developer retreats, and other events in my town of Crested Butte, Colorado. Your contributions might not be easily seen, but they are deeply important.

Dedication

For my beloved father, E. Wayne Eckel.

April 1, 1924—November 23, 2016.

Introduction

“The limits of my language are the limits
of my world”—Wittgenstein

This is true of both spoken/written languages and programming languages. It’s often subtle: A language gently guides you into certain modes of thought and away from others. Java is particularly opinionated.

Java is a derived language. The original language designers didn’t want to use C++ for a project, so created a new language which unsurprisingly looked a lot like C++, but with improvements (their original project never came to fruition). The core changes were the incorporation of a *virtual machine* and *garbage collection*, both of which are described in detail in this book. Java is also responsible for pushing the industry forward in other ways; for example, most languages are now expected to include documentation markup syntax and a tool to produce HTML documentation.

One of the most predominant Java concepts came from the SmallTalk language, which insists that the “object” (described in the next

chapter) is the fundamental unit of programming, so everything must be an object. Time has tested this belief and found it overenthusiastic. Some folks even declare that objects are a complete failure and should be discarded. Personally, I find that making everything an object is not only an unnecessary burden but also pushes many designs in a poor direction. However, there are still situations where objects shine. Requiring that everything be an object (especially all the way down to the lowest level) is a design mistake, but banning objects altogether seems equally draconian.

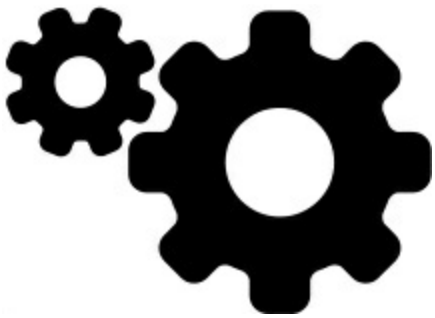
Other Java language decisions haven't panned out as promised. Throughout this book I attempt to explain these so you not only understand those features, but also why they might not feel quite right to you. It's not about declaring that Java is a good language or a bad one. If you understand the flaws and limitations of the language you will:

1. Not get stymied when you encounter a feature that seems "off."
2. Design and code better by knowing where the boundaries are.

Programming is about managing complexity: the complexity of the problem, laid upon the complexity of the machine. Because of this complexity, most of our programming projects fail.

Many language design decisions are made with complexity in mind, but at some point other issues are considered essential. Inevitably, those other issues are what cause programmers to eventually “hit the wall” with a language. For example, C++ had to be backward-compatible with C (to allow easy migration for C programmers), as well as efficient. Those are both useful goals and account for much of the success of C++, but they also expose extra complexity that prevent some projects from finishing. Certainly, you can blame programmers and management, but if a language can help by catching your mistakes, why shouldn’t it?

Visual BASIC (VB) was tied to BASIC, which wasn’t really designed as an extensible language. All the extensions piled upon VB have produced some truly un-maintainable syntax. Perl is backward-compatible with **awk**, **sed**, **grep**, and other Unix tools it was meant to replace, and as a result it is often accused of producing “write-only code” (that is, you can’t read your own code). On the other hand, C++,



VB, Perl, and other languages such as SmallTalk had *some* of their design efforts focused on the issue of complexity and as a result are remarkably successful in solving certain types of problems.

The communication revolution enables all of us to communicate with each other more easily: one-on-one as well as in groups and as a planet. I've heard it suggested that the next revolution is the formation of a kind of global mind that results from enough people and enough interconnectedness. Java might or might not be one of the tools for that revolution, but at least the possibility has made me feel like I'm doing something meaningful by attempting to teach the language.

Prerequisites

This book assumes you have some programming familiarity, so you understand:

A program is a collection of statements

The idea of a subroutine/function/macro

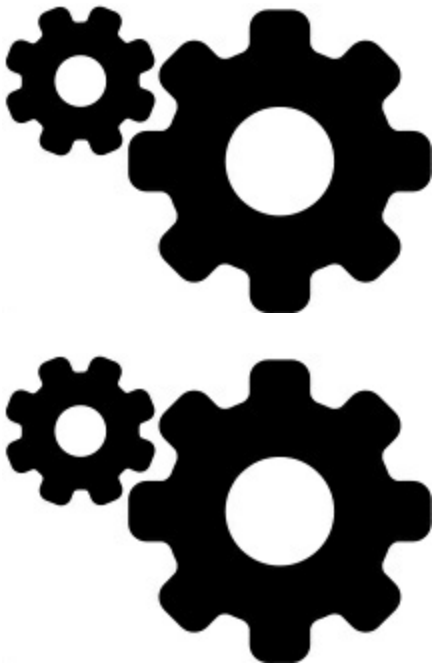
Control statements such as "if" and looping constructs such as "while"

Etc.

You might have learned this in many places, typically school, books, or the Internet. As long as you you feel comfortable with the basic ideas

of programming, you can work through this book. The *Thinking in C* multimedia seminar freely downloadable from OnJava8.com will bring you up to speed on the fundamentals necessary to learn Java. *On Java 8* does introduce the concepts of object-oriented programming (OOP) and Java's basic control mechanisms.

Although I make references to C and C++ language features, these are not intended to be insider comments, but instead to help all



programmers put Java in perspective with those languages, from which, after all, Java is descended. I attempt to make these references simple and to explain anything that might be unfamiliar to a non-C/C++ programmer.

JDK HTML

Documentation

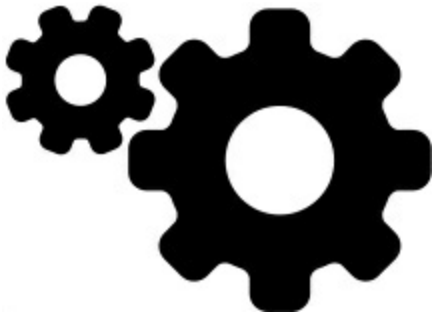
The *Java Development Kit* (JDK) from Oracle (a free download) comes with documentation in electronic form, readable through your Web browser. Unless necessary, this book will not repeat that documentation, because it's usually much faster to find the class descriptions with your browser than to look them up in a book (also, the online documentation is current). I'll simply refer to "the JDK documentation." I'll provide extra descriptions of the classes only when it's necessary to supplement that documentation so you understand a particular example.

Thinking in C

The *Thinking in C* multimedia seminar is freely downloadable from www.OnJava8.com. This gives an introduction to the C syntax, operators, and functions that are the foundation of Java syntax.

Thinking in C also provides a gentle introduction to coding, assuming even less about the student's programming background than does this book.

I commissioned Chuck Allison to create *Thinking in C* as a standalone product, which was later included in book CDs, and finally reworked as a free download. By freely providing this seminar online, I can ensure that everyone begins with adequate preparation.



Source Code

All the source code for this book is available as copyrighted freeware,

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classroom and other educational situations.

The primary goal of the copyright is to ensure that the source of the

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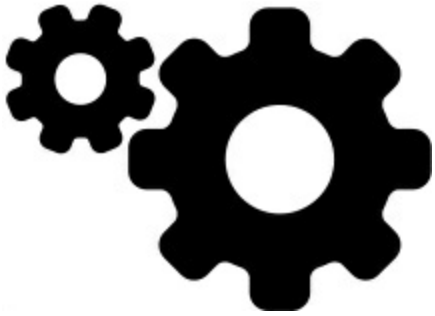
Please note that MindView LLC maintains a Web site which

is the sole distribution point for electronic copies of the Source Code, https://github.com/BruceEckel/OnJava8-examples, where it is freely available under the terms stated above.



If you think you've found an error in the Source Code, please submit a correction at: https://github.com/BruceEckel/OnJava8-examples/issues

You may use the code in your projects and in the classroom (including your presentation materials) as long as the copyright notice that appears in each source file is retained.

Coding Standards

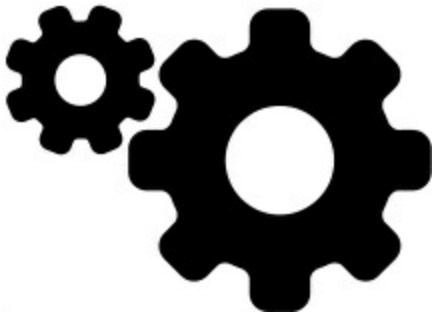
In the text of this book, identifiers (keywords, methods, variables, and class names) are set in bold, fixed-width **code font**. Some keywords, such as **class**, are used so much that the bolding can become tedious. Those which are distinctive enough are left in normal font.

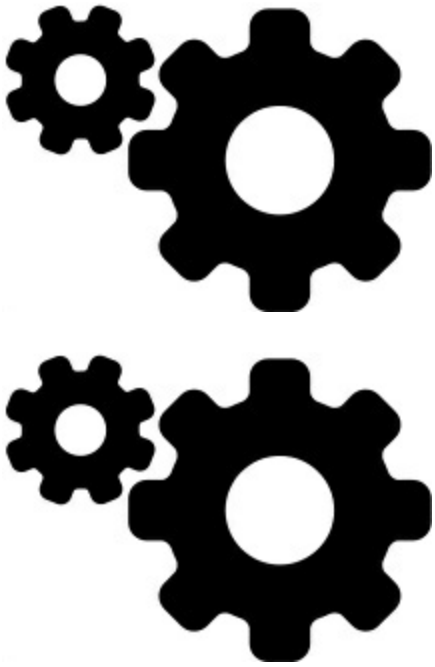
I use a particular coding style for the examples in this book. As much

as possible within the book's formatting constraints, this follows the style that Oracle itself uses in virtually all code you find at its site, and seems to be supported by most Java development environments. As the subject of formatting style is good for hours of hot debate, I'll just say I'm not trying to dictate correct style via my examples; I have my own motivation for using the style I do. Because Java is a free-form programming language, continue to use whatever style you're comfortable with. One solution to the coding style issue is to use an IDE (*integrated development environment*) tool like IntelliJ IDEA, Eclipse or NetBeans to change formatting to that which suits you.

The code files in this book are tested with an automated system, and should work without compiler errors (except those specifically tagged) in the latest version of Java.

This book focuses on and is tested with Java 8. If you must learn about earlier releases of the language not covered here, the 4th edition of





Thinking in Java is freely downloadable at www.OnJava8.com.

Bug Reports

No matter how many tools a writer uses to detect errors, some always creep in and these often leap off the page for a fresh reader. If you discover anything you believe to be an error, please submit the error along with your suggested correction, for either the book's prose or examples, here. Your help is appreciated.

Mailing List

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What About User

Interfaces?

Graphical user interfaces and desktop programming in Java have had a tumultuous—some would say tragic—history.

The original design goal of the graphical user interface (GUI) library in Java 1.0 was to enable the programmer to build a GUI to look good on all platforms. That goal was not achieved. Instead, the Java 1.0 *Abstract Windowing Toolkit* (AWT) produced a GUI that looked equally mediocre on all systems. In addition, it was restrictive; you could use only four fonts and you could not access any of the more sophisticated GUI elements that exist in your operating system. The Java 1.0 AWT programming model was also awkward and non-object-oriented. A student in one of my seminars (who had been at Sun during the creation of Java) explained why: The original AWT had been conceived, designed, and implemented in a month. Certainly a marvel of productivity, and also an object lesson in why design is important.

The situation improved with the Java 1.1 AWT event model, which took a much clearer, object-oriented approach, along with the addition of JavaBeans, a component programming model (now dead) oriented toward the easy creation of visual programming environments. Java 2

(Java 1.2) finished the transformation away from the old Java 1.0 AWT by essentially replacing everything with the *Java Foundation Classes* (JFC), the GUI portion of which is called “Swing.” These are a rich set of JavaBeans that create a reasonable GUI. The *revision 3* rule of the software industry (“a product isn’t good until revision 3”) seems to hold true with programming languages as well.

It seemed that Swing was the final GUI library for Java. This assumption turned out to be wrong—Sun made a final attempt, called *JavaFX*. When Oracle bought Sun they changed the original ambitious project (which included a scripting language) into a library, and now it appears to be the only UI toolkit getting development effort (see the Wikipedia article on JavaFX)—but even that effort has diminished. JavaFX, too, seems eventually doomed.

Swing is still part of the Java distribution (but it only receives maintenance, no new development), and with Java now an open-source project it should always be available. Also, Swing and JavaFX have some limited interactivity, presumably to aid the transition to JavaFX.

Ultimately, desktop Java never took hold, and never even touched the designers’ ambitions. Other pieces, such as JavaBeans, were given

much fanfare (and many unfortunate authors spent a lot of effort writing books solely on Swing and even books just on JavaBeans) but never gained any traction. Most usage you'll see for desktop Java is for integrated development environments (IDEs) and some in-house corporate applications. People do develop user interfaces in Java, but it's safe to consider that a niche usage of the language.

If you must learn Swing, it's covered in the freely-downloadable *Thinking in Java, 4th Edition* (available at www.OnJava8.com), and in books dedicated to the topic.

What is an Object?

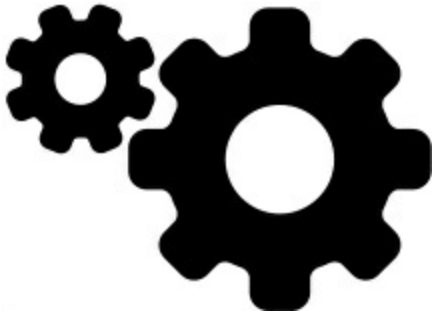
"We do not realize what tremendous power the structure of an habitual language has. It is not an exaggeration to say that it enslaves us through the mechanism of semantic reactions and that the structure which a language exhibits, and impresses upon us unconsciously, is automatically projected upon the world around us."—Alfred

Korzybski (1930)

The genesis of the computer revolution was in a machine. Our programming languages thus tend to look like that machine.

But computers are not so much machines as they are mind amplification tools (“bicycles for the mind,” as Steve Jobs was fond of saying) and a different kind of expressive medium. As a result, tools are beginning to look less like machines and more like parts of our minds.

Programming languages are the fabric of thought for creating



applications. Languages take inspiration from other forms of expression such as writing, painting, sculpture, animation, and filmmaking.

Object-oriented programming (OOP) is one experiment in using the computer as an expressive medium.

Many people feel uncomfortable wading into object-oriented programming without understanding the big picture, so the concepts

introduced here give you an overview of OOP. Others might not understand such an overview until they are exposed to the mechanism, becoming lost without seeing code. If you're part of this latter group and are eager to get to the specifics of the language, feel free to jump past this chapter—skipping it now will not prevent you from writing programs or learning the language. However, come back here eventually to fill in your knowledge so you understand why objects are important and how to design with them.

This chapter assumes you have some programming experience, although not necessarily in C. If you need more preparation in programming before tackling this book, work through the *Thinking in C* multimedia seminar, freely downloadable from www.OnJava8.com.

The Progress of Abstraction

All programming languages are abstractions. It can be argued that the complexity of the problems you're able to solve is directly related to the kind and quality of abstraction. By "kind" I mean, "What is it you are abstracting?" Assembly language is a minimal abstraction of the underlying machine. Many so-called "imperative" languages (such as FORTRAN, BASIC, and C) were themselves abstractions of assembly language. Although they were big improvements, their primary

abstraction still requires you to think in terms of the structure of the computer rather than the structure of the problem you are trying to solve. The programmer must establish the association between the machine model (the “solution space,” the place where you’re implementing that solution, such as a computer) and the model of the problem that is actually solved (the “problem space,” the place where the problem exists, such as a business). The effort required to perform this mapping, and the fact it is extrinsic to the programming language, produces programs that are difficult to write and expensive to maintain.

The alternative to modeling the machine is to model the problem you’re trying to solve. Early languages such as LISP and APL chose particular views of the world (“All problems are ultimately lists” or “All problems are algorithmic,” respectively). Prolog casts all problems into chains of decisions. Languages have been created for constraint-based programming and for programming exclusively by manipulating graphical symbols. Each of these approaches can be a good solution to the particular class of problem they’re designed to solve, but when you step outside of that domain they become awkward.

The object-oriented approach goes a step further by providing tools for

the programmer to represent elements in the problem space. This representation is general enough that the programmer is not constrained to any particular type of problem. We refer to the elements in the problem space and their representations in the solution space as “objects.” (Note that some objects don’t have problem-space analogs.) The idea is that the program adapts itself to the lingo of the problem by adding new types of objects. When you read the code describing the solution, you’re reading words that also express the problem. This is a more flexible and powerful language abstraction than what we’ve had before. Thus, OOP describes the problem in terms of the problem, rather than in terms of the computer where the solution will run. There’s still a connection, because objects look somewhat like little computers: Each has state and performs operations. This is similar to objects in the real world—they all have characteristics and behaviors.

Alan Kay summarized five basic characteristics of SmallTalk, the first successful object-oriented language and a language that inspired Java. These characteristics represent a pure approach to object-oriented programming:

1. **Everything is an object**. Think of an object as a fancy variable;

it stores data, but you can “make requests”, asking it to perform operations on itself. You can usually take any conceptual component in the problem you’re trying to solve (dogs, buildings, services, etc.) and represent it as an object in your program.

2. **A program is a bunch of objects telling each other what to do by sending messages**. When you “send a message” to an object, it’s a request to call a method that belongs to that object.

3. **Each object has its own memory made up of other objects**. Put another way, you create a new kind of object by packaging existing objects. This hides the complexity of a program behind the simplicity of objects.

4. **Every object has a type**. Each object is an *instance* of a *class*, where “class” is (approximately) synonymous with “type.” The most important distinguishing characteristic of a class is “What messages can you send to it?”

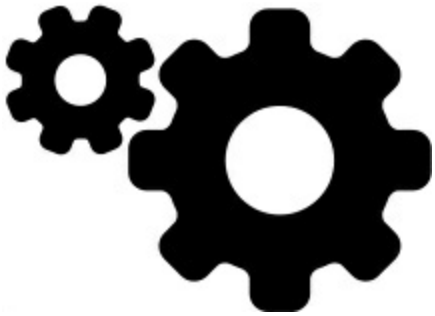
5. **All objects of a particular type can receive the same messages**. This is a loaded statement, as you will see later. Because an object of type “circle” is also an object of type “shape,” a circle is guaranteed to accept shape messages. This means you can write code that talks to shapes and automatically handles

anything that fits the description of a shape. This *substitutability* is a foundation of OOP.

Grady Booch offers an even more succinct description of an object:

An object has state, behavior and identity

This means an object can have internal data (which gives it state),



methods (to produce behavior), and each object is uniquely distinguished from every other object—that is, every object has a unique address in memory. [1]

An Object Has an Interface

Aristotle was probably the first to begin a careful study of the concept of *type*; he spoke of “the class of fishes and the class of birds.” The idea that all objects, while unique, are also part of a class of objects that have characteristics and behaviors in common was used directly in the first object-oriented language, Simula-67, with its fundamental keyword **class** that introduces a new type into a program.

Simula, as its name implies, was created for developing simulations such as the classic “bank teller problem.” In this, you have numerous tellers, customers, accounts, transactions, and units of money—many “objects.” Objects that are identical except for their state are grouped together into “classes of objects,” and that’s where the keyword **class** arose.

Creating abstract data types (classes) is a fundamental concept in object-oriented programming. Abstract data types work almost exactly like built-in types: You create variables of a type (called *objects* or *instances* in object-oriented parlance) and manipulate those variables (called *sending messages* or *requests*; you send a message and the object figures out what to do with it). The members (elements) of each class share some commonality: Every account has a balance, every teller can accept a deposit, etc. At the same time, each member has its own state: Each account has a different balance, each teller has a name. Thus, the tellers, customers, accounts, transactions, etc., can each be represented with a unique entity in the program. This entity is the object, and each object belongs to a particular class that defines its characteristics and behaviors.

So, although what we really do in object-oriented programming is

create new data types, virtually all object-oriented programming languages use the “class” keyword. When you see the word “type” think “class” and vice versa.2

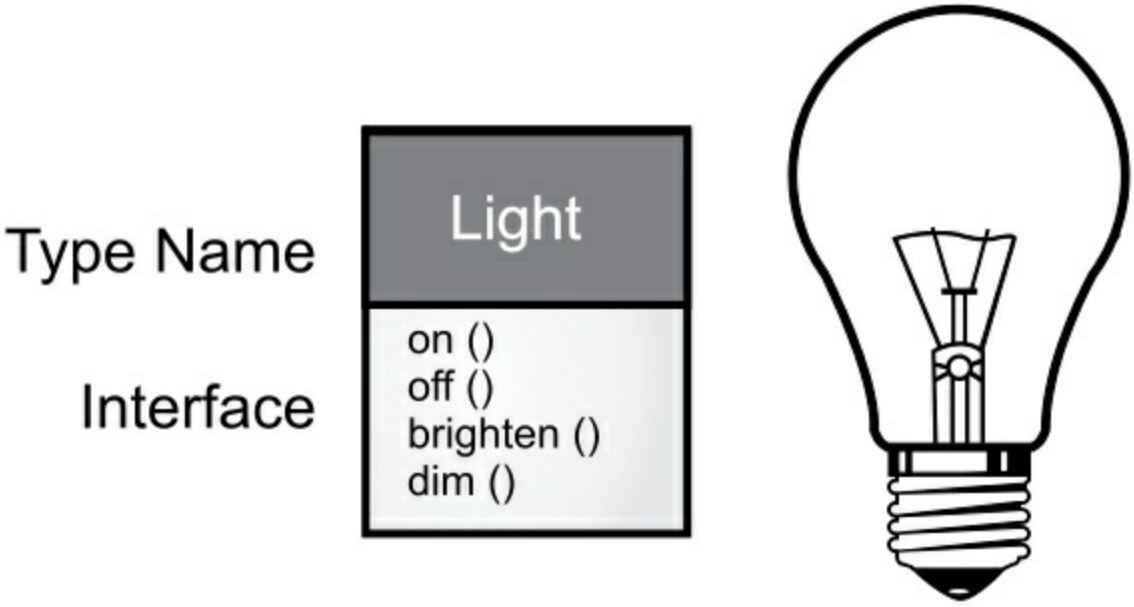
Since a class describes a set of objects that have identical characteristics (data elements) and behaviors (functionality), a class is really a data type because a floating point number, for example, also has a set of characteristics and behaviors. The difference is that a programmer defines a class to fit a problem rather than being forced to use an existing data type that was designed to represent a unit of storage in a machine. You extend the programming language by adding new data types specific to your needs. The programming system welcomes the new classes and gives them the same care and type checking it gives to built-in types.

The object-oriented approach is not limited to building simulations. Whether or not you agree that any program is a simulation of the system you’re designing, OOP techniques help reduce a large set of problems to a simpler solution.

Once a class is established, make as many objects of that class as you like, then manipulate those objects as if they are the elements that exist in your problem. Indeed, one of the challenges of object-oriented

programming is creating a one-to-one mapping between the elements in the problem space and objects in the solution space.

How do you get an object to do useful work? You make a request of that object—complete a transaction, draw something on the screen, turn on a switch. Each object accepts only certain requests, defined by its *interface* The type determines the interface. As a simple example, consider a representation for a light bulb:



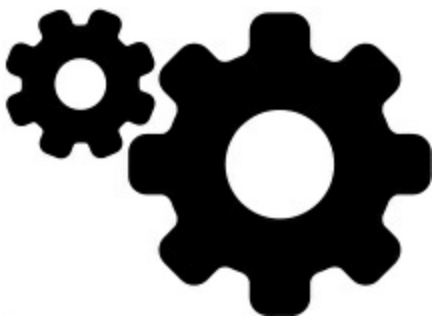

```
Light lt = new Light();
lt.on();
```

The interface determines the requests you can make for a particular object. However, there must be code somewhere to satisfy that request. This, along with the hidden data, comprises the

implementation. A type has a method associated with each possible request, and when you make a particular request to an object, that method is called. This process is usually summarized by saying you "send a message" (make a request) to an object, and the object figures out what to do with that message (it executes code).

Here, the name of the class is **Light**, the name of this particular **Light** object is **lt**, and the requests you can make of a **Light** object are to turn it on, turn it off, make it brighter, or make it dimmer. You create a **Light** object by defining a "reference" (**lt**) for that object and calling **new** to request a new object of that type. To send a message to the object, you state the name of the object and connect it to the message request with a period (dot). From the standpoint of the user of a predefined class, that's pretty much all there is to programming with objects.

The preceding diagram follows the format of the *Unified Modeling Language* (UML). Each class is represented by a box, with the type



name in the top portion of the box, any *data members* you care to describe in the middle portion of the box, and the *methods* (the functions that belong to this object, which receive any messages you send to that object) in the bottom portion of the box. Often, only the name of the class and the public methods are shown in UML design diagrams, so the middle portion is not shown, as in this case. If you're interested only in the class name, the bottom portion doesn't need to be shown, either.

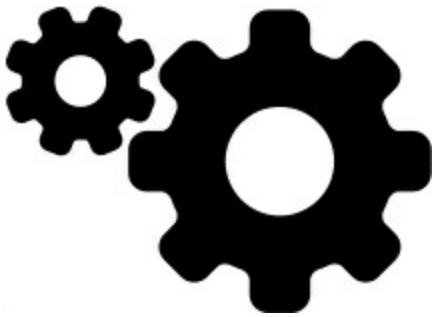
Objects Provide Services

When trying to develop or understand a program design, an excellent way to think about objects is as "service providers." Your program itself will provide services to the user, and it will accomplish this by using the services offered by other objects. Your goal is to produce (or better, locate in existing code libraries) a set of objects providing the ideal services to solve your problem.

A way to start doing this is to ask, "If I could magically pull them out of a hat, what objects would solve my problem right away?" For example, suppose you are creating a bookkeeping program. You might imagine objects that contain predefined bookkeeping input screens, other

objects that perform bookkeeping calculations, and an object that handles printing of checks and invoices on all different kinds of printers. Maybe some of these objects already exist, and for the ones that don’t, what would they look like? What services would those objects provide, and what objects would they need to fulfill their obligations? If you keep doing this, you eventually reach a point where you say either, “That object seems simple enough to sit down and write” or “I’m sure that object must exist already.” This is a reasonable way to decompose a problem into a set of objects.

Thinking of an object as a service provider has an additional benefit: It



helps improve the cohesiveness of the object. *High cohesion* is a fundamental quality of software design: It means the various aspects of a software component (such as an object, although this could also apply to a method or a library of objects) “fit together” well. One problem people have when designing objects is cramming too much functionality into one object. For example, in your check printing

module, you might decide you need an object that knows all about formatting and printing. You'll probably discover this is too much for one object, and that what you need is three or more objects. One object might be a catalog of all the possible check layouts, which can be queried for information about how to print a check. One object or set of objects can be a generic printing interface that knows all about different kinds of printers (but nothing about bookkeeping—that is a candidate for buying rather than writing yourself). A third object uses the services of the other two to accomplish the task. Thus, each object has a cohesive set of services it offers. In good object-oriented design, each object does one thing well, but doesn't try to do too much. This not only discovers objects that might be purchased (the printer interface object), but it also produces new objects that might be reused somewhere else (the catalog of check layouts).

Treating objects as service providers is useful not only during the design process, but also when someone else is trying to understand your code or reuse an object. If they can see the value of the object based on what service it provides, it makes it much easier to fit it into the design.

The Hidden

Implementation

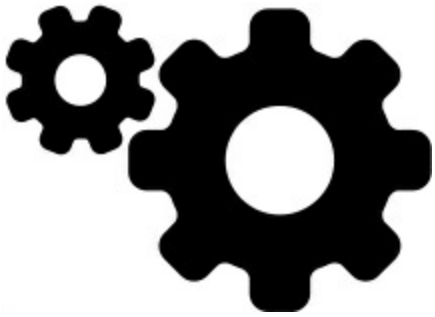
We can break up the playing field into *class creators* (those who create new data types) and *client programmer*s [3] (the class consumers who use the data types in their applications). The goal of the client programmer is to collect a toolbox full of classes to use for rapid application development. The goal of the class creator is to build a class that exposes only what's necessary to the client programmer and keeps everything else hidden. Why? Because if it's hidden, the client programmer can't access it, which means the class creator can change the hidden portion at will without worrying about the impact on anyone else. The hidden portion usually represents the tender insides of an object that could easily be corrupted by a careless or uninformed client programmer, so hiding the implementation reduces program bugs.

All relationships need boundaries, respected by all parties involved. When you create a library, you establish a relationship with the client programmer, who is also a programmer, but one who is putting together an application by using your library, possibly to build a bigger library. If all members of a class are available to everyone, the client programmer can do anything with that class and there's no way to enforce rules. Even though you might prefer that the client

programmer not directly manipulate some of the members of your class, without access control there's no way to prevent it. Everything's naked to the world.

So the first reason for access control is to keep client programmers' hands off portions they shouldn't touch—parts necessary for the internal operation of the data type but not part of the interface that users need to solve their particular problems. This is actually a service to client programmers because they can easily see what's important and what they can ignore. (Notice this is also a philosophical decision. Some programming languages assume that if a programmer wishes to access the internals, they should be allowed.)

The second reason for access control is to enable the library designer to change the internal workings of the class without worrying about how it will affect the client programmer. For example, you might implement a particular class in a simple fashion to ease development, then later discover you must rewrite it to make it run faster. If the interface and implementation are clearly separated and protected, you can accomplish this easily.



Java has three explicit keywords to set the boundaries in a class: **public**, **private**, and **protected**. These *access specifiers* determine who can use the definitions that follow. **public** means the element is available to everyone. **private** means no one can access that element except you, the creator of the type, inside methods of that type. **private** is a brick wall between you and the client programmer. Anyone trying to access a **private** member gets a compile-time error. **protected** acts like **private**, with the exception that an inheriting class may access **protected** members, but not **private** members. Inheritance is introduced shortly.

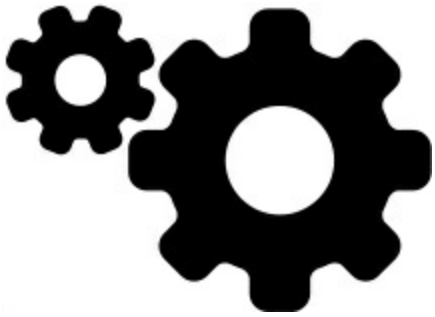
Java also has a “default” access, which comes into play if you don’t use one of the aforementioned specifiers. This is usually called *package access* because classes can access the members of other classes in the same **package** (library component), but outside the package those same members appear to be **private**.

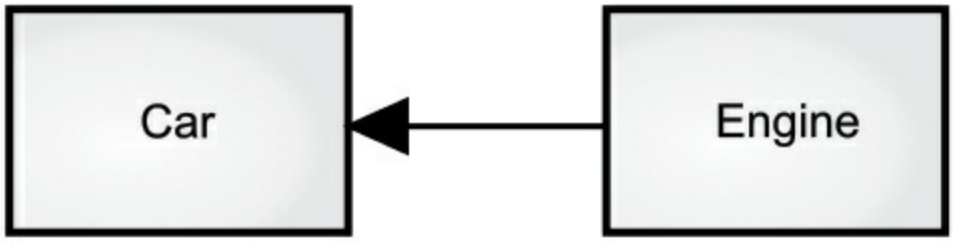
Reusing the

Implementation

Once a class is tested, it should (ideally) represent a useful unit of code. This reusability is not nearly so easy to achieve as many hope; it takes experience and insight to produce a reusable object design. But once you have such a design, it begs for reuse. Code reuse is an argument for object-oriented programming languages.

The simplest way to reuse a class is to use an object of that class directly, but you can also place an object of that class inside a new class. Your new class can be made up of any number and type of other objects, in any combination, to produce the desired functionality. Because you *compose* a new class from existing classes, this concept is





called *composition* (if composition is dynamic, it's usually called

aggregation). Composition is often called a *has-a* relationship, as in "A car has an engine."

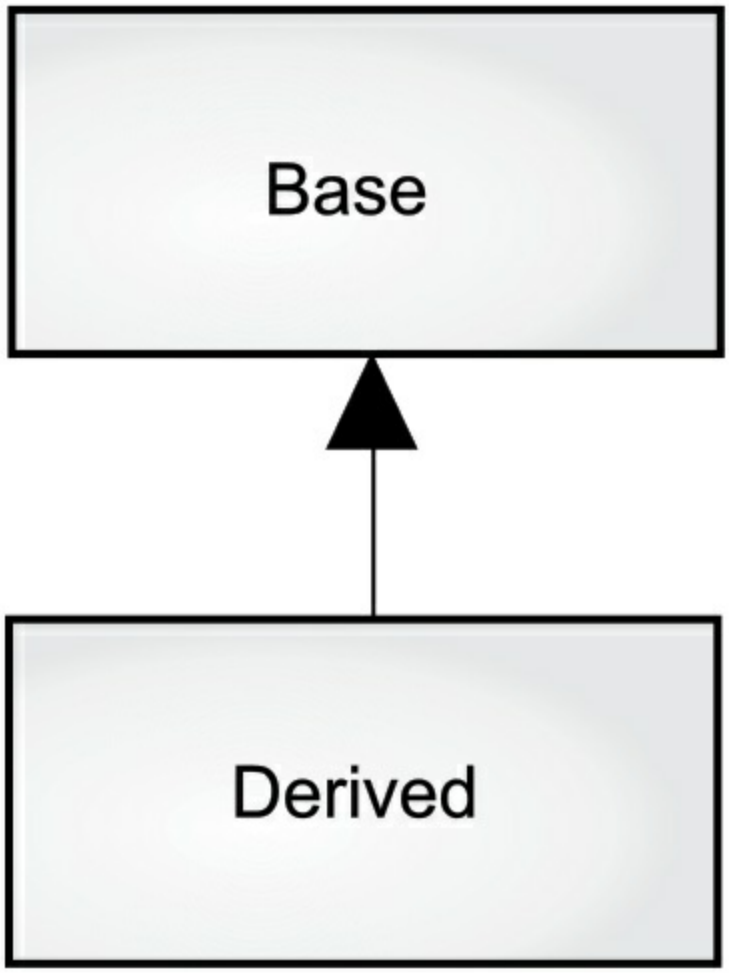
(This diagram indicates composition with the filled diamond, which states there is one car. I typically use a simpler form: just a line, without the diamond, to indicate an association.[4]

Composition comes with a great deal of flexibility. The member objects of your new class are typically private, making them inaccessible to client programmers who use the class. This means changing those members doesn't disturb existing client code. You can also change the member objects at run time, to dynamically change the behavior of your program. Inheritance, described next, does not have this flexibility since the compiler must place compile-time restrictions on classes created using inheritance.

Inheritance is is often highly emphasized in object-oriented programming. A new programmer can get the impression that inheritance should be used everywhere. This can result in awkward and overly complicated designs. Instead, first look to composition when creating new classes, since it is simpler, more flexible, and produces cleaner designs. Once you've had some experience, it is reasonably obvious when you need inheritance.

Inheritance

By itself, the idea of an object is a convenient tool. Objects package



data and functionality together by *concept* and represent an appropriate problem-space idea rather than being forced to use the idioms of the underlying machine. These concepts are expressed as fundamental units in the programming language by using the **class** keyword.

It seems a pity, however, to go to all the trouble to create a class, then

be forced to create a brand new one that might have similar functionality. It's nicer if we can take the existing class, clone it, then make additions and modifications to the clone. This is effectively what you get with *inheritance*, with the exception that if the original class (called the *base class* or *superclass* or *parent class*) is changed, the modified "clone" (called the *derived class* or *inherited class* or *subclass* or *child class*) also reflects those changes.

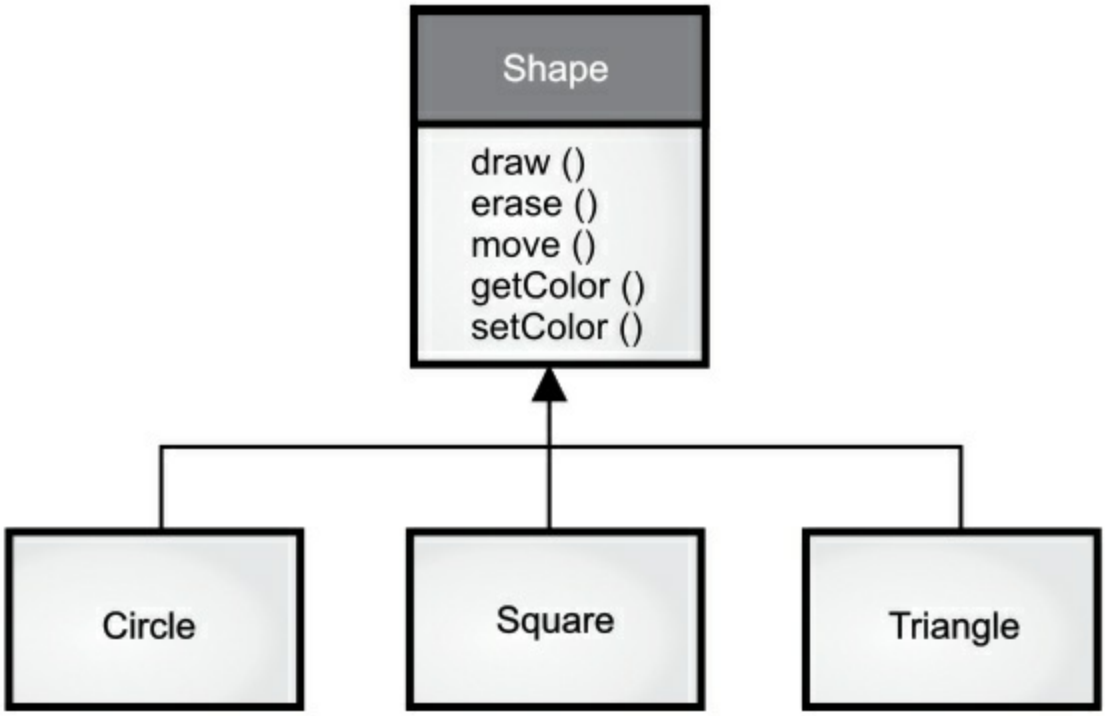
The arrow in this diagram points from the derived class to the base class. As you will see, there is commonly more than one derived class.

A type does more than describe the constraints on a set of objects; it also relates to other types. Two types can have characteristics and behaviors in common, but one type might contain more characteristics than another and might also handle more messages (or handle them differently). Inheritance expresses this similarity through the concept of base types and derived types. A base type contains all characteristics and behaviors shared among the types derived from it. You create a base type to represent the core of your ideas. From the base type, you derive other types to express the different ways this core can be realized.

For example, a trash-recycling machine sorts pieces of trash. The base type is "trash." Each piece of trash has a weight, a value, and so on,

and can be shredded, melted, or decomposed. From this, more specific types of trash are derived with additional characteristics (a bottle has a color, a steel can is magnetic) or behaviors (you can crush an aluminum can). In addition, some behaviors can be different (the value of paper depends on its type and condition). Using inheritance, you build a type hierarchy that expresses the problem you're trying to solve in terms of its types.

A second example is the common "shape" example, perhaps used in a computer-aided design system or game simulation. The base type is "shape," and each shape has a size, a color, a position, and so on. Each shape can be drawn, erased, moved, colored, etc. From this, specific types of shapes are derived (inherited)—circle, square, triangle, and so on—each of which can have additional characteristics and behaviors. Certain shapes can be flipped, for example. Some behaviors might be different, such as when you calculate the area of a shape. The type hierarchy embodies both the similarities and differences between the shapes.

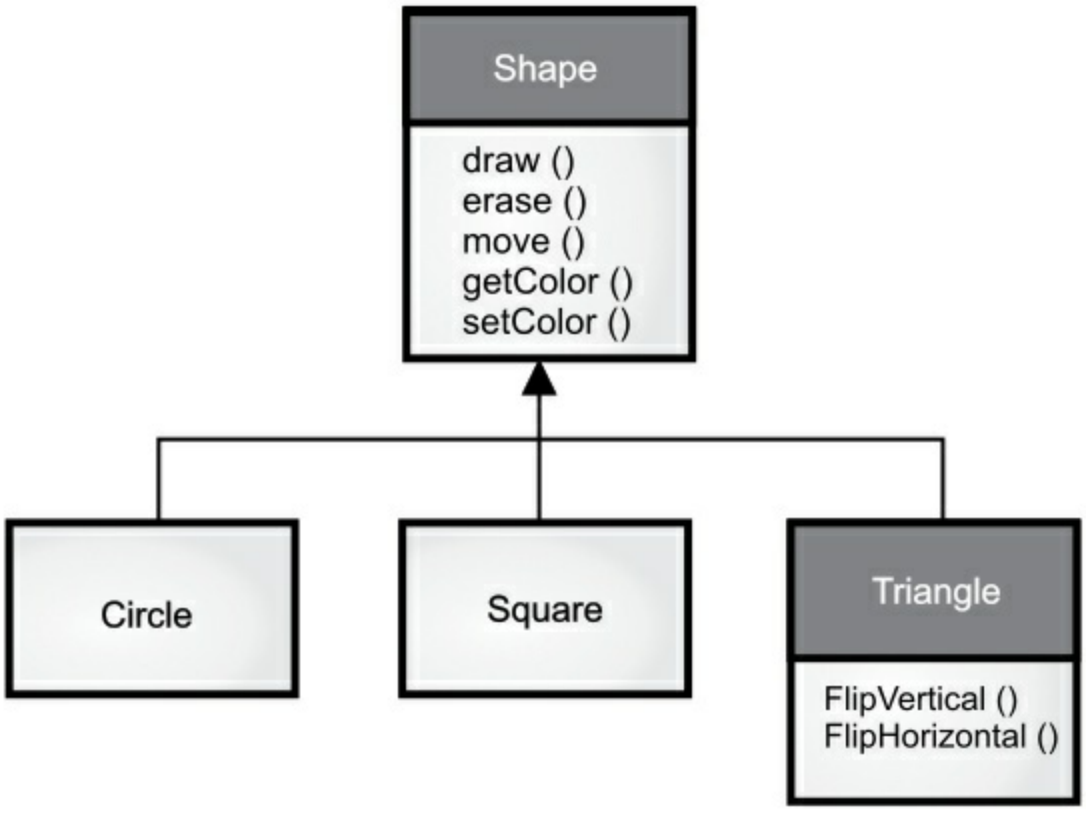


Casting the solution in the same terms as the problem is useful because you don’t need intermediate models to get from a description of the problem to a description of the solution. With objects, the type hierarchy is an important aspect of the model, so you go directly from the description of the system in the real world to the description of the system in code. Indeed, sometimes people who are trained to look for complex solutions have difficulty with the simplicity of object-oriented design.

Inheriting from an existing type creates a new type. This new type contains not only all the members of the existing type (although the **private** ones are hidden away and inaccessible), but more

importantly it duplicates the interface of the base class. That is, all messages accepted by base-class objects are also accepted by derived-class objects. We know the type of a class by the messages it accepts, so the derived class *is the same type as the base class*. In the previous example, “A circle is a shape.” This type equivalence via inheritance is one of the fundamental gateways in understanding the meaning of object-oriented programming.

Since both base class and derived class have the same fundamental interface, there must be some implementation to go along with that

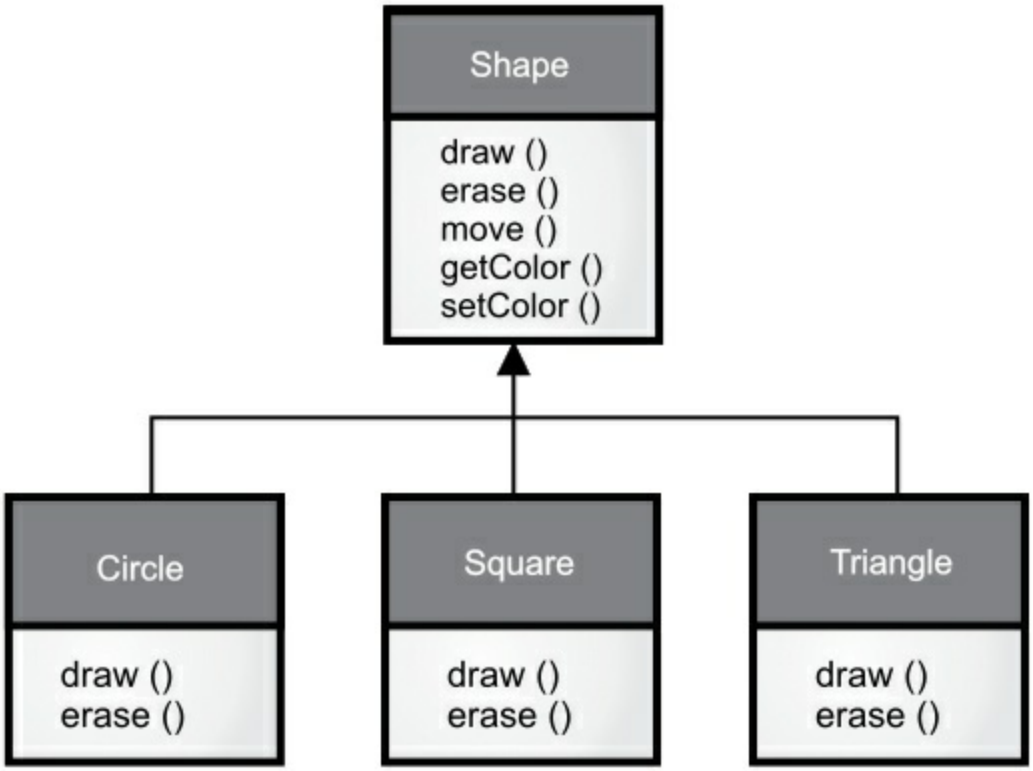


interface. That is, there must be executable code when an object

receives a particular message. If you inherit a class and don’t do anything else, the methods from the base-class interface come right along into the derived class. That means objects of the derived class have not only the same type, they also have the same behavior, which isn’t particularly interesting.

There are two ways to differentiate your new derived class from the original base class. The first is straightforward: add brand new methods to the derived class. These new methods are not part of the base-class interface. This means the base class didn’t do as much as you wanted, so you added more methods. This simple and primitive use for inheritance is, at times, the perfect solution to your problem. However, look closely for the possibility that your base class might also need these additional methods (or that you should be using composition instead). This process of discovery and iteration of your design happens regularly in object-oriented programming.

Although inheritance can sometimes imply (especially in Java, where the keyword for inheritance is **extends**) that you are going to add



new methods to the interface, that's not necessarily true. The second and more important way to differentiate your new class is to change the behavior of an existing base-class method. This is called *overriding* that method.

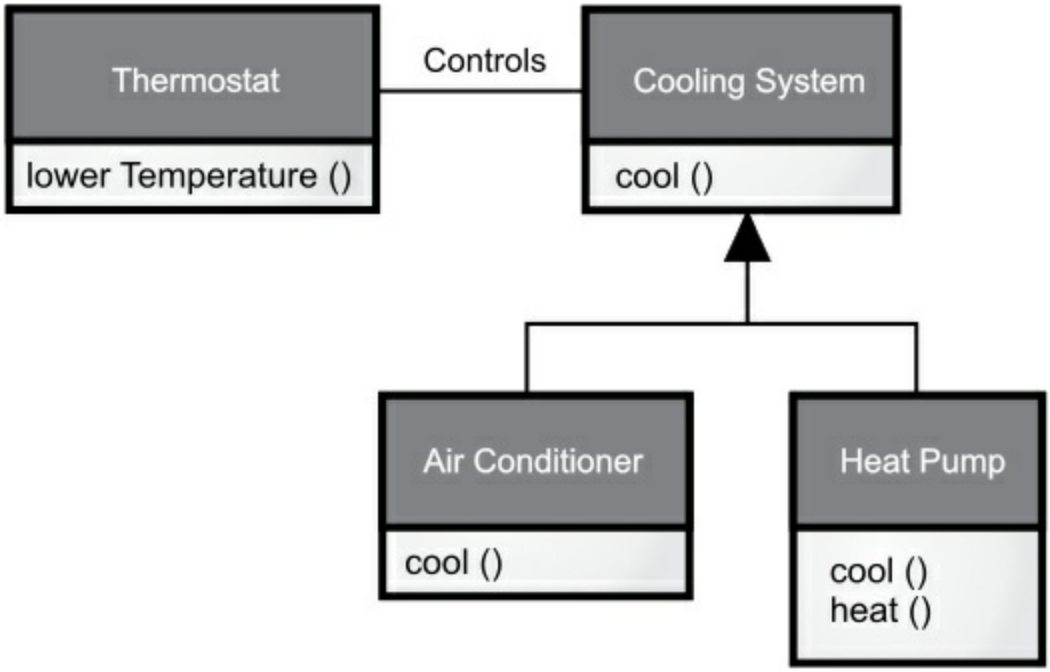
To override a method, you create a new definition for the method in the derived class. You're saying, "I'm using the same interface method here, but I want it to do something different for my new type."

Is-a vs. Is-Like-a

Relationships

There's a certain debate that can occur about inheritance: Should

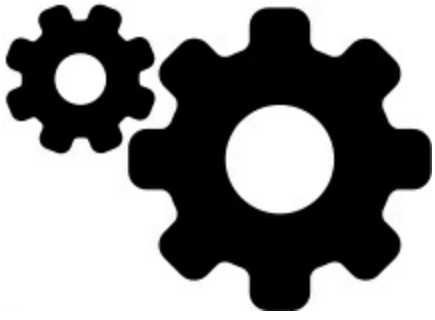
inheritance override *only* base-class methods (and not add new methods that aren't in the base class)? This would mean that the derived class is *exactly* the same type as the base class since it has exactly the same interface. As a result, you can perfectly substitute an object of the derived class for an object of the base class. This can be



thought of as *pure substitution*, and it's often called the *substitution principle* 5. In a sense, this is the ideal way to treat inheritance. We often refer to the relationship between the base class and derived classes in this case as an *is-a* relationship, because you can say, "A circle *is a* shape." A test for inheritance is to see if the is-a relationship makes sense for your classes.

Sometimes you add new interface elements to a derived type, thus

extending the interface. The new type can still substitute for the base type, but the substitution isn't perfect because your new methods are not accessible from the base type. This can be described as an *is-like-a* relationship (my term). The new type has the interface of the old type but it also contains other methods, so you can't really say it's exactly the same. For example, consider an air conditioner. Suppose your house is wired with all the controls for cooling; that is, it has an interface that to control cooling. Imagine that the air conditioner breaks down and you replace it with a heat pump, which can both heat and cool. The heat pump *is-like-an* air conditioner, but it can do more. Because the control system of your house is designed only to control cooling, it is restricted to communication with the cooling part of the new object. The interface of the new object is extended, and the existing system only knows about the original interface.



Once you see this design it becomes clear that the base class "cooling system" is not general enough, and should be renamed to

“temperature control system” so it can also include heating—at which point the substitution principle will work. However, this diagram shows what can happen with design in the real world.

When you see the substitution principle it’s easy to feel like this approach (pure substitution) is the only way to do things, and in fact it *is* nice if your design works out that way. But you’ll find there are times when it’s equally clear you must add new methods to the interface of a derived class (extension). With inspection both cases should be reasonably obvious.

Interchangeable

Objects with

Polymorphism

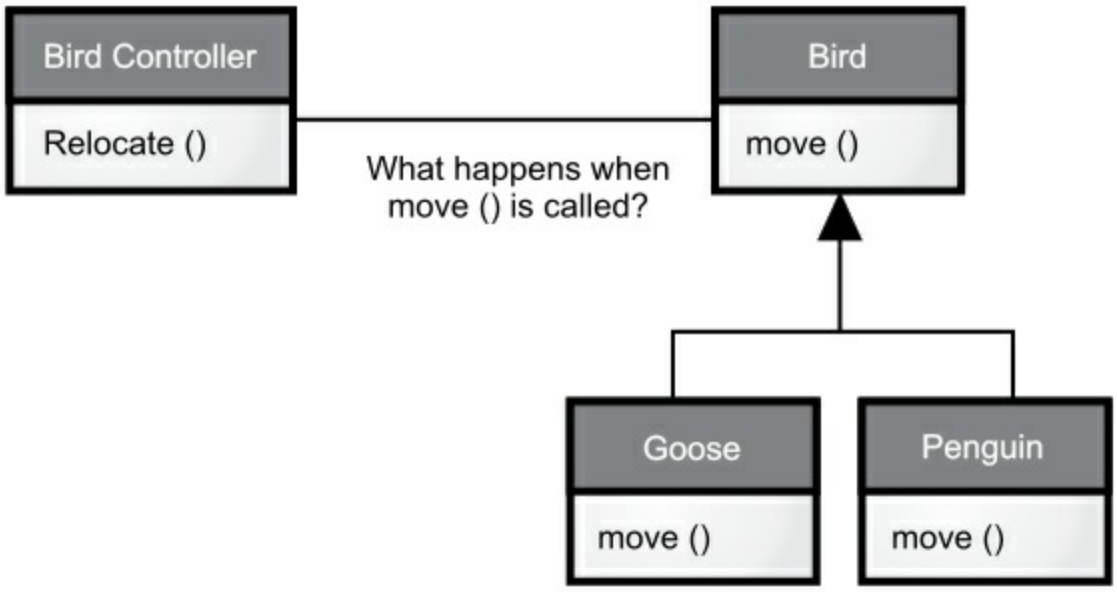
When dealing with type hierarchies, you often treat an object not as the specific type it is, but as its base type. This way you can write code that doesn’t depend on specific types. In the shape example, methods manipulate generic shapes, unconcerned about whether they’re circles, squares, triangles, or some shape that hasn’t even been defined yet. All shapes can be drawn, erased, and moved, so these methods send a message to a shape object without worrying how the object copes with the message.

Such code is unaffected by the addition of new types, and adding new types is a common way to extend an object-oriented program to handle new situations. For example, you can derive a new subtype of shape called “pentagon” without modifying methods that deal only with generic shapes. This ability to easily extend a design by deriving new subtypes is one of the essential ways to encapsulate change. This improves designs while reducing the cost of software maintenance.

There’s a problem when attempting to treat derived-type objects as their generic base types (circles as shapes, bicycles as vehicles, cormorants as birds, etc.). If a method tells a generic shape to draw itself, or a generic vehicle to steer, or a generic bird to move, the compiler cannot know at compile time precisely what piece of code is executed. That’s the whole point—when the message is sent, the programmer doesn’t *want* to know what piece of code is executed; the draw method can be applied equally to a circle, a square, or a triangle, and the object will execute the proper code depending on its specific type.

If you don’t need to know what piece of code is executed, when you add a new subtype, the code it executes can be different without requiring changes to the code that calls it. But what does the compiler

do when it cannot know precisely what piece of code is executed? For example, in the following diagram the **BirdController** object just works with generic **Bird** objects and does not know what exact type they are. This is convenient from **BirdController**s perspective because it doesn't require special code to determine the exact type of **Bird** it's working with or that **Bird**s behavior. So how does it happen that, when **move()** is called while ignoring the specific type of **Bird**, the right behavior will occur (a **Goose** walks, flies, or swims, and a **Penguin** walks or swims)?



The answer is the primary twist of inheritance: The compiler cannot make a function call in the traditional sense. The function call generated by a non-OOP compiler produces what is called *early*

binding, a term you might not have heard because you've never thought about it any other way. It means the compiler generates a call to a specific function name, which resolves to the absolute address of the code to be executed. With inheritance, the program cannot determine the address of the code until run time, so some other scheme is necessary when a message is sent to an object.

To solve the problem, object-oriented languages use the concept of *late binding*. When you send a message to an object, the code called isn't determined until run time. The compiler does ensure that the method exists and performs type checking on the arguments and return value, but it doesn't know the exact code to execute.

To perform late binding, Java uses a special bit of code in lieu of the absolute call. This code calculates the address of the method body, using information stored in the object (this process is covered in great detail in the Polymorphism chapter). Thus, each object behaves differently according to the contents of that special bit of code. When you send a message to an object, the object actually does figure out what to do with that message.

In some languages you must explicitly grant a method the flexibility of late-binding properties. For example, C++ uses the **virtual** keyword. In such languages, methods are *not* dynamically bound by

default. In Java, dynamic binding is the default behavior and you don't need extra keywords to produce polymorphism.

Consider the shape example. The family of classes (all based on the same uniform interface) was diagrammed earlier in this chapter. To demonstrate polymorphism, we write a single piece of code that ignores specific details of type and talks only to the base class. That code is *decoupled* from type-specific information and thus is simpler to write and easier to understand. And, if a new type—a **Hexagon**, for example—is added through inheritance, code works just as well for the new type of **Shape** as it did on the existing types. Thus, the program is *extensible*.

If you write a method in Java (you will soon learn how):

```
void doSomething(Shape shape) {
shape.erase();
// ...
shape.draw();
}
```

This method speaks to any **Shape**, so it is independent of the specific type of object it's drawing and erasing. If some other part of the program uses the **doSomething()** method:

Circle circle = **new** Circle();

Triangle triangle = **new** Triangle();

Line line = **new** Line();

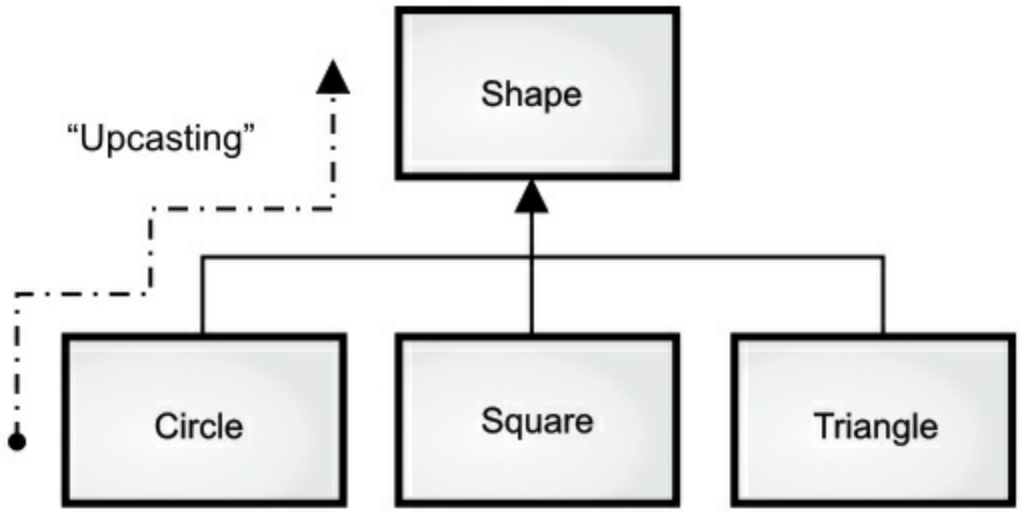
doSomething(circle);

doSomething(triangle);

doSomething(line);

The calls to **doSomething()** automatically work correctly,

regardless of the exact type of the object.



This is a rather amazing trick. Consider the line:

doSomething(circle);

What's happening here is that a **Circle** is passed into a method that

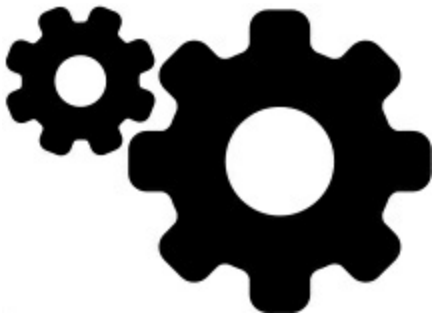
expects a **Shape**. Since a **Circle** *is* a **Shape** it is treated as such by **doSomething()**. That is, any message that **doSomething()** can

send to a **Shape**, a **Circle** can accept. It is a completely safe and logical thing to do.

We call this process of treating a derived type as though it were its base type *upcasting*. The name *cast* is used in the sense of casting into a mold and the *up* comes from the way the inheritance diagram is typically arranged, with the base type at the top and the derived classes fanning out downward. Thus, casting to a base type is moving up the inheritance diagram: “upcasting.”

An object-oriented program contains upcasting somewhere, because that’s how you decouple yourself from knowing the exact type you’re working with. Look at the code in **doSomething()**:

```
shape.erase();
// ...
shape.draw();
```



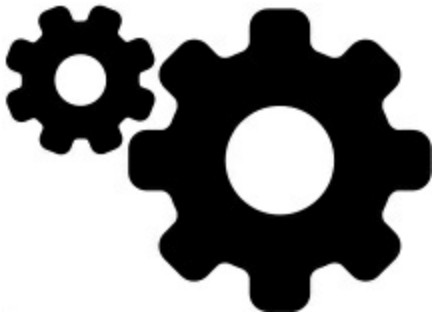
Notice it doesn’t say, “If you’re a **Circle**, do this, if you’re a **Square**, do that, etc.” If you write that kind of code, which checks for all the

possible types a **Shape** can actually be, it's messy and you must change it every time you add a new kind of **Shape**. Here, you just say, "You're a shape, I know you can **erase()** and **draw()** yourself, do it, and take care of the details correctly."

What's impressive about the code in **doSomething()** is that, somehow, the right thing happens. Calling **draw()** for **Circle** causes different code to be executed than calling **draw()** for a **Square** or a **Line**, but when the **draw()** message is sent to an anonymous **Shape**, the correct behavior occurs based on the actual type of the **Shape**. This is amazing because when the Java compiler is compiling the code for **doSomething()**, it cannot know exactly what types it is dealing with. Ordinarily, you'd expect it to end up calling the version of **erase()** and **draw()** for the base class **Shape**, and not for the specific **Circle**, **Square**, or **Line**. And yet the right thing happens—that's polymorphism. The compiler and runtime system handle the details; all you must know is it happens, and more importantly, how to design with it. When you send a message to an object, the object will do the right thing, even when upcasting is involved.

The Singly-Rooted Hierarchy

An OOP issue that has become especially prominent since the introduction of C++ is whether all classes should by default be inherited from a single base class. In Java (as with virtually all other OOP languages *except* for C++) the answer is yes, and the name of this



ultimate base class is simply **Object**.

There are many benefits to a singly-rooted hierarchy. All objects have a common interface, so they are all ultimately the same fundamental type. The alternative (provided by C++) is that you don't know that everything is the same basic type. From a backward-compatibility standpoint this fits the model of C better and can be thought of as less restrictive, but for full-on object-oriented programming you must build your own hierarchy to provide the same convenience that's built into other OOP languages. And in any new class library you acquire, some other incompatible interface is used. It requires effort to work the new interface into your design. Is the extra "flexibility" of C++ worth it? If you need it—if you have a large investment in C—it's quite

valuable. If you're starting from scratch, alternatives such as Java can be more productive.

A singly rooted hierarchy makes it much easier to implement a *garbage collector*, one of the fundamental improvements of Java over C++. And since information about the type of an object is guaranteed to be in all objects, you'll never end up with an object whose type you cannot determine. This is especially important with system-level operations, such as *exception handling* (a language mechanism for reporting errors), and to allow greater flexibility in programming.

Collections

In general, you don't know how many objects you need to solve a particular problem, or how long they will last. You also don't know how to store those objects. How can you know how much space to create if that information isn't known until run time?

The solution to most problems in object-oriented design seems flippant: You create another type of object. The new type of object that solves this particular problem holds references to other objects. You can also do the same thing with an *array*, available in most languages. But this new object, generally called a *collection* (also called a *container*, but the Java libraries use "collection" almost universally),

will expand itself whenever necessary to accommodate everything you place inside it. You don't need to know how many objects you're going to hold in a collection—just create a collection object and let it take care of the details.

Fortunately, a good OOP language comes with a set of collections as part of the package. In C++, it's part of the Standard C++ Library and is often called the *Standard Template Library* (STL). SmallTalk has a very complete set of collections. Java also has numerous collections in its standard library. In some libraries, one or two generic collections is considered good enough for all needs, and in others (Java, for example) the library has different types of collections for different needs: several different kinds of **List** classes (to hold sequences), **Map**s (also known as *associative arrays*, to associate objects with other objects), **Set**s (to hold one of each type of object), and more components such as queues, trees, stacks, etc.

From a design standpoint, all you really want is a collection you can manipulate to solve your problem. If a single type of collection satisfied all of your needs, we wouldn't need different kinds. There are two reasons you need a choice of collections:

1. Collections provide different types of interfaces and external

behavior. Stacks and queues are different from sets and lists. One of these might provide a more flexible solution to your problem than another.

2. Different implementations have different efficiencies for certain operations. For example, there are two basic types of **List**: **ArrayList** and **LinkedList**. Both are simple sequences that can have identical interfaces and external behaviors. But some operations have significantly different costs. Randomly accessing elements in an **ArrayList** is a constant-time operation; it takes the same amount of time regardless of the element you select.

However, in a **LinkedList** it is expensive to move through the list to randomly select an element, and it takes longer to find an element that is farther down the list. On the other hand, to insert an element in the middle of a sequence, it’s cheaper in a **LinkedList** than in an **ArrayList**. These and other operations have different efficiencies depending on the underlying structure of the sequence. You might start building your program

with a **LinkedList** and, when tuning for performance, change to an **ArrayList**. Because of the abstraction via the interface **List**, you can change from one to the other with minimal impact on your code.

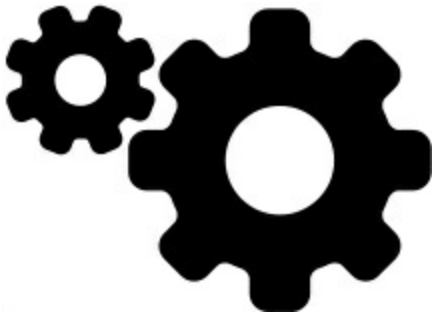
Parameterized Types

(Generics)

Before Java 5, collections held the one universal type in Java: **Object**. The singly rooted hierarchy means everything is an **Object**, so a collection that holds **Object**s can hold anything. 6 This made collections easy to reuse.

To use such a collection, you add object references to it and later ask for them back. But, since the collection holds only **Object**s, when you add an object reference into the collection it is upcast to **Object**, thus losing its character. When fetching it back, you get an **Object** reference, and not a reference to the type you put in. How do you turn it back into something with the specific type of the object you put into the collection?

Here, the cast is used again, but this time you're not casting up the inheritance hierarchy to a more general type. Instead, you cast down the hierarchy to a more specific type, so this manner of casting is



called *downcasting*. With upcasting, you know that a **Circle** is a type of **Shape** so it's safe to upcast, but you don't know that an **Object** is necessarily a **Circle** or a **Shape** so it's not safe to downcast unless you determine extra type information about that object.

It's not completely dangerous because if you downcast to the wrong type you'll get a runtime error called an *exception*, described shortly. When you fetch **Object** references from a collection, however, you need some way to remember exactly what they are in order to perform a proper downcast.

Downcasting and the associated runtime checks require extra time for the running program and extra effort from the programmer. Wouldn't it make sense to somehow create the collection so it knows the types it holds, eliminating the need for the downcast and a possible mistake? The solution is called a *parameterized type* mechanism. A parameterized type is a class that the compiler can automatically

customize to work with particular types. For example, with a parameterized collection, the compiler can customize that collection so it accepts only **Shape**s and fetches only **Shape**s.

Java 5 added parameterized types, called *generics*, which is a major feature. You'll recognize generics by the angle brackets with types inside; for example, you can create an **ArrayList** to hold **Shape** like this:

```
ArrayList<Shape> shapes = new ArrayList<>();
```

There have also been changes to many of the standard library components to take advantage of generics. You will see that generics have an impact on much of the code in this book.

Object Creation & Lifetime

One critical issue when working with objects is the way they are created and destroyed. Each object requires resources, most notably memory, to exist. When an object is no longer needed it must be cleaned up so these resources are released for reuse. In simple programming situations the question of how an object is cleaned up doesn't seem too challenging: You create the object, use it for as long as it's needed, then it should be destroyed. However, it's not hard to

encounter situations that are more complex.

Suppose, for example, you are designing a system to manage air traffic for an airport. (The same model might also work for managing crates in a warehouse, or a video rental system, or a kennel for boarding pets.) At first it seems simple: Make a collection to hold airplanes, then create a new airplane and place it in the collection for each airplane that enters the air-traffic-control zone. For cleanup, simply clean up the appropriate airplane object when a plane leaves the zone. But suppose you have some other system to record data about the planes; perhaps data that doesn't require such immediate attention as the main controller function. Maybe it's a record of the flight plans of all the small planes that leave the airport. So you have a second collection of small planes, and whenever you create a plane object you also put it in this second collection if it's a small plane. Then some background process performs operations on the objects in this collection during idle moments.

Now the problem is more difficult: How can you possibly know when to destroy the objects? When you're done with the object, some other part of the system might not be. This same problem can arise in a number of other situations, and in programming systems (such as

C++) where you must explicitly delete an object this can become quite complex.

Where is the data for an object and how is the lifetime of the object controlled? C++ takes the approach that efficiency is the most important issue, so it gives the programmer a choice. For maximum runtime speed, the storage and lifetime can be determined while the program is written, by placing the objects on the stack (these are sometimes called *automatic* or *scoped* variables) or in the static storage area. This places a priority on the speed of storage allocation and release, and this control can be very valuable in certain situations. However, you sacrifice flexibility because you must know the exact quantity, lifetime, and type of objects while you're writing the program. If you are trying to solve a more general problem such as computer-aided design, warehouse management, or air-traffic control, this is too restrictive.

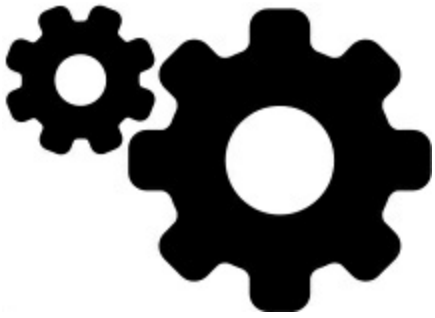
The second approach is to create objects dynamically in a pool of memory called the *heap*. In this approach, you don't know until run time how many objects you need, what their lifetime is, or what their exact type is. Those are determined at the spur of the moment while the program is running. If you need a new object, you simply make it

on the heap when you need it. Because the storage is managed dynamically, at run time, the amount of time required to allocate storage on the heap can be longer than the time to create storage on the stack (but not necessarily). Creating storage on the stack is often a single assembly instruction to move the stack pointer down and another to move it back up. The time to create heap storage depends on the design of the storage mechanism.

The dynamic approach makes the generally logical assumption that objects tend to be complicated, so the extra overhead of finding storage and releasing that storage will not have an important impact on the creation of an object. In addition, the greater flexibility is essential to solve general programming problems.

Java uses dynamic memory allocation, exclusively.[7] Every time you create an object, you use the **new** operator to build a dynamic instance of that object.

There's another issue, however, and that's the lifetime of an object.



With languages that allow objects to be created on the stack, the compiler determines how long the object lasts and automatically destroys it. However, if you create it on the heap the compiler has no knowledge of its lifetime. In a language like C++, you must determine programmatically when to destroy the object, which can lead to memory leaks if you don't do it correctly. Java is built upon a *garbage collector* which automatically discovers when an object is no longer in use and releases it. A garbage collector is much more convenient because it reduces the number of issues you must track and the code you must write. Thus, the garbage collector provides a much higher level of insurance against the insidious problem of memory leaks, which has brought many a C++ project to its knees.

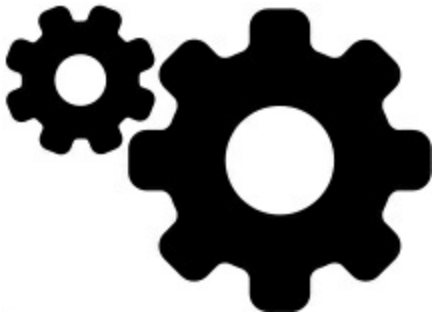
With Java, the garbage collector is designed to take care of the problem of releasing memory (although this doesn't include other aspects of cleaning up an object). The garbage collector "knows" when an object is no longer in use, and automatically releases the memory for that object. This, combined with the fact that all objects are inherited from the single root class **Object** and you can create objects only one way—on the heap—makes the process of programming in Java much simpler than programming in C++. You

have far fewer decisions to make and hurdles to overcome.

Exception Handling:

Dealing with Errors

Since the beginning of programming languages, error handling has been especially difficult. Because it’s so hard to design a good error-handling scheme, many languages ignore the issue, passing the problem on to library designers who come up with halfway measures that work in many situations but can easily be circumvented, generally by just ignoring errors. A major problem with most error-handling schemes is that they rely on programmers to follow an agreed-upon convention that is not enforced by the language. If the programmer is



not vigilant—often the case if they are in a hurry—these schemes can easily be forgotten.

Exception handling wires error handling directly into the programming language and sometimes even the operating system. An exception is an object that is “thrown” from the site of the error and

can be “caught” by an appropriate exception handler designed for that particular type of error. It’s as if exception handling is a different, parallel path of execution, taken when things go wrong. Because it uses a separate execution path, it doesn’t interfere with your normally executing code. This can make that code simpler to write because you aren’t constantly forced to check for errors. In addition, a thrown exception is unlike an error value returned from a method or a flag set by a method to indicate an error condition—these can be ignored. An exception cannot be ignored, so it’s guaranteed to be dealt with at some point. Finally, exceptions provide a way to reliably recover from a bad situation. Instead of just exiting the program, you are sometimes able to set things right and restore execution, which produces more robust programs.

Java’s exception handling stands out among programming languages, because in Java, exception handling was wired in from the beginning and you’re forced to use it. It is the single acceptable way to report errors. If you don’t write your code to properly handle exceptions, you’ll get a compile-time error message. This guaranteed consistency can sometimes make error handling much easier.

It’s worth noting that exception handling isn’t an object-oriented

feature, although in object-oriented languages the exception is normally represented by an object. Exception handling existed before object-oriented languages.

Summary

A procedural program contains data definitions and function calls. To find the meaning of such a program, you must work at it, looking through the function calls and low-level concepts to create a model in your mind. This is the reason we need intermediate representations when designing procedural programs—by themselves, these programs tend to be confusing because the terms of expression are oriented more toward the computer than to the problem you're solving.

Because OOP adds many new concepts on top of what you find in a procedural language, your natural assumption might be that the resulting Java program is far more complicated than the equivalent procedural program. Here, you'll be pleasantly surprised: A well-written Java program is generally simpler and easier to understand than a procedural program. What you'll see are the definitions of the objects that represent concepts in your problem space (rather than the issues of the computer representation) and messages sent to those objects to indicate activities in that space. One of the delights of

object-oriented programming is that, with a well-designed program, it's easy to understand the code by reading it. Usually, there's a lot less code as well, because many problems are solved by reusing existing library code.

OOP and Java might not be for everyone. It's important to evaluate your own needs and decide whether Java will optimally satisfy those needs, or if you might be better off with another programming system (perhaps the one you're currently using). If your needs are very specialized for the foreseeable future and you have specific constraints that might not be satisfied by Java, you owe it to yourself to investigate the alternatives (in particular, I recommend looking at Python). If you still choose Java as your language, you'll at least understand what the options were and have a clear vision of why you took that direction.

1. This is actually a bit restrictive, since objects can conceivably exist in different machines and address spaces, and they can also be stored on disk. In these cases, the identity of the object must be determined by something other than a memory address. ↩

2. In some cases we make a distinction, stating that type determines the interface while class is a particular implementation of that interface.↩

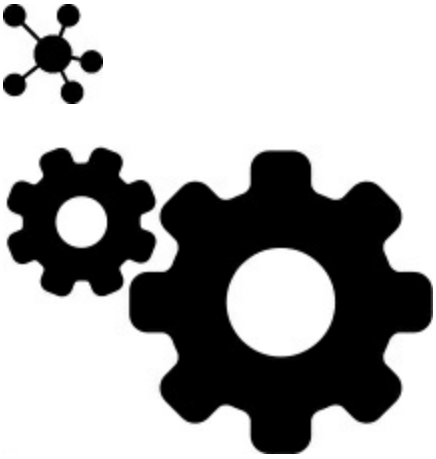
3. I'm indebted to my friend Scott Meyers for this term. ↩

4. This is enough detail for most diagrams, and you don't need to get specific about whether you're using aggregation or composition.↩

5. Or *Liskov Substitution Principle*, after Barbara Liskov who first described it↩

6. They do not hold primitives, but *autoboxing* simplifies this restriction somewhat. This is discussed in detail later in the book. ↩

7. Primitive types, which you'll learn about later, are a special case. ↩



Installing Java and the Book Examples

In which we provision ourselves for the journey.

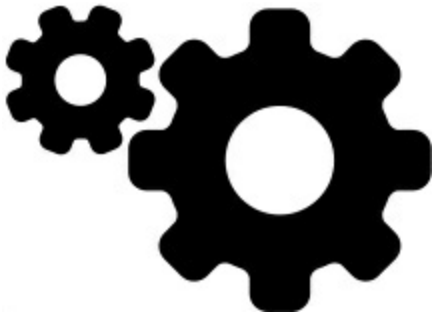
Before you can begin learning the language, you must install Java and the book's source-code examples. Because it is possible for a

“dedicated beginner” to learn programming from this book, I explain the process in detail, assuming you haven’t previously used the computer’s command-line shell. If you have, you can skip forward to the installation instructions.

If any terminology or processes described here are still not clear to you, you can usually find explanations or answers through Google. For more specific issues or problems, try StackOverflow. Sometimes you can find installation instructions on YouTube.

Editors

To create and modify Java program files—the code listings shown in this book—you need a program called an *editor*. You’ll also need an



editor to make changes to your system configuration files, which is sometimes required during installation.

Programming editors vary from heavyweight *Integrated Development Environments* (IDEs, like Eclipse, NetBeans and IntelliJ IDEA) to more basic text manipulation applications. If you already have an IDE and are comfortable with it, feel free to use that for this book, but in

the interest of keeping things simple, I recommend the *Atom* editor. Find it at atom.io.

Atom is free and open-source, is very simple to install, works on all platforms (Windows, Mac and Linux), and has a built-in Java mode that is automatically invoked when you open a Java file. It isn't a heavy-duty IDE so it doesn't get confusing, which is ideal for this book. On the other hand, it has some handy editing features that you'll probably come to love. More details are on their site.

There are many other editors; these are a subculture unto themselves and people even get into heated arguments about their merits. If you find one you like better, it's not too hard to change. The important thing is to choose one and get comfortable with it.

The Shell

If you haven't programmed before, you might be unfamiliar with your operating system *shell* (also called the *command prompt* in Windows). The shell harkens back to the early days of computing when everything happened by typing commands and the computer responded by displaying responses; it was all text-based.

Although it can seem primitive in the age of graphical user interfaces, a shell provides a surprising number of valuable features. We'll use the

shell regularly in this book, both as part of the installation process and to run Java programs.

Starting a Shell

Mac: Click on the *Spotlight* (the magnifying-glass icon in the upper-right corner of the screen) and type “terminal.” Click on the application that looks like a little TV screen (you might also be able to hit “Return”). This starts a shell in your home directory.

Windows: First, start the Windows Explorer to navigate through your directories:

Windows 7: click the “Start” button in the lower left corner of the screen. In the Start Menu search box area type “explorer” then press the “Enter” key.

Windows 8: click Windows+Q, type “explorer” then press the “Enter” key.

Windows 10: click Windows+E.

Once the Windows Explorer is running, move through the folders on your computer by double-clicking on them with the mouse. Navigate

to the desired folder. Now click the file tab at the top left of the Explorer window and select “Open command prompt.” This opens a shell in the destination directory.

Linux: To open a shell in your home directory:

Debian: Press Alt+F2. In the dialog that pops up, type ‘gnome-terminal’

Ubuntu: Either right-click on the desktop and select ‘Open Terminal’, or press Ctrl+Alt+T

Redhat: Right-click on the desktop and select ‘Open Terminal’

Fedora: Press Alt+F2. In the dialog that pops up, type ‘gnome-terminal’

Directories

Directories are one of the fundamental elements of a shell. Directories

hold files, as well as other directories. Think of a directory as a tree with branches. If **books** is a directory on your system and it has two other directories as branches, for example **math** and **art**, we say you have a directory **books** with two *subdirectories* **math** and **art**. We refer to them as **books/math** and **books/art** since **books** is their *parent* directory. Note that Windows uses backslashes rather than forward slashes to separate the parts of a directory.

Basic Shell Operations

The shell operations I show here are approximately identical across operating systems. For the purposes of this book, here are the essential operations in a shell:

Change directory: Use **cd** followed by the name of the directory where you want to move, or **cd ..** if you want to move up a directory. If you want to move to a different directory while remembering where you came from, use **pushd** followed by the different directory name. Then, to return to the previous directory, just say **popd**.

Directory listing: **ls** (**dir** in Windows) displays all the files and subdirectory names in the current directory. Use the wildcard ***** (asterisk) to narrow your search. For example, if you want to list all the files ending in ".java," you say **ls *.java** (Windows:

dir *.java). If you want to list the files starting with “F” and ending in “.java,” you say **ls F*.java** (Windows: **dir F*.java**).

Create a directory: use the **mkdir** (“make directory”) command (Windows: **md**), followed by the name of the directory you want to create. For example, **mkdir books** (Windows: **md books**).

Remove a file: Use **rm** (“remove”) followed by the name of the file you wish to remove (Windows: **del**). For example, **rm somefile.java** (Windows: **del somefile.java**).

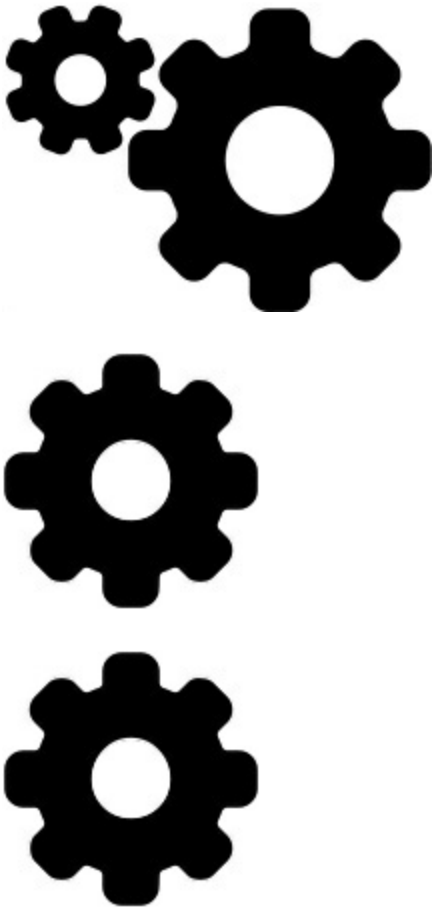
Remove a directory: use the **rm -r** command to remove the files in the directory and the directory itself (Windows: **deltree**). For example, **rm -r books** (Windows: **deltree books**).

Repeat a command: The “up arrow” on all three operating systems moves through previous commands so you can edit and repeat them. On Mac/Linux, **!!** repeats the last command and **!n** repeats the nth command.

Command history: Use **history** in Mac/Linux or press the F7 key in Windows. This gives you a list of all the commands

you've entered. Mac/Linux provides numbers to refer to when you want to repeat a command.

Unpacking a zip archive: A file name ending with **.zip** is an archive containing other files in a compressed format. Both Linux and Mac have command-line **unzip** utilities, and you can install a command-line **unzip** for Windows via the Internet. However, in all three systems the graphical file browser (Windows Explorer, the Mac Finder, or Nautilus or equivalent on Linux) will browse to



the directory containing your zip file. Then right-mouse-click on

the file and select “Open” on the Mac, “Extract Here” on Linux, or “Extract all …” on Windows.

To learn more about your shell, search Wikipedia for Windows Shell or, for Mac/Linux, Bash Shell.

Installing Java

To compile and run the examples, you must first install the *Java development kit*. In this book we use JDK8 (Java 1.8).

Windows

1. Follow the instructions at this link to Install Chocolatey.

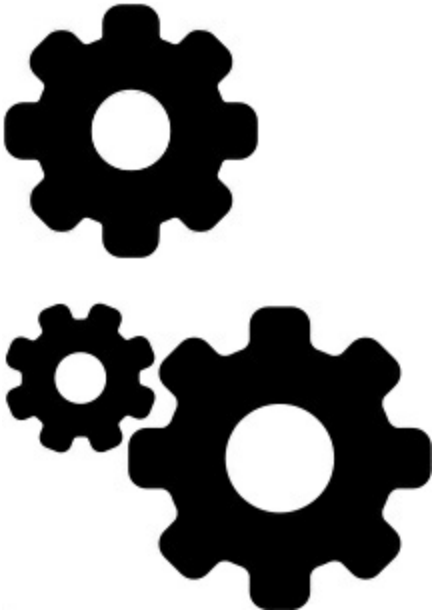
2. At a shell prompt, type: **choco install jdk8**. This takes some time, but when it’s finished Java is installed and the necessary environment variables are set.

Macintosh

The Mac comes with a much older version of Java that won’t work for the examples in this book, so you must first update it to Java 8. You will need administration rights to perform these steps.

1. Follow the instructions at this link to Install HomeBrew. Then at a shell prompt, execute **brew update** to make sure you have the latest changes.

2. At a shell prompt, execute **brew cask install java**.



Once HomeBrew and Java are installed, all other activities described in this book can be accomplished within a guest account, if that suits your needs.

Linux

Use the standard package installer with the following shell commands:

Ubuntu/Debian:

1. **sudo apt-get update**

2. **sudo apt-get install default-jdk**

Fedora/Redhat:

1. **su-c "yum install java-1.8.0-openjdk"**

Verify Your

Installation

Open a new shell and type:

java -version

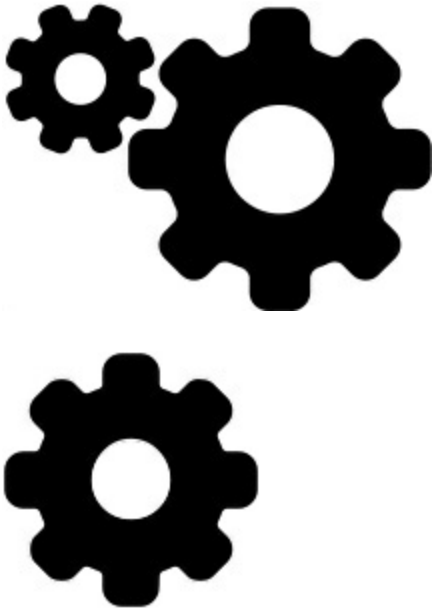
You should see something like the following (Version numbers and actual text will vary):

java version "1.8.0_112"

Java(TM) SE Runtime Environment (build 1.8.0_112-b15)

Java HotSpot(TM) 64-Bit Server VM (build 25.112-b15, mixed mode)

If you see a message that the command is not found or not recognized, review the installation instructions in this chapter. If you still can't get it to work, check StackOverflow.



Installing and Running the Book Examples

Once you have Java installed, the process to install and run the book examples is the same for all platforms:

1. Download the book examples from the GitHub Repository.

2. **unzip** (as described in Basic Shell Operations) the downloaded file into the directory of your choice.

3. Use the Windows Explorer, the Mac Finder, or Nautilus or equivalent on Linux to browse to the directory where you unzipped **OnJava8-Examples**, and open a shell there.

4. If you're in the right directory, you should see files named **gradlew** and **gradlew.bat** in that directory, along with numerous other files and directories. The directories correspond to the chapters in the book.

5. At the shell prompt, type **gradlew run** (Windows) or **./gradlew run** (Mac/Linux).

The first time you do this, Gradle will install itself and numerous other packages, so it will take some time. After everything is installed, subsequent builds and runs are faster.

Note you must be connected to the Internet the first time you run **gradlew** so that Gradle can download the necessary packages.

Basic Gradle Tasks

There are a large number of Gradle tasks automatically available with this book's build. Gradle uses an approach called *convention over configuration* which results in the availability of many tasks even if

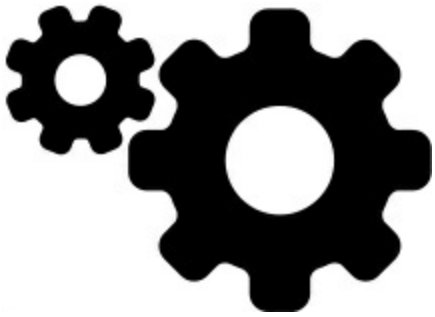
you’re only trying to accomplish something very basic. Some of the tasks that “came along for the ride” with this book are inappropriate or don’t successfully execute. Here is a list of the Gradle tasks you will typically use:

gradlew compileJava: Compiles all the Java files in the book *that can be compiled* (some files don’t compile, to demonstrate incorrect language usage).

gradlew run: First compiles, then executes all the Java files in the book *that can be executed* (some files are library components).

gradlew test: Executes all the *unit tests* (you’ll learn about these in Validating Your Code).

gradlew *chapter***:** *ExampleName*: Compiles and runs a specific example program. For instance, **gradlew objects:HelloDate**.



Objects Everywhere

“If we spoke a different language, we would perceive a somewhat different world.”— *Ludwig Wittgenstein (1889-1951)*

Although it is based on C++, Java is more of a “pure” object-oriented language. Both C++ and Java are hybrid languages, but in Java the designers felt that the hybridization was not as important as it was in C++. A hybrid language allows multiple programming styles; the reason C++ is hybrid is to support backward compatibility with the C language. Because C++ is a superset of the C language, it includes many of that language’s undesirable features, which can make some aspects of C++ overly complicated.

The Java language assumes you’re *only* writing object-oriented programs. Before you can begin you must shift your mindset into an object-oriented world. In this chapter you’ll see the basic components

of a Java program and learn that (almost) everything in Java is an object.

You Manipulate Objects with References

What's in a name? That which we call a
rose, by any other word would smell as
sweet. (Shakespeare, *Romeo & Juliet*)

Every programming language manipulates elements in memory. Sometimes the programmer must be constantly aware of that manipulation. Do you manipulate the element directly, or use an indirect representation that requires special syntax (for example, pointers in C or C++)?

Java simplifies the issue by considering everything an object, using a single consistent syntax. Although you *treat* everything as an object, the identifier you manipulate is actually a "reference" to an object.1

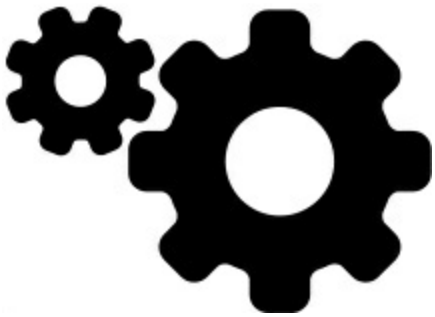
You might imagine a television (the object) and a remote control (the reference). As long as you're holding this reference, you have a connection to the television, but when someone says, "Change the channel" or "Lower the volume," what you're manipulating is the

reference, which in turn modifies the object. To move around the room and still control the television, you take the remote/reference with you, not the television.

Also, the remote control can stand on its own, with no television. That is, just because you have a reference doesn't mean there's necessarily an object connected to it. To hold a word or sentence, you create a **String** reference:

String s;

But here you've created *only* the reference, not an object. If you now decide to send a message to **s**, you get an error because **s** isn't actually



attached to anything (there's no television). A safer practice is to always initialize a reference when you create it:

String s = "asdf";

This uses a special Java feature: Strings can be initialized with quoted text. You must use a more general type of initialization for other types of objects.

You Must Create All the Objects

The point of a reference is to connect it to an object. You usually create objects with the **new** operator. The keyword **new** says, “Make one of these.” So in the preceding example, you can say:

```
String s = new String("asdf");
```

Not only does this mean “Make a new **String**,” but it also gives information about *how* to make the **String** by supplying an initial group of characters.

Java comes with a plethora of ready-made types in addition to **String**. On top of that, you can create your own types. In fact, creating new types is the fundamental activity in Java programming, and it’s what you’ll be learning about in the rest of this book.

Where Storage Lives

It’s useful to visualize the way things are laid out while the program is running—in particular, how memory is arranged. There are five different places to store data:

1. **Registers**. This is the fastest storage because it exists in a place different from that of other storage: inside the *central processing*

unit (CPU)2. However, the number of registers is severely limited, so registers are allocated as they are needed. You don't have direct

control over register allocation, nor do you see any evidence in

your programs that registers even exist (C & C++, on the other

hand, allow you to suggest register allocation to the compiler).

2. **The stack**. This lives in the general random-access memory

(RAM) area, but has direct support from the processor via its

stack pointer. The stack pointer is moved down to create new

memory and moved up to release that memory. This is an

extremely fast and efficient way to allocate storage, second only to

registers. The Java system must know, while it is creating the

program, the exact lifetime of all the items stored on the stack.

This constraint places limits on the flexibility of your programs, so

while some Java storage exists on the stack—in particular, object

references—Java objects themselves are not placed on the stack.

3. **The heap**. This is a general-purpose pool of memory (also in the

RAM area) where all Java objects live. Unlike the stack, the

compiler doesn't need to know how long objects must stay on the

heap. Thus, there's a great deal of flexibility when using heap

storage. Whenever you need an object, you write the code to create it using **new**, and the storage is allocated on the heap when that code is executed. There's a price for this flexibility: It can take more time to allocate and clean up heap storage than stack storage (if you even *could* create objects on the stack in Java, as you can in C++). Over time, however, Java's heap allocation mechanism has become very fast, so this is not an issue for concern.

4. **Constant storage**. Constant values are often placed directly in the program code, which is safe since they can never change. Sometimes constants are cordoned off by themselves so they can be optionally placed in read-only memory (ROM), in embedded systems. [3]

5. **Non-RAM storage**. If data lives completely outside a program, it can exist while the program is not running, outside the control of the program. The two primary examples of this are *serialized objects*, where objects are turned into streams of bytes, generally

sent to another machine, and *persistent objects*, where the objects are placed on disk so they will hold their state even when the program is terminated. The trick with these types of storage is turning the objects into something that exist on the other medium, and yet be resurrected into a regular RAM-based object when necessary. Java provides support for *lightweight persistence*. Libraries such as JDBC and Hibernate provide more sophisticated support for storing and retrieving object information using databases.

Special Case: Primitive Types

One group of types that you'll often use gets special treatment. You can think of these as "primitive" types. The reason for the special treatment is that creating an object with **new**—especially a small, simple variable—isn't very efficient, because **new** places objects on the heap. For these types Java falls back on the approach taken by C and C++. That is, instead of creating the variable using **new**, an "automatic" variable is created that is *not a reference*. The variable holds the value directly, and it's placed on the stack, so it's much more efficient.

Java specifies the size of each primitive type, and these sizes don't change from one machine architecture to another as they do in some

languages. This size invariance is one reason Java programs are more portable than programs in some other languages.

Primitive Size

Min

Max

Wrapper

boolean

Boolean

Unicode

16

65,535

char

0

bits

\uffff

Character

\u0000

byte

8 bits

-128

+127

Byte

16

short

-215

+215-1

Short

bits

32

int

-231

+231-1

Integer

bits

64

long

-263

+263-1

Long

bits

32

float

IEEE754

IEEE754

Float

bits

64

double

IEEE754

IEEE754

Double

bits

void

Void

All numeric types are signed, so don’t look for unsigned types.

The size of the **boolean** type is not explicitly specified; it is defined to take the literal values **true** or **false**.

“Wrapper” classes for primitive data types create a non-primitive object on the heap to represent that primitive type. For example:

char c = 'x';

Character ch = **new** Character(c);

Or you can also use:

Character ch = **new** Character('x');

Autoboxing automatically converts a primitive to a wrapped object:

Character ch = 'x';

and back:

char c = ch;

The reasons for wrapping primitives are shown in a later chapter.

High-Precision Numbers

Java includes two classes for performing high-precision arithmetic: **BigInteger** and **BigDecimal**. Although these fit approximately the same category as the “wrapper” classes, neither one has a corresponding primitive.

Both classes have methods that provide analogues for the operations you perform on primitive types. That is, you can do anything with a **BigInteger** or **BigDecimal** you can with an **int** or **float**, it’s just that you must use method calls instead of operators. Also, since there are more calculations involved, the operations are slower. You’re exchanging speed for accuracy.

BigInteger supports arbitrary-precision integers. This means you

can accurately represent integral values of any size without losing any information during operations.

BigDecimal is for arbitrary-precision fixed-point numbers; you can use these for accurate monetary calculations, for example.

Consult the JDK documentation for details about these two classes.

Arrays in Java

Many programming languages support some kind of array. Using arrays in C and C++ is perilous because those arrays are only blocks of memory. If a program accesses the array outside of its memory block or uses the memory before initialization (common programming errors), the results are unpredictable.

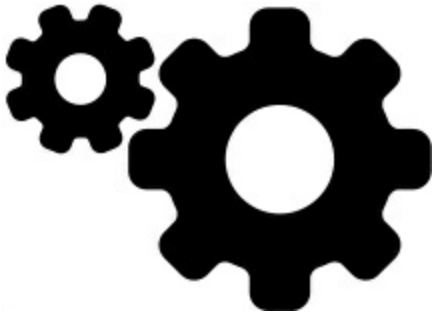
One of the primary goals of Java is safety, so many of the problems that plague programmers in C and C++ are not repeated in Java. A Java array is guaranteed to be initialized and cannot be accessed outside of its range. This range checking comes at the price of having a small amount of memory overhead for each array as well as extra time to verify the index at run time, but the assumption is that the safety

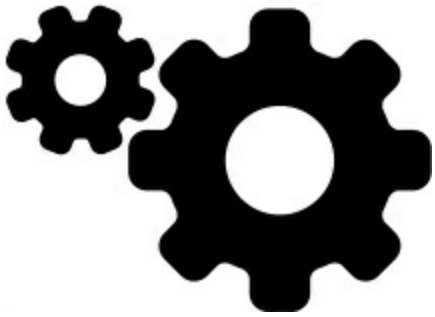
and increased productivity are worth the expense (and Java can often optimize these operations).

When you create an array of objects, you are really creating an array of references, and each of those references is automatically initialized to a special value with its own keyword: **null**. When Java sees **null**, it recognizes that the reference in question isn't pointing to an object. You must assign an object to each reference before you use it, and if you try to use a reference that's still **null**, the problem is reported at run time. Thus, typical array errors are prevented in Java.

You can also create an array of primitives. The compiler guarantees initialization by zeroing the memory for that array.

Arrays are covered in detail later in the book, and specifically in the Arrays chapter.





Comments

There are two types of comments in Java. The first are the traditional C-style comment which begin with a **/*** and continue, possibly across many lines, until a ***/**. Note that many programmers begin each line of a multiline comment with a *****, so you'll often see:

/ This is a comment*

** that continues*

** across lines*

**/*

Remember, however, that everything inside the **/*** and ***/** is ignored, so there's no difference if you say instead:

/ This is a comment that*

*continues across lines */*

The second form of comment comes from C++. It is the single-line comment, which starts with a **//** and continues until the end of the line. This type of comment is convenient and commonly used because

it’s easy. So you often see:

// This is a one-line comment

You Never Need to

Destroy an Object

In some programming languages, managing storage lifetime requires significant effort. How long does a variable last? If you are supposed to destroy it, when should you? Confusion over storage lifetime can lead to many bugs, and this section shows how Java simplifies the issue by

releasing storage for you.

Scoping

Most procedural languages have the concept of *scope*. This determines both the visibility and lifetime of the names defined within that scope. In C, C++, and Java, scope is determined by the placement of curly braces **{}**. Here is a fragment of Java code demonstrating scope:

```
{
int x = 12;
// Only x available
```

```
{
int q = 96;
// Both x & q available
}
// Only x available
// q is "out of scope"
}
```

A variable defined within a scope is available only until the end of that scope.

Indentation makes Java code easier to read. Since Java is a free-form language, the extra spaces, tabs, and carriage returns do not affect the resulting program.

You *cannot* do the following, even though it is legal in C and C++:

```
{
int x = 12;
{
int x = 96; // Illegal
}
}
```

The Java compiler will announce that the variable **x** has already been

defined. Thus the C and C++ ability to “hide” a variable in a larger

scope is not allowed, because the Java designers thought it led to confusing programs.

Scope of Objects

Java objects do not have the same lifetimes as primitives. When you create a Java object using **new**, it persists past the end of the scope. Thus, if you say:

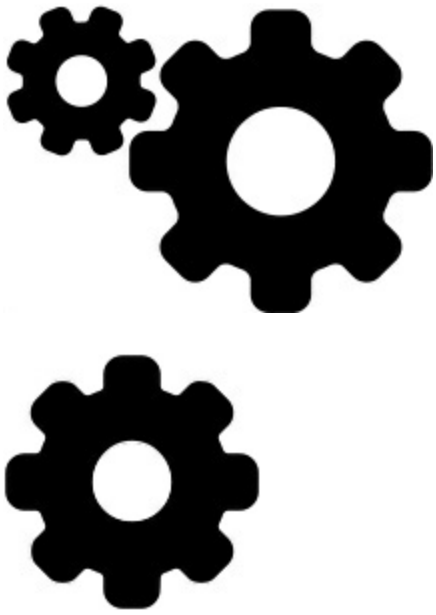
```
{
String s = new String("a string");
} // End of scope
```

the reference **s** vanishes at the end of the scope. However, the **String** object that **s** points to is still occupying memory. In this bit of code, there is no way to access the object after the end of the scope, because the only reference to it is out of scope. In later chapters you’ll see how the reference to the object can be passed around and duplicated during the course of a program.

Because objects created with **new** exist as long as you need them, a

whole slew of C++ programming problems vanish in Java. In C++ you must not only make sure that the objects stay around as long as necessary, you must also destroy the objects when you're done with them.

This brings up a question. If Java leaves the objects lying around, what keeps them from filling up memory and halting your program, which is exactly the kind of problem that occurs in C++? In Java, a bit of magic happens: the *garbage collector* looks at all the objects created with **new** and finds those that are no longer referenced. It then releases the memory for those objects, so the memory can be used for new objects. This means you don't worry about reclaiming memory yourself. You simply create objects, and when you no longer need them, they go away by themselves. This prevents an important class of



programming problem: the so-called “memory leak,” when a programmer forgets to release memory.

Creating New Data

Types: class

If everything is an object, what determines how a particular class of object looks and behaves? Put another way, what establishes the *type* of an object? You might expect a keyword called “type,” and that would certainly make sense. Historically, however, most object-oriented languages use the keyword **class** to describe a new kind of object.

The **class** keyword (so common it will often not be bold-faced throughout this book) is followed by the name of the new type. For example:

```
class ATypeName {
// Class body goes here
}
```

This introduces a new type, although here the class body consists only of a comment, so there is not too much you can do with it. However, you can create an object of **ATypeName** using **new**:

```
ATypeName a = new ATypeName();
```

You can’t tell it to do much of anything—that is, you cannot send it any

interesting messages—until you define some methods for it.

Fields

When you define a class, you can put two types of elements in your class: *fields* (sometimes called *data members*), and *methods* (sometimes called *member functions*). A field is an object of any type you can talk to via its reference. A field can also be a primitive type. If it is a reference to an object, you must initialize that reference to connect it to an actual object (using **new**, as seen earlier).

Each object keeps its own storage for its fields. Ordinarily, fields are not shared among objects. Here is an example of a class with some fields:

```
class DataOnly {
int i;
double d;
boolean b;
}
```

This class doesn't do anything except hold data. As before, you create an object like this:

```
DataOnly data = new DataOnly();
```

You can assign values to the fields by referring to object members. To do this, you state the name of the object reference, followed by a period (dot), followed by the name of the member inside the object:

objectReference.member

For example:

```
data.i = 47;
data.d = 1.1;
data.b = false;
```

What if your object contains other objects that contain data you want to modify? You just keep "connecting the dots." For example:

```
myPlane.leftTank.capacity = 100;
```

You can nest many objects this way (although such a design might

become confusing).

Default Values for Primitive Members

When a primitive data type is a field in a class, it is guaranteed to get a default value if you do not initialize it:

Primitive

Default

boolean

false

\u0000

char

(**null**)

byte

(byte)0

short

(short)0

int

0

long

0L

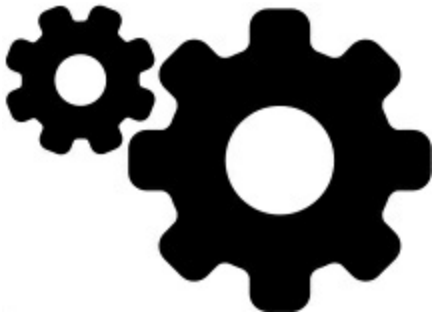
float

0.0f

double

0.0d

The default values are only what Java guarantees when the variable is



used *as a member of a class*. This ensures that primitive fields will always be initialized (something C++ doesn't do), reducing a source of bugs. However, this initial value might not be correct or even legal for the program you are writing. It's best to always explicitly initialize your variables.

This guarantee doesn't apply to *local variables*—those that are not fields of a class. Thus, if within a method definition you have:

int x;

Then **x** will get some arbitrary value (as it does in C and C++); it will not automatically be initialized to zero. You are responsible for assigning an appropriate value before you use **x**. If you forget, Java definitely improves on C++: You get a compile-time error telling you

the variable might not be initialized. (C++ compilers often warn you about uninitialized variables, but in Java these are errors.)

Methods, Arguments, and Return Values

In many languages (like C and C++), the term *function* is used to describe a named subroutine. In Java, we use the term *method*, as in "a way to do something."

Methods in Java determine the messages an object can receive. The fundamental parts of a method are the name, the arguments, the return type, and the body. Here is the basic form:

```
ReturnType methodName( /* Argument list */ ) {
// Method body
}
```

ReturnType indicates the type of value produced by the method

when you call it. The argument list gives the types and names for the information you pass into the method. The method name and argument list are collectively called the *signature* of the method. The

signature uniquely identifies that method.

Methods in Java can only be created as part of a class. A method can

be called only for an object4, and that object must be able to perform that method call. If you try to call the wrong method for an object,

you'll get an error message at compile time.

You call a method for an object by giving the object reference followed

by a period (dot), followed by the name of the method and its

argument list, like this:

objectReference.methodName(arg1, arg2, arg3);

Consider a method **f()** that takes no arguments and returns a value

of type **int**. For a reference **a** that accepts calls to **f()**, you can say this:

int x = a.f();

The type of the return value must be compatible with the type of **x**.

This act of calling a method is sometimes termed *sending a message*

to an object. In the preceding example, the message is **f()** and the

object is **a**. Object-oriented programming can be summarized as

"sending messages to objects."

The Argument List

The method argument list specifies the information you pass into the

method. As you might guess, this information—like everything else in

Java—takes the form of objects. The argument list must specify the

object types and the name of each object. As always, where you seem to be handing objects around, you are actually passing references.5 The type of the reference must be correct, however. If a **String** argument is expected, you must pass in a **String** or the compiler will give an error.

Here is the definition for a method that takes a **String** as its argument. It must be placed within a class for it to compile:

```
int storage(String s) {
return s.length() * 2;
}
```

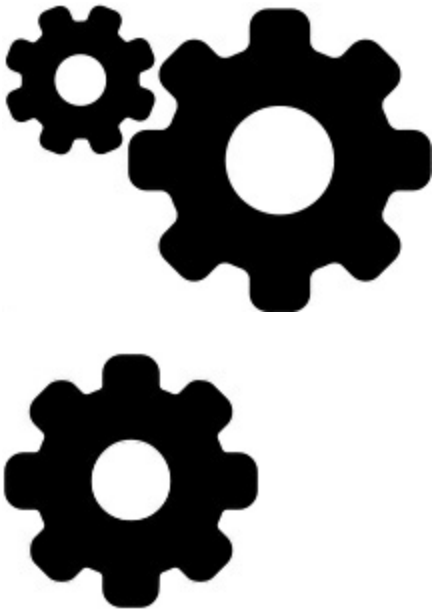
This method calculates and delivers the number of bytes required to hold the information in a particular **String**. The argument **s** is of type **String**. Once **s** is passed into **storage()**, you can treat it like any other object—you can send it messages. Here, we call **length()**, which is a **String** method that returns the number of characters in a **String**. The size of each **char** in a **String** is 16 bits, or two bytes.

You can also see the **return** keyword, which does two things. First, it means “Leave the method, I’m done.” Second, if the method produces a value, that value is placed right after the **return** statement. Here, the return value is produced by evaluating the expression

s.length() * 2.

You can return any type you want, but if you don’t return anything at all, you do so by indicating that the method produces **void** (nothing). Here are some examples:

```
boolean flag() { return true; }
double naturalLogBase() { return 2.718; }
void nothing() { return; }
void nothing2() {}
```



When the return type is **void**, the **return** keyword is used only to exit the method, and is therefore unnecessary if called at the end of the method. You can return from a method at any point, but if you’ve given a non-**void** return type, the compiler will force you to return the appropriate type of value regardless of where you return.

It might look like a program is just a bunch of objects with methods that take other objects as arguments and send messages to those other objects. That is indeed much of what goes on, but in the following Operators chapter you'll learn how to do the detailed low-level work by making decisions within a method. For this chapter, sending messages will suffice.

Writing a Java

Program

There are several other issues you must understand before seeing your first Java program.

Name Visibility

A problem in any programming language is the control of names. If you use a name in one module of the program, and another programmer uses the same name in another module, how do you distinguish one name from another and prevent the two names from "clashing?" In C this is especially challenging because a program is often an unmanageable sea of names. C++ classes (on which Java classes are modeled) nest functions within classes so they cannot clash with function names nested within other classes. However, C++ continues to allow global data and global functions, so clashing is still possible. To solve this problem, C++ introduced *namespaces* using

additional keywords.

Java avoided all these problems by taking a fresh approach. To produce an unambiguous name for a library, the Java creators want you to use your Internet domain name in reverse, because domain names are guaranteed to be unique. Since my domain name is **MindviewInc.com**, my **foibles** utility library is named **com.mindviewinc.utility.foibles**. Following your reversed domain name, the dots are intended to represent subdirectories.

In Java 1.0 and Java 1.1 the domain extensions **com**, **edu**, **org**, **net**, etc., were capitalized by convention, so the library would appear:

Com.mindviewinc.utility.foibles. Partway through the development of Java 2, however, they discovered this caused problems, so now the entire package name is lowercase.

This mechanism means all your files automatically live in their own namespaces, and each class within a file has a unique identifier. This way, the language prevents name clashes.

Using reversed URLs was a new approach to namespaces, never before tried in another language. Java has a number of these “inventive” approaches to problems. As you might imagine, adding a feature without experimenting with it first risks discovering problems with

that feature in the future, after the feature is used in production code, typically when it's too late to do anything about it (some mistakes were bad enough to actually remove things from the language).

The problem with associating namespaces with file paths using reversed URLs is by no means one that causes bugs, but it does make it challenging to manage source code. By using **com.mindviewinc.utility.foibles**, I create a directory hierarchy with "empty" directories **com** and **mindviewinc** whose only job is to reflect the reversed URL. This approach seemed to open the door to what you will encounter in production Java programs: deep directory hierarchies filled with empty directories, not just for the reversed URLs but also to capture other information. These long paths

are basically being used to store data about what is in the directory. If you expect to use directories in the way they were originally designed, this approach lands anywhere from "frustrating" to "maddening," and for production Java code you are essentially forced to use one of the IDEs specifically designed to manage code that is laid out in this

fashion, such as NetBeans, Eclipse, or IntelliJ IDEA. Indeed, those IDEs both manage and create the deep empty directory hierarchies for you.

For this book's examples, I didn't want to burden you with the extra annoyance of the deep hierarchies, which would have effectively required you to learn one of the big IDEs before getting started. The examples for each chapter are in a shallow subdirectory with a name reflecting the chapter title. This caused me occasional struggles with tools that follow the deep-hierarchy approach.

Using Other Components

Whenever you use a predefined class in your program, the compiler must locate that class. In the simplest case, the class already exists in the source-code file it's being called from. In that case, you simply use the class—even if the class doesn't get defined until later in the file (Java eliminates the so-called "forward referencing" problem).

What about a class that exists in some other file? You might think the compiler should be smart enough to go and find it, but there is a problem. Imagine you use a class with a particular name, but more than one definition for that class exists (presumably these are different definitions). Or worse, imagine that you're writing a program, and as

you’re building it you add a new class to your library that conflicts with the name of an existing class.

To solve this problem, you must eliminate all potential ambiguities by telling the Java compiler exactly what classes you want using the **import** keyword. **import** tells the compiler to bring in a package, which is a library of classes. (In other languages, a library could

consist of functions and data as well as classes, but remember that all activities in Java take place within classes.)

Much of the time you’ll use components from the standard Java libraries that come with your compiler. With these, you don’t worry about long, reversed domain names; you just say, for example:

import java.util.ArrayList;

This tells the compiler to use Java’s **ArrayList** class, located in its **util** library.

However, **util** contains a number of classes, and you might want to use several of them without declaring them all explicitly. This is easily accomplished by using ***** to indicate a wild card:

import java.util.*;

The examples in this book are small and for simplicity's sake we'll usually use the ***** form. However, many style guides specify that each class should be individually imported.

The static Keyword

Creating a class describes the look of its objects and the way they behave. You don't actually get an object until you create one using **new**, at which point storage is allocated and methods become available.

This approach is insufficient in two cases. Sometimes you want only a single, shared piece of storage for a particular field, regardless of how many objects of that class are created, or even if no objects are created. The second case is if you need a method that isn't associated with any particular object of this class. That is, you need a method you can call even if no objects are created.

The **static** keyword (adopted from C++) produces both these effects. When you say something is **static**, it means the field or method is not tied to any particular object instance. Even if you've never created an object of that class, you can call a **static** method or access a **static** field. With ordinary, non-**static** fields and

methods, you must create an object and use that object to access the field or method, because non-**static** fields and methods must target a particular object.6

Some object-oriented languages use the terms *class data* and *class methods*, meaning that the data and methods exist only for the class as a whole, and not for any particular objects of the class. Sometimes Java literature uses these terms too.

To make a field or method **static**, you place the keyword before the definition. The following produces and initializes a **static** field:

```
class StaticTest {
static int i = 47;
}
```

Now even if you make two **StaticTest** objects, there is still only one piece of storage for **StaticTest.i**. Both objects share the same **i**. For example:

```
StaticTest st1 = new StaticTest();
StaticTest st2 = new StaticTest();
```

Both **st1.i** and **st2.i** have the same value of 47 since they are the same piece of memory.

There are two ways to refer to a **static** variable. As in the preceding

example, you can name it via an object; for example, **st2.i**. You can also refer to it directly through its class name, something you cannot do with a non-**static** member:

StaticTest.i++;

The ++ operator adds one to the variable. Now both **st1.i** and **st2.i** have the value 48.

Using the class name is the preferred way to refer to a **static** variable because it emphasizes the variable's **static** nature[7].

Similar logic applies to **static** methods. You can refer to a **static** method either through an object as you can with any method, or with the special additional syntax **ClassName.method()**. You define a **static** method like this:

```
class Incrementable {
static void increment() { StaticTest.i++; }
}
```

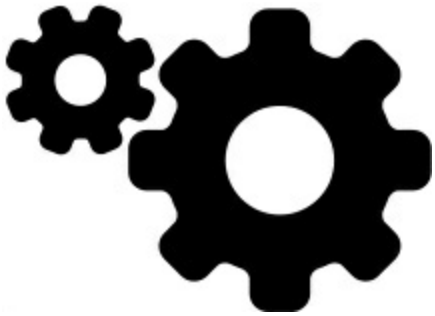
The **Incrementable** method **increment()** increments the **static int i** using the ++ operator. You can call **increment()** in the typical way, through an object:

```
Incrementable sf = new Incrementable();
sf.increment();
```

However, the preferred approach is to call it directly through its class:

Incrementable.increment();

static applied to a field definitely changes the way the data is created—one for each class versus the non-**static** one for each



object. When applied to a method, **static** allows you to call that method without creating an object. This is essential, as you will see, in defining the **main()** method that is the entry point for running an application.

Your First Java Program

Finally, here's the first complete program. It starts by displaying a **String**, followed by the date, using the **Date** class from the Java standard library.

```
// objects/HelloDate.java
import java.util.*;
public class HelloDate {
```

```
public static void main(String[] args) {
System.out.println("Hello, it's: ");
System.out.println(new Date());
}
}
```

In this book I treat the first line specially; it's always a comment line containing the the path information to the file (using the directory name **objects** for this chapter) followed by the file name. I have tools to automatically extract and test the book's code based on this information, and you will easily find the code example in the repository by referring to the first line.

At the beginning of each program file, you must place **import** statements to bring in any extra classes you need for the code in that file. I say "extra" because there's a certain library of classes automatically included in every Java file: **java.lang**. Start up your Web browser and look at the documentation from Oracle. If you haven't downloaded the JDK documentation from the Oracle Java site, do so now[8], or find it on the Internet. If you look at the list of packages, you'll see all the different class libraries that come with Java.

Select **java.lang**. This will bring up a list of all the classes that are part of that library. Since **java.lang** is implicitly included in every

Java code file, these classes are automatically available. There's no **Date** class listed in **java.lang**, which means you must import another library to use that. If you don't know the library where a particular class is, or if you want to see all classes, select "Tree" in the Java documentation. Now you can find every single class that comes with Java. Use the browser's "find" function to find **Date**. You'll see it listed as **java.util.Date**, which tells you it's in the **util** library and you must **import java.util.*** in order to use **Date**.

If inside the documentation you select **java.lang**, then **System**, you'll see that the **System** class has several fields, and if you select **out**, you'll discover it's a **static PrintStream** object. Since it's **static**, you don't need to use **new**—the **out** object is always there, and you can just use it. What you can do with this **out** object is determined by its type: **PrintStream**. Conveniently, **PrintStream** is shown in the description as a hyperlink, so if you click on that, you'll see a list of all the methods you can call for **PrintStream**. There are quite a few, and these are covered later in the book. For now all we're interested in is **println()**, which in effect means "Print what I'm giving you out to the console and end with a newline." Thus, in any Java program you can write something

like this:

System.out.println("A String of things");

whenever you want to display information to the console.

One of the classes in the file must have the same name as the file. (The compiler complains if you don't do this.) When you're creating a standalone program such as this one, the class with the name of the file must contain an *entry point* from which the program starts. This special method is called **main()**, with the following signature and return type:

public static void main(String[] args) {

The **public** keyword means the method is available to the outside world (described in detail in the Implementation Hiding chapter). The argument to **main()** is an array of **String** objects. The **args** won't be used in the current program, but the Java compiler insists they be there because they hold the arguments from the command line.

The line that prints the date is interesting:

System.out.println(**new** Date());

The argument is a **Date** object that is only created to send its value (automatically converted to a **String**) to **println()**. As soon as this statement is finished, that **Date** is unnecessary, and the garbage collector can come along and get it anytime. We don't worry about

cleaning it up.

When you look at the JDK documentation, you see that **System** has many other useful methods (one of Java's assets is its large set of standard libraries). For example:

```
// objects/ShowProperties.java
public class ShowProperties {
public static void main(String[] args) {
System.getProperties().list(System.out);
System.out.println(System.getProperty("user.name"));
System.out.println(
System.getProperty("java.library.path"));
}
}
/* Output: (First 20 Lines)
-- listing properties --
java.runtime.name=Java(TM) SE Runtime Environment
sun.boot.library.path=C:\Program
Files\Java\jdk1.8.0_112\jr...
java.vm.version=25.112-b15
java.vm.vendor=Oracle Corporation
```

java.vendor.url=http://java.oracle.com/

path.separator=;

java.vm.name=Java HotSpot(TM) 64-Bit Server VM

file.encoding.pkg=sun.io

user.script=

user.country=US

sun.java.launcher=SUN_STANDARD

sun.os.patch.level=

java.vm.specification.name=Java Virtual Machine

Specification

user.dir=C:\Users\Bruce\Documents\GitHub\on-ja...

java.runtime.version=1.8.0_112-b15

java.awt.graphicsenv=sun.awt.Win32GraphicsEnvironment

java.endorsed.dirs=C:\Program

Files\Java\jdk1.8.0_112\jr...

os.arch=amd64

java.io.tmpdir=C:\Users\Bruce\AppData\Local\Temp

...

**/*

The first line in **main()** displays all “properties” from the system

where you are running the program, so it gives you environment information. The **list()** method sends the results to its argument, **System.out**. You will see later in the book that you can send the results elsewhere, to a file, for example. You can also ask for a specific property—here, **user.name** and **java.library.path**.

The **/* Output:** tag at the end of the file indicates the beginning of the output generated by this file. Most examples in this book that produce output will contain the output in this commented form, so

you see the output and know it is correct. The tag allows the output to be automatically updated into the text of this book after being checked with a compiler and executed.

Compiling and Running

To compile and run this program, and all the other programs in this book, you must first have a Java programming environment. The installation process was described in Installing Java and the Book Examples. If you followed these instructions, you are using the Java Developer's Kit (JDK), free from Oracle. If you use another

development system, look in the documentation for that system to

determine how to compile and run programs.

Installing Java and the Book Examples also describes how to install the examples for this book. Move to the subdirectory named

objects and type:

javac HelloDate.java

This command should produce no response. If you get any kind of an

error message, it means you haven't installed the JDK properly and

you must investigate those problems.

On the other hand, if you just get your command prompt back, you can

type:

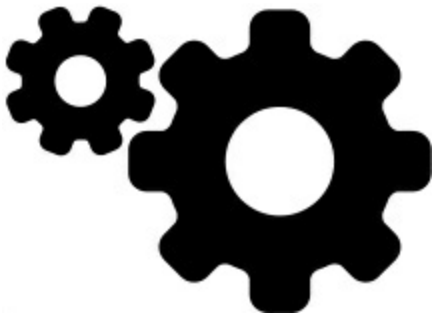
java HelloDate

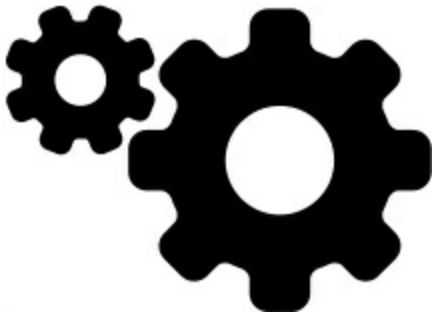
and you'll get the message and the date as output.

This is the process to compile and run each program (containing a

main()) in this book. However, the source code for this book also has a file called **build.gradle** in the root directory, and this

contains the *Gradle* configuration for automatically building, testing,





and running the files for the book. When you run the **gradlew** command for the first time, Gradle will automatically install itself (assuming you have Java installed).

Coding Style

The style described in the document *Code Conventions for the Java Programming Language* 10 is to capitalize the first letter of a class name. If the class name consists of several words, they are run together (that is, you don't use underscores to separate the names), and the first letter of each embedded word is capitalized, such as:

class AllTheColorsOfTheRainbow { // ...

This is sometimes called "camel-casing." For almost everything else—methods, fields (member variables), and object reference names—the accepted style is just as it is for classes *except* that the first letter of the identifier is lowercase. For example:

class AllTheColorsOfTheRainbow {

int anIntegerRepresentingColors;

```
void changeTheHueOfTheColor(int newHue) {
// ...
}
// ...
}
```

The user must also type these long names, so be merciful.

The Java code you find in the Oracle libraries also follows the placement of open-and-close curly braces in this book.

Summary

This chapter shows you just enough Java so you understand how to write a simple program. You've also seen an overview of the language and some of its basic ideas. However, the examples so far have all been of the form "Do this, then do that, then do something else." The next two chapters will introduce the basic operators used in Java programming, and show you how to control the flow of your program.

1. This can be a flashpoint. There are those who say, "Clearly, it's a pointer," but this presumes an underlying implementation. Also, the syntax of Java references is much more akin to C++ references than to pointers. In the 1st edition of *Thinking in Java*, I chose to invent a new term, "handle," because C++ references and Java

references have some important differences. I was coming out of C++ and did not want to confuse the C++ programmers whom I assumed would be the largest audience for Java. In the 2nd edition of *Thinking in Java*, I decided that “reference” was the more commonly used term, and that anyone changing from C++ would have a lot more to cope with than the terminology of references, so they might as well jump in with both feet. However, there are people who disagree even with the term “reference.” In one book I read that it was “completely wrong to say that Java supports pass by reference,” because Java object identifiers (according to that author) are *actually* “object references.” And (he goes on) everything is *actually* pass by value. So you’re not passing by reference, you’re “passing an object reference by value.” One could argue for the precision of such convoluted explanations, but I think my approach simplifies the understanding of the concept without hurting anything (well, language lawyers may claim I’m lying to you, but I’ll say that I’m providing an appropriate abstraction).↩

2. Most microprocessor chips do have additional *cache* memory but this is organized as traditional memory and not as registers↩

3. An example of this is the **String** pool. All literal **String**s and **String**-valued constant expressions are interned automatically and put into special static storage. ↩

4. **static** methods, which you'll learn about soon, can be called *for the class*, without an object.↩

5. With the usual exception of the aforementioned "special" data types **boolean**, **char**, **byte**, **short**, **int**, **long**, **float**, and **double**. In general, though, you pass objects, which really means you pass references to objects. ↩

6. **static** methods don't require objects to be created before they are used, so they cannot *directly* access non-**static** members or methods by calling those other members without referring to a named object (since non-**static** members and methods must be tied to a particular object).↩

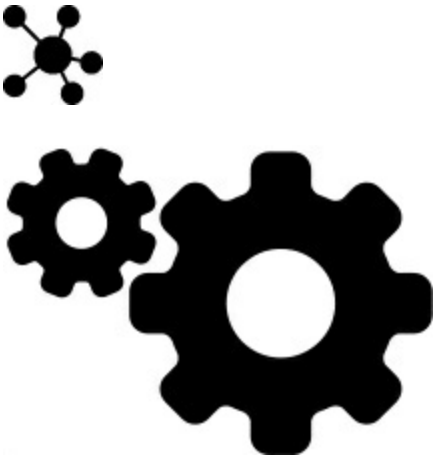
7. In some cases it also gives the compiler better opportunities for optimization↩

8. Note this documentation doesn't come packed with the JDK; you must do a separate download to get it. ↩

9. For every program in this book to compile and run through the command line, you might also need to set your CLASSPATH. ↩

10. (Search the Internet; also look for "Google Java Style"). To keep

code listings narrow for this book, not all these guidelines could be followed, but you'll see that the style I use here matches the Java standard as much as possible.↩



Operators

Operators manipulate data.

Because Java was inherited from C++, most of its operators are familiar to C and C++ programmers. Java also adds some improvements and simplifications.

If you know C or C++ syntax, you can skim through this chapter and the next, looking for places where Java is different from those languages. However, if you find yourself floundering a bit in these two chapters, make sure you go through the free multimedia seminar *Thinking in C*, downloadable from www.OnJava8.com. It contains audio lectures, slides, exercises, and solutions specifically designed to bring you up to speed with the fundamentals necessary to learn Java.

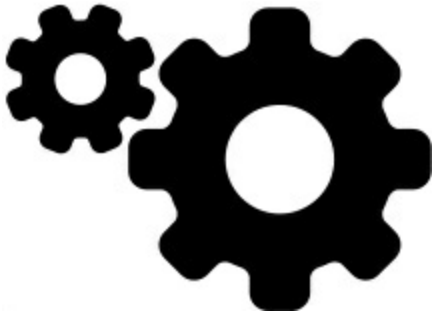
Using Java Operators

An operator takes one or more arguments and produces a new value.

The arguments are in a different form than ordinary method calls, but

the effect is the same. Addition and unary plus (+), subtraction and

unary minus (-), multiplication (*****), division (/), and assignment (=) all work much the same in any programming language.



All operators produce a value from their operands. In addition, some

operators change the value of an operand. This is called a *side effect*.

The most common use for operators that modify their operands is to

generate the side effect, but keep in mind that the value produced is

available for your use, just as in operators without side effects.

Almost all operators work only with primitives. The exceptions are =,

== and **!=**, which work with all objects (and are a point of confusion

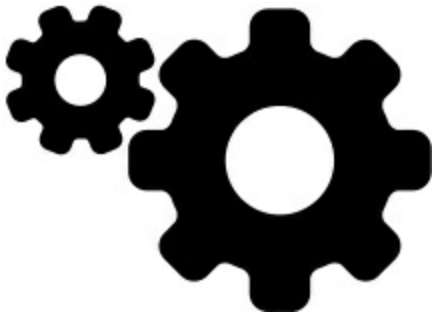
for objects). In addition, the **String** class supports + and +=.

Precedence

Operator precedence defines expression evaluation when several

operators are present. Java has specific rules that determine the order of evaluation. The easiest one to remember is that multiplication and division happen before addition and subtraction. Programmers often forget the other precedence rules, and use parentheses to make the order of evaluation explicit. For example, look at statements **[1]** and **[2]**:

```
// operators/Precedence.java
public class Precedence {
public static void main(String[] args) {
int x = 1, y = 2, z = 3;
int a = x + y - 2/2 + z; // [1]
int b = x + (y - 2)/(2 + z); // [2]
System.out.println("a = " + a);
System.out.println("b = " + b);
}
}
/* Output:
a = 5
b = 1
*/
```



These statements look roughly the same, but from the output you see they have very different meanings depending on the use of parentheses.

Notice that **System.out.println()** uses the **+** operator. In this context, **+** means "**String** concatenation" and, if necessary, "**String** conversion." When the compiler sees a **String** followed by a **+** followed by a non-**String**, it attempts to convert the non-**String** into a **String**. The output shows it successfully converts from **int** into **String** for **a** and **b**.

Assignment

The operator **=** performs assignment. It means "Take the value of the right-hand side (often called the *rvalue*) and copy it into the left-hand side (often called the *lvalue*)." An rvalue is any constant, variable, or expression that produces a value, but an lvalue must be a distinct, named variable. (That is, there must be a physical space to store the value.) For instance, you can assign a constant value to a variable:

a = 4;

but you cannot assign anything to a constant value—it cannot be an lvalue. (You can't say **4 = a;** .)

Assigning primitives is straightforward. Since the primitive holds the actual value and not a reference to an object, when you assign primitives, you copy the contents from one place to another. For example, if you say **a = b** for primitives, the contents of **b** are copied into **a**. If you then go on to modify **a**, **b** is naturally unaffected by this modification. As a programmer, this is what you can expect for most situations.

When you assign objects, however, things change. Whenever you manipulate an object, what you're manipulating is the reference, so when you assign "from one object to another," you're actually copying a reference from one place to another. This means if you say **c = d** for objects, you end up with both **c** and **d** pointing to the object where, originally, only **d** pointed. Here's an example that demonstrates this behavior:

```
// operators/Assignment.java
// Assignment with objects is a bit tricky
class Tank {
int level;
```

```
}
public class Assignment {
public static void main(String[] args) {
Tank t1 = new Tank();
Tank t2 = new Tank();
t1.level = 9;
t2.level = 47;
System.out.println("1: t1.level: " + t1.level +
", t2.level: " + t2.level);
t1 = t2;
System.out.println("2: t1.level: " + t1.level +
", t2.level: " + t2.level);
t1.level = 27;
System.out.println("3: t1.level: " + t1.level +
", t2.level: " + t2.level);
}
}
/* Output:
1: t1.level: 9, t2.level: 47
2: t1.level: 47, t2.level: 47
```

3: t1.level: 27, t2.level: 27

/

The **Tank** class is simple, and two instances (**t1** and **t2**) are created within **main()**. The **level** field within each **Tank** is given a

different value, then **t2** is assigned to **t1**, and **t1** is changed. In many programming languages you expect **t1** and **t2** to be independent at all times, but because you've assigned a reference, changing the **t1** object appears to change the **t2** object as well! This is because both **t1** and **t2** contain references that point to the same object. (The original reference that was in **t1**, that pointed to the object holding a value of 9, was overwritten during the assignment and effectively lost; its object is cleaned up by the garbage collector.)

This phenomenon is often called *aliasing*, and it's a fundamental way that Java works with objects. But what if you don't want aliasing to occur here? You can forego the assignment and say:

t1.level = t2.level;

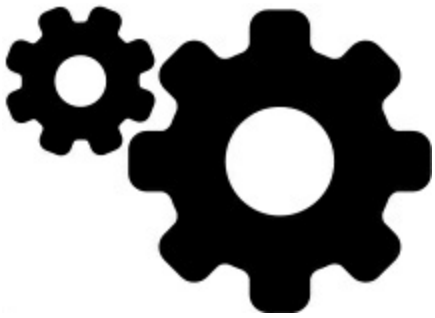
This retains the two separate objects instead of discarding one and

tying **t1** and **t2** to the same object. Manipulating the fields within objects goes against Java design principles. This is a nontrivial topic, so keep in mind that assignment for objects can add surprises.

Aliasing During Method Calls

Aliasing will also occur when you pass an object into a method:

```
// operators/PassObject.java
// Passing objects to methods might not be
// what you're used to
class Letter {
char c;
}
public class PassObject {
static void f(Letter y) {
y.c = 'z';
```



```
}
public static void main(String[] args) {
```

```
Letter x = new Letter();
x.c = 'a';
System.out.println("1: x.c: " + x.c);
f(x);
System.out.println("2: x.c: " + x.c);
}
}
/* Output:
1: x.c: a
2: x.c: z
*/
```

In many programming languages, the method **f()** appears to make a copy of its argument **Letter y** inside the scope of the method. But once again a reference is passed, so the line

```
y.c = 'z';
```

is actually changing the object *outside* of **f()**.

Aliasing and its solution is a complex issue covered in the Appendix: Passing and Returning Objects. You're aware of it now so you can watch for pitfalls.

Mathematical

Operators

The basic mathematical operators are the same as the ones available in most programming languages: addition (**+**), subtraction (**-**), division (**/**), multiplication (*****) and modulus (**%**, which produces the remainder from division). Integer division truncates, rather than rounds, the result.

Java also uses the shorthand notation from C/C++ that performs an operation and an assignment at the same time. This is denoted by an operator followed by an equal sign, and is consistent with all the operators in the language (whenever it makes sense). For example, to add 4 to the variable **x** and assign the result to **x**, use: **x += 4**.

This example shows the mathematical operators:

```
// operators/MathOps.java
// The mathematical operators
import java.util.*;
public class MathOps {
public static void main(String[] args) {
// Create a seeded random number generator:
Random rand = new Random(47);
int i, j, k;
```

```
// Choose value from 1 to 100:
j = rand.nextInt(100) + 1;
System.out.println("j : " + j);
k = rand.nextInt(100) + 1;
System.out.println("k : " + k);
i = j + k;
System.out.println("j + k : " + i);
i = j - k;
System.out.println("j - k : " + i);
i = k / j;
System.out.println("k / j : " + i);
i = k * j;
System.out.println("k * j : " + i);
i = k % j;
System.out.println("k % j : " + i);
j %= k;
System.out.println("j %= k : " + j);
// Floating-point number tests:
float u, v, w; // Applies to doubles, too
v = rand.nextFloat();
```

```
System.out.println("v : " + v);
w = rand.nextFloat();
System.out.println("w : " + w);
u = v + w;
System.out.println("v + w : " + u);
u = v - w;
System.out.println("v - w : " + u);
u = v * w;
System.out.println("v * w : " + u);
u = v / w;
System.out.println("v / w : " + u);
// The following also works for char,
// byte, short, int, long, and double:
u += v;
System.out.println("u += v : " + u);
u -= v;
System.out.println("u -= v : " + u);
u *= v;
System.out.println("u *= v : " + u);
u /= v;
```

```
System.out.println("u /= v : " + u);
}
}
```

/ Output:*

j : 59

k : 56

j + k : 115

j - k : 3

k / j : 0

*k * j : 3304*

k % j : 56

j %= k : 3

v : 0.5309454

w : 0.0534122

v + w : 0.5843576

v - w : 0.47753322

*v * w : 0.028358962*

v / w : 9.940527

u += v : 10.471473

u -= v : 9.940527

*u *= v : 5.2778773*

u /= v : 9.940527

/

To generate numbers, the program first creates a **Random** object. If you create a **Random** object with no arguments, Java uses the current

time as a seed for the random number generator, and will thus produce different output for each execution of the program. However, in the examples in this book, it is important that the output at the end of each example be as consistent as possible so it can be verified with external tools. By providing a *seed* (an initialization value for the random number generator that always produces the same sequence for a particular seed value) when creating the **Random** object, the same random numbers are generated each time the program is executed, so the output is verifiable.1 To generate more varying output, feel free to remove the seed in the examples in the book.

The program generates a number of different types of random numbers with the **Random** object by calling the methods **nextInt()**

and **nextFloat()** (you can also call **nextLong()** or **nextDouble()**). The argument to **nextInt()** sets the upper bound on the generated number. The lower bound is zero, which we don't want because of the possibility of a divide-by-zero, so the result is offset by one.

Unary Minus and Plus Operators

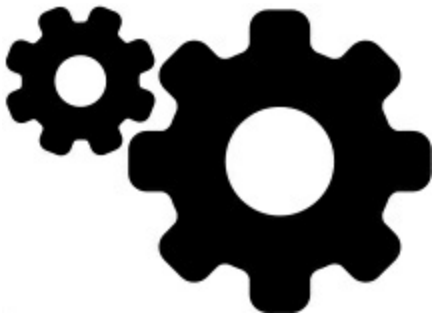
The unary minus (-) and unary plus (+) are the same operators as binary minus and plus. The compiler figures out which use is intended by the way you write the expression. For instance, the statement

```
x = -a;
```

has an obvious meaning. The compiler is able to figure out:

```
x = a * -b;
```

but the reader might get confused, so it is sometimes clearer to say:



```
x = a * (-b);
```

Unary minus inverts the sign on the data. Unary plus provides

symmetry with unary minus, but its only effect is to promote smaller-type operands to **int**.

Auto Increment and

Decrement

Java, like C, has a number of shortcuts. Shortcuts can make code much easier to type, and either easier or harder to read.

Two of the nicer shortcuts are the increment and decrement operators (often called the auto-increment and auto-decrement operators). The decrement operator is **--** and means “decrease by one unit.” The increment operator is **++** and means “increase by one unit.” If **a** is an **int**, for example, the expression **++a** is equivalent to **a = a + 1**. Increment and decrement operators not only modify the variable, but also produce the value of the variable as a result.

There are two versions of each type of operator, often called *prefix* and *postfix*. *Pre-increment* means the **++** operator appears before the variable, and *post-increment* means the **++** operator appears after the variable. Similarly, *pre-decrement* means the **--**operator appears before the variable, and *post-decrement* means the **--** operator appears after the variable. For pre-increment and pre-decrement (i.e., **++a** or **--a**), the operation is performed and the value is produced.

For post-increment and post-decrement (i.e., **a++** or **a--**), the value is produced, then the operation is performed.

```
// operators/AutoInc.java
// Demonstrates the ++ and -- operators
public class AutoInc {
public static void main(String[] args) {
int i = 1;
System.out.println("i: " + i);
System.out.println("++i: " + ++i); // Pre-increment
System.out.println("i++: " + i++); // Post-increment
System.out.println("i: " + i);
System.out.println("--i: " + --i); // Pre-decrement
System.out.println("i--: " + i--); // Post-decrement
System.out.println("i: " + i);
}
}
/* Output:
i: 1
++i: 2
i++: 2
```

i: 3

--i: 2

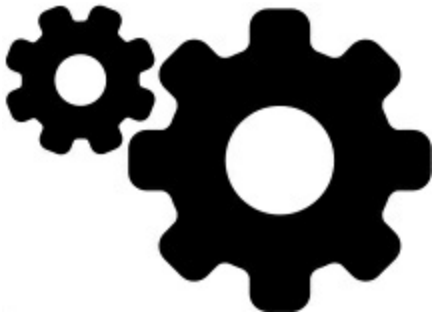
i--: 2

i: 1

**/*

For the prefix form, you get the value after the operation is performed, but with the postfix form, you get the value before the operation is performed. These are the only operators, other than those involving assignment, that have side effects—they change the operand rather than just using its value.

The increment operator is one explanation for the name C++, implying "one step beyond C." In an early Java speech, Bill Joy (one of the Java creators), said that "**Java = C++--**" (C plus plus minus minus), suggesting that Java is C++ with the unnecessary hard parts removed, and therefore a much simpler language. As you progress, you'll see that many parts are simpler, and yet in other ways Java isn't much easier than C++.



Relational Operators

Relational operators produce a **boolean** result indicating the relationship between the values of the operands. A relational expression produces **true** if the relationship is true, and **false** if the relationship is untrue. The relational operators are less than (<), greater than (>), less than or equal to (<=), greater than or equal to (>=), equivalent (==) and not equivalent (**!**=). Equivalence and non-equivalence work with all primitives, but the other comparisons won't work with type **boolean**. Because **boolean** values can only be **true** or **false**, "greater than" or "less than" doesn't make sense.

Testing Object Equivalence

The relational operators == and **!**= also work with all objects, but their meaning often confuses the first-time Java programmer. Here's

an example:

```
// operators/Equivalence.java
public class Equivalence {
public static void main(String[] args) {
Integer n1 = 47;
Integer n2 = 47;
System.out.println(n1 == n2);
System.out.println(n1 != n2);
}
}
/* Output:
true
false
*/
```

The statement **System.out.println(n1 == n2)** will print the result of the **boolean** comparison within it. Surely the output should be “true”, then “false,” since both **Integer** objects are the same. But while the *contents* of the objects are the same, the references are not the same. The operators **==** and **!=** compare object references, so the output is actually “false”, then “true.” Naturally, this surprises people

at first.

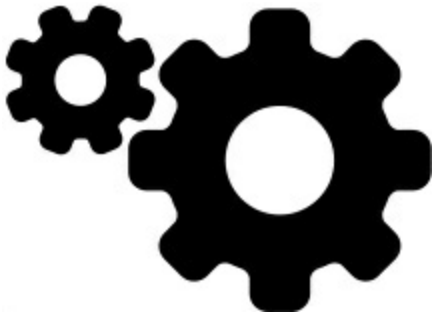
How do you compare the actual contents of an object for equivalence? You must use the special method **equals()** that exists for all objects (not primitives, which work fine with **==** and **!=**). Here's how it's used:

```
// operators/EqualsMethod.java
public class EqualsMethod {
public static void main(String[] args) {
Integer n1 = 47;
Integer n2 = 47;
System.out.println(n1.equals(n2));
}
}
/* Output:
true
*/
```

The result is now what you expect. Ah, but it's not as simple as that. Create your own class:

```
// operators/EqualsMethod2.java
// Default equals() does not compare contents
```

```
class Value {
int i;
}
public class EqualsMethod2 {
public static void main(String[] args) {
```



```
Value v1 = new Value();
Value v2 = new Value();
v1.i = v2.i = 100;
System.out.println(v1.equals(v2));
}
}
/* Output:
false
*/
```

Now things are confusing again: The result is **false**. This is because the default behavior of **equals()** is to compare references. So unless

you *override* **equals()** in your new class you won't get the desired

behavior. Unfortunately, you won't learn about overriding until the

Reuse chapter and about the proper way to define **equals()** until the Appendix: Collection Topics, but being aware of the way

equals() behaves might save you some grief in the meantime.

Most of the Java library classes implement **equals()** to compare the

contents of objects instead of their references.

Logical Operators

Each of the logical operators AND (**&&**), OR (||) and NOT (**!**) produce a **boolean** value of **true** or **false** based on the logical

relationship of its arguments. This example uses the relational and

logical operators:

```
// operators/Bool.java

// Relational and logical operators

import java.util.*;

public class Bool {

public static void main(String[] args) {

Random rand = new Random(47);

int i = rand.nextInt(100);

int j = rand.nextInt(100);

System.out.println("i = " + i);
```

```
System.out.println("j = " + j);
System.out.println("i > j is " + (i > j));
System.out.println("i < j is " + (i < j));
System.out.println("i >= j is " + (i >= j));
System.out.println("i <= j is " + (i <= j));
System.out.println("i == j is " + (i == j));
System.out.println("i != j is " + (i != j));
// Treating an int as a boolean is not legal Java:
//- System.out.println("i && j is " + (i && j));
//- System.out.println("i || j is " + (i || j));
//- System.out.println("!i is " + !i);
System.out.println("(i < 10) && (j < 10) is "
+ ((i < 10) && (j < 10)) );
System.out.println("(i < 10) || (j < 10) is "
+ ((i < 10) || (j < 10)) );
}
}
/* Output:
i = 58
j = 55
```

i > j is true

i < j is false

i >= j is true

i <= j is false

i == j is false

i != j is true

(i < 10) && (j < 10) is false

(i < 10) || (j < 10) is false

**/*

You can apply AND, OR, or NOT to **boolean** values only. You can't use a non-**boolean** as if it were a **boolean** in a logical expression as you can in C and C++. The failed attempts at doing this are commented out with a //-. The subsequent expressions, however, produce **boolean** values using relational comparisons, then use logical operations on the results.

Note that a **boolean** value is automatically converted to an appropriate text form if it is used where a **String** is expected.

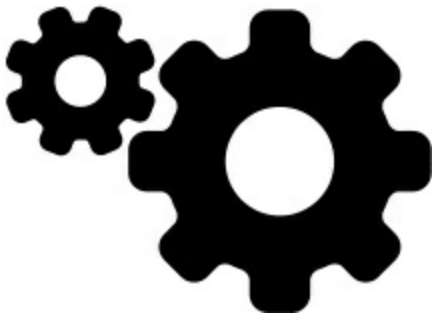
You can replace the definition for **int** in the preceding program with any other primitive data type except **boolean**. Be aware, however, that the comparison of floating point numbers is very strict. A number that is the tiniest fraction different from another number is still "not equal." A number that is the tiniest bit above zero is still nonzero.

Short-Circuiting

Logical operators support a phenomenon called "short-circuiting." this means the expression is evaluated only *until* the truth or falsehood of the entire expression can be unambiguously determined. As a result, the latter parts of a logical expression might not be evaluated. Here's a demonstration:

```
// operators/ShortCircuit.java
// Short-circuiting behavior with logical operators
public class ShortCircuit {
static boolean test1(int val) {
System.out.println("test1(" + val + ")");
System.out.println("result: " + (val < 1));
return val < 1;
}
static boolean test2(int val) {
```

```
System.out.println("test2(" + val + ")");
System.out.println("result: " + (val < 2));
return val < 2;
}
static boolean test3(int val) {
System.out.println("test3(" + val + ")");
System.out.println("result: " + (val < 3));
return val < 3;
}
public static void main(String[] args) {
```



```
boolean b = test1(0) && test2(2) && test3(2);
System.out.println("expression is " + b);
}
}
/* Output:
test1(0)
```

result: true

test2(2)

result: false

expression is false

*/

Each test performs a comparison against the argument and returns **true** or **false**. It also prints information to show you it's being called. The tests are used in the expression:

test1(0) && test2(2) && test3(2)

You might naturally expect all three tests to execute, but the output shows otherwise. The first test produces a **true** result, so the expression evaluation continues. However, the second test produces a **false** result. Since this means the whole expression must be **false**, why continue evaluating the rest of the expression? It might be expensive. The reason for short-circuiting, in fact, is that you can get a potential performance increase if all the parts of a logical expression do not need evaluation.

Literals

Ordinarily, when you insert a literal value into a program, the compiler knows exactly what type to make it. When the type is

ambiguous, you must guide the compiler by adding some extra information in the form of characters associated with the literal value. The following code shows these characters:

```
// operators/Literals.java
public class Literals {
public static void main(String[] args) {
int i1 = 0x2f; // Hexadecimal (lowercase)
System.out.println(
"i1: " + Integer.toBinaryString(i1));
int i2 = 0X2F; // Hexadecimal (uppercase)
System.out.println(
"i2: " + Integer.toBinaryString(i2));
int i3 = 0177; // Octal (leading zero)
System.out.println(
"i3: " + Integer.toBinaryString(i3));
char c = 0xffff; // max char hex value
System.out.println(
"c: " + Integer.toBinaryString(c));
byte b = 0x7f; // max byte hex value 10101111;
System.out.println(
```

```
"b: " + Integer.toBinaryString(b));
short s = 0x7fff; // max short hex value
System.out.println(
"s: " + Integer.toBinaryString(s));
long n1 = 200L; // long suffix
long n2 = 200l; // long suffix (can be confusing)
long n3 = 200;
// Java 7 Binary Literals:
byte blb = (byte)0b00110101;
System.out.println(
"blb: " + Integer.toBinaryString(blb));
short bls = (short)0B0010111110101111;
System.out.println(
"bls: " + Integer.toBinaryString(bls));
int bli = 0b00101111101011111010111110101111;
System.out.println(
"bli: " + Integer.toBinaryString(bli));
long bll = 0b00101111101011111010111110101111;
System.out.println(
"bll: " + Long.toBinaryString(bll));
```

```
float f1 = 1;
float f2 = 1F; // float suffix
float f3 = 1f; // float suffix
double d1 = 1d; // double suffix
double d2 = 1D; // double suffix
// (Hex and Octal also work with long)
}
}
/* Output:
i1: 101111
i2: 101111
i3: 1111111
c: 1111111111111111
b: 1111111
s: 111111111111111
blb: 110101
bls: 10111110101111
bli: 10111110101111101011111010111
bll: 10111110101111101011111010111
*/
```

A trailing character after a literal value establishes its type. Uppercase or lowercase **L** means **long** (however, using a lowercase **l** is confusing because it can look like the number one). Uppercase or lowercase **F** means **float**. Uppercase or lowercase **D** means **double**.

Hexadecimal (base 16), which works with all the integral data types, is denoted by a leading **0x** or **0X** followed by **0-9** or **a-f** either in uppercase or lowercase. If you try to initialize a variable with a value bigger than it can hold (regardless of the numerical form of the value), the compiler will give you an error message. Notice in the preceding code the maximum possible hexadecimal values for **char**, **byte**, and **short**. If you exceed these, the compiler will automatically make the value an **int** and declare you need a *narrowing cast* for the assignment (casts are defined later in this chapter). You'll know you've stepped over the line.

Octal (base 8) is denoted by a leading zero in the number and digits from 0-7.

Java 7 introduced binary literals, denoted by a leading **0b** or **0B**, which can initialize all integral types.

When working with integral types, it’s useful to display the binary form of the results. This is easily accomplished with the **static toBinaryString()** methods from the **Integer** and **Long** classes. Notice that when passing smaller types to **Integer.toBinaryString()**, the type is automatically converted to an **int**.

Underscores in Literals

There’s a thoughtful addition in Java 7: you can include underscores in numeric literals in order to make the results clearer to read. This is especially helpful for grouping digits in large values:

```
// operators/Underscores.java
public class Underscores {
public static void main(String[] args) {
double d = 341_435_936.445_667;
System.out.println(d);
int bin = 0b0010_1111_1010_1111_1010_1111_1010_1111;
System.out.println(Integer.toBinaryString(bin));
```

```
System.out.printf("%x%n", bin); // [1]

long hex = 0x7f_e9_b7_aa;

System.out.printf("%x%n", hex);

}

}

/* Output:

3.41435936445667E8

10111110101111101011111010111 1

2fafafaf

7fe9b7aa

*/
```

There are (reasonable) rules:

1. Single underscores only—you can’t double them up.

2. No underscores at the beginning or end of a number.

3. No underscores around suffixes like **F**, **D** or **L**.

4. No around binary or hex identifiers **b** and **x**.

[1] Notice the use of **%n**. If you’re familiar with C-style languages,

you're probably used to seeing **\n** to represent a line ending. The problem with that is it gives you a "Unix style" line ending. If you are on Windows, you must specify **\r\n** instead. This difference is a needless hassle; the programming language should take care of it for you. That's what Java has achieved with **%n**, which always produces the appropriate line ending for the platform it's running on—but only when you're using **System.out.printf()** or **System.out.format()**. For **System.out.println()** you must still use **\n**; if you use **%n**, **println()** will simply emit **%n** and not a newline.

Exponential Notation

Exponents use a notation I've always found rather dismaying:

```
// operators/Exponents.java
// "e" means "10 to the power."
public class Exponents {
public static void main(String[] args) {
// Uppercase and lowercase 'e' are the same:
float expFloat = 1.39e-43f;
expFloat = 1.39E-43f;
System.out.println(expFloat);
```

```
double expDouble = 47e47d; // 'd' is optional
double expDouble2 = 47e47; // Automatically double
System.out.println(expDouble);
}
}
/* Output:
1.39E-43
4.7E48
*/
```

In science and engineering, **e** refers to the base of natural logarithms, approximately 2.718. (A more precise **double** value is available in Java as **Math.E**.) This is used in exponentiation expressions such as 1.39 x e-43, which means 1.39 x 2.718-43. However, when the FORTRAN programming language was invented, they decided that **e** would mean “ten to the power,” an odd decision because FORTRAN was designed for science and engineering, and one would think its designers would be sensitive about introducing such an ambiguity. 2 At any rate, this custom was followed in C, C++ and now Java. So if you’re used to thinking in terms of **e** as the base of natural logarithms, you must do a mental translation when you see an expression such as **1.39 e-43f** in Java; it means 1.39 x 10-43.

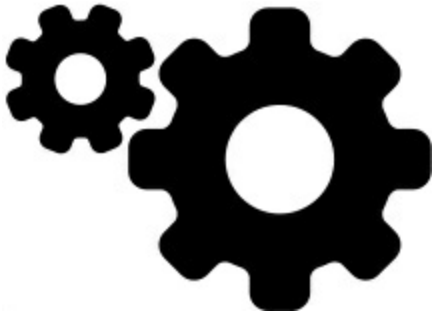
Note you don’t need the trailing character when the compiler can figure out the appropriate type. With

long n3 = 200;

there’s no ambiguity, so an **L** after the 200 is superfluous. However, with

float f4 = 1e-43f; *// 10 to the power*

the compiler normally takes exponential numbers as doubles, so without the trailing **f**, it will give you an error declaring you must use a cast to convert **double** to **float**.



Bitwise Operators

The bitwise operators allow you to manipulate individual bits in an integral primitive data type. Bitwise operators perform Boolean algebra on the corresponding bits in the two arguments to produce the result.

The bitwise operators come from C’s low-level orientation, where you often manipulate hardware directly and must set the bits in hardware

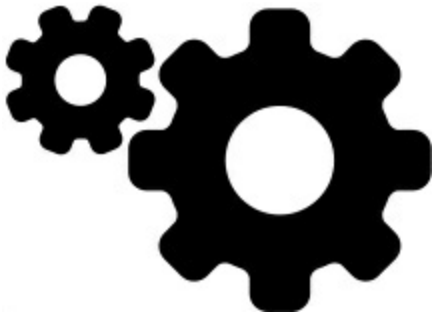
registers. Java was originally designed to be embedded in TV set-top boxes, so this low-level orientation still made sense. However, you probably won't use the bitwise operators much.

The bitwise AND operator (**&**) produces a one in the output bit if both input bits are one; otherwise, it produces a zero. The bitwise OR operator (|) produces a one in the output bit if either input bit is a one and produces a zero only if both input bits are zero. The bitwise EXCLUSIVE OR, or XOR (^), produces a one in the output bit if one or the other input bit is a one, but not both. The bitwise NOT (~, also called the *ones complement* operator) is a unary operator; it takes only one argument. (All other bitwise operators are binary operators.) Bitwise NOT produces the opposite of the input bit—a one if the input bit is zero, a zero if the input bit is one.

The bitwise operators and logical operators use the same characters, so a mnemonic device helps you remember the meanings: Because bits are "small," there is only one character in the bitwise operators.

Bitwise operators can be combined with the = sign to unite the operation and assignment: **&=**, |= and ^= are all legitimate. (Since ~ is a unary operator, it cannot be combined with the = sign.)

The **boolean** type is treated as a one-bit value, so it is somewhat



different. You can perform a bitwise AND, OR, and XOR, but you can't perform a bitwise NOT (presumably to prevent confusion with the logical NOT). For **boolean**s, the bitwise operators have the same effect as the logical operators except they do not short circuit. Also, bitwise operations on **boolean**s include an XOR logical operator that is not included under the list of "logical" operators. You cannot use **boolean**s in shift expressions, which are described next.

Shift Operators

The shift operators also manipulate bits. They can be used solely with primitive, integral types. The left-shift operator (<<) produces the operand to the left of the operator after it is shifted to the left by the number of bits specified to the right of the operator (inserting zeroes at the lower-order bits). The signed right-shift operator (>>) produces the operand to the left of the operator after it is shifted to the right by the number of bits specified to the right of the operator. The signed right shift >> uses *sign extension*: If the value is positive, zeroes are inserted

at the higher-order bits; if the value is negative, ones are

inserted at the higher-order bits. Java has also added the unsigned

right shift >>> , which uses *zero extension*: Regardless of the sign, zeroes are inserted at the higher-order bits. This operator does not

exist in C or C++.

If you shift a **char**, **byte**, or **short**, it is promoted to **int** before the shift takes place, and the result is an **int**. Only the five low-order bits

of the right-hand side are used. This prevents you from shifting more

than the number of bits in an **int**. If you're operating on a **long**,

you'll get a **long** result. Only the six low-order bits of the right-hand

side are used, so you can't shift more than the number of bits in a

long.

Shifts can be combined with the equal sign (<<= or >>= or >>>=).

The lvalue is replaced by the lvalue shifted by the rvalue. There is a

problem, however, with the unsigned right shift combined with

assignment. If you use it with **byte** or **short**, you don't get the

correct results. Instead, these are promoted to **int** and right shifted,

but then truncated as they are assigned back into their variables, so

you get **-1** in those cases. Here's a demonstration:

// operators/URShift.java

// Test of unsigned right shift

```
public class URShift {
public static void main(String[] args) {
int i = -1;
System.out.println(Integer.toBinaryString(i));
i >>>= 10;
System.out.println(Integer.toBinaryString(i));
long l = -1;
System.out.println(Long.toBinaryString(l));
l >>>= 10;
System.out.println(Long.toBinaryString(l));
short s = -1;
System.out.println(Integer.toBinaryString(s));
s >>>= 10;
System.out.println(Integer.toBinaryString(s));
byte b = -1;
System.out.println(Integer.toBinaryString(b));
b >>>= 10;
System.out.println(Integer.toBinaryString(b));
b = -1;
System.out.println(Integer.toBinaryString(b));
```

```
System.out.println(Integer.toBinaryString(b>>>10));
}
}
/* Output:
11111111111111111111111111111111
11111111111111111111
11111111111111111111111111111111111111111111111111111111
11111111
11111111111111111111111111111111111111111111111111111111
11111111111111111111111111111111
11111111111111111111111111111111
11111111111111111111111111111111
11111111111111111111111111111111
11111111111111111111111111111111
11111111111111111111
*/
```

In the last shift, the resulting value is not assigned back into **b**, but is printed directly, so the correct behavior occurs.

Here’s an example that exercises all the operators involving bits:

```
// operators/BitManipulation.java
```

```
// Using the bitwise operators
import java.util.*;
public class BitManipulation {
public static void main(String[] args) {
Random rand = new Random(47);
int i = rand.nextInt();
int j = rand.nextInt();
printBinaryInt("-1", -1);
printBinaryInt("+1", +1);
int maxpos = 2147483647;
printBinaryInt("maxpos", maxpos);
int maxneg = -2147483648;
printBinaryInt("maxneg", maxneg);
printBinaryInt("i", i);
printBinaryInt("~i", ~i);
printBinaryInt("-i", -i);
printBinaryInt("j", j);
printBinaryInt("i & j", i & j);
printBinaryInt("i | j", i | j);
printBinaryInt("i ^ j", i ^ j);
```

```
printBinaryInt("i << 5", i << 5);
printBinaryInt("i >> 5", i >> 5);
printBinaryInt("(~i) >> 5", (~i) >> 5);
printBinaryInt("i >>> 5", i >>> 5);
printBinaryInt("(~i) >>> 5", (~i) >>> 5);
long l = rand.nextLong();
long m = rand.nextLong();
printBinaryLong("-1L", -1L);
printBinaryLong("+1L", +1L);
long ll = 9223372036854775807L;
printBinaryLong("maxpos", ll);
long lln = -9223372036854775808L;
printBinaryLong("maxneg", lln);
printBinaryLong("l", l);
printBinaryLong("~l", ~l);
printBinaryLong("-l", -l);
printBinaryLong("m", m);
printBinaryLong("l & m", l & m);
printBinaryLong("l | m", l | m);
printBinaryLong("l ^ m", l ^ m);
```

```
printBinaryLong("l << 5", l << 5);
printBinaryLong("l >> 5", l >> 5);
printBinaryLong("(~l) >> 5", (~l) >> 5);
printBinaryLong("l >>> 5", l >>> 5);
printBinaryLong("(~l) >>> 5", (~l) >>> 5);
}
static void printBinaryInt(String s, int i) {
System.out.println(
s + ", int: " + i + ", binary:\n " +
Integer.toBinaryString(i));
}
static void printBinaryLong(String s, long l) {
System.out.println(
s + ", long: " + l + ", binary:\n " +
Long.toBinaryString(l));
}
}
/* Output: (First 32 Lines)
-1, int: -1, binary:
11111111111111111111111111111111
```

+1, int: 1, binary:

1

maxpos, int: 2147483647, binary:

11111111111111111111111111111111

maxneg, int: -2147483648, binary:

10000000000000000000000000000000

i, int: -1172028779, binary:

10111010001001000100001010010101

~i, int: 1172028778, binary:

01000101110110111011110101101010

-i, int: 1172028779, binary:

01000101110110111011110101101011

j, int: 1717241110, binary:

01100110010110110000010100010110

i & j, int: 570425364, binary:

00010000000000000000000010100

i | j, int: -25213033, binary:

11111100111111101000111100010111

i ^ j, int: -595638397, binary:

11011100011111110100011110000011

i << 5, int: 1149784736, binary:

10001001000100001010010101000000

i >> 5, int: -36625900, binary:

11111101110100010010001000010100

(~i) >> 5, int: 36625899, binary:

10001011101101110111101011

i >>> 5, int: 97591828, binary:

10111010001001000100001010 0

(~i) >>> 5, int: 36625899, binary:

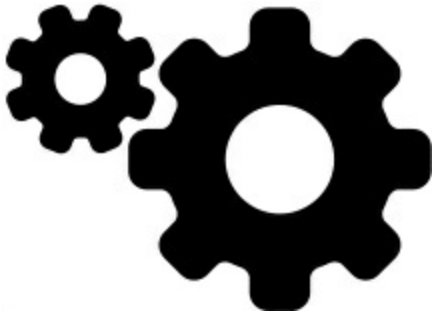
10001011101101110111101011

...

**/*

The two methods at the end, **printBinaryInt()** and **printBinaryLong()**, take an **int** or a **long**, respectively, and display it in binary format along with a descriptive **String**. As well as demonstrating the effect of all the bitwise operators for **int** and **long**, this example also shows the minimum, maximum, +1, and -1 values for **int** and **long** so you see what they look like. Note that the high bit represents the sign: 0 means positive and 1 means negative. The output for the **int** portion is displayed above.

The binary representation of the numbers is called *signed twos complement*.



Ternary if-else

Operator

The *ternary* operator, also called the *conditional* operator, is unusual because it has three operands. It is truly an operator because it produces a value, unlike the ordinary **if-else** statement that you'll see in the next section of this chapter. The expression is of the form:

boolean-exp ? value0 : value1

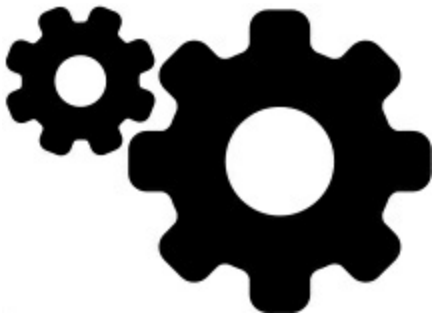
If *boolean-exp* evaluates to **true**, *value0* is evaluated, and its result becomes the value produced by the operator. If *boolean-exp* is **false**, *value1* is evaluated and its result becomes the value produced by the operator.

You can also use an ordinary **if-else** statement (described later), but the ternary operator is much terser. Although C (where this operator originated) prides itself on being a terse language, and the

ternary operator might have been introduced partly for efficiency, be somewhat wary of using it on an everyday basis—it's easy to produce unreadable code.

The ternary operator is different from **if-else** because it produces a value. Here's an example comparing the two:

```
// operators/TernaryIfElse.java
public class TernaryIfElse {
static int ternary(int i) {
return i < 10 ? i * 100 : i * 10;
}
static int standardIfElse(int i) {
if(i < 10)
return i * 100;
else
```



```
return i * 10;
}
```

```
public static void main(String[] args) {
System.out.println(ternary(9));
System.out.println(ternary(10));
System.out.println(standardIfElse(9));
System.out.println(standardIfElse(10));
}
}
/* Output:
900
100
900
100
*/
```

The code in **ternary()** is more compact than what you'd write without the ternary operator, in **standardIfElse()**. However, **standardIfElse()** is easier to understand, and doesn't require a lot more typing. Ponder your reasons when choosing the ternary operator—it's primarily warranted when you're setting a variable to one of two values.

String Operator + and

+=

There's one special usage of an operator in Java: The + and += operators can concatenate **String**s, as you've already seen. It seems a natural use of these operators even though it doesn't fit with the traditional way they are used.

This capability seemed like a good idea in C++, so *operator overloading* was added to C++ to allow the C++ programmer to add meanings to almost any operator. Unfortunately, operator overloading combined with some of the other restrictions in C++ turns out to be a fairly complicated feature for programmers to design into their classes. Although operator overloading would have been much simpler to implement in Java than it was in C++ (as demonstrated by the C# language, which *does* have straightforward operator overloading), this feature was still considered too complex, so Java programmers cannot implement their own overloaded operators like C++ and C# programmers can.

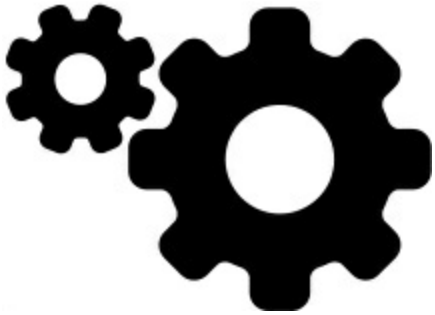
If an expression begins with a **String**, all operands that follow must be **String**s (remember that the compiler automatically turns a double-quoted sequence of characters into a **String**):

// operators/StringOperators.java

```
public class StringOperators {
public static void main(String[] args) {
int x = 0, y = 1, z = 2;
String s = "x, y, z ";
System.out.println(s + x + y + z);
// Converts x to a String:
System.out.println(x + " " + s);
s += "(summed) = "; // Concatenation operator
System.out.println(s + (x + y + z));
// Shorthand for Integer.toString():
System.out.println("" + x);
}
}
/* Output:
x, y, z 012
0 x, y, z
x, y, z (summed) = 3
0
*/
```

Note that the output from the first print statement is **o12** instead of

just **3**, which you'd get if it was summing the integers. This is because the Java compiler converts **x**, **y**, and **z** into their **String**



representations and concatenates those **String**s, instead of adding them together first. The second print statement converts the leading variable into a **String**, so the **String** conversion does not depend on what comes first. Finally, you see the **+=** operator to append a **String** to **s**, and parentheses to control the order of evaluation of the expression so the **int**s are actually summed before they are displayed. Notice the last example in **main()**: you sometimes see an empty **String** followed by a **+** and a primitive as a way to perform the conversion without calling the more cumbersome explicit method (**Integer.toString()**, here).

Common Pitfalls When

Using Operators

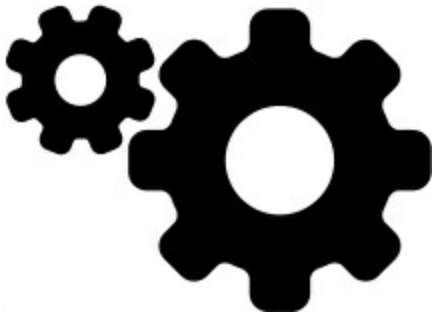
One of the pitfalls when using operators is attempting to leave out the parentheses when you are even the least bit uncertain about how an

expression will evaluate. This is still true in Java.

An extremely common error in C and C++ looks like this:

```
while(x = y) {
// ...
}
```

The programmer was clearly trying to test for equivalence (==) rather than do an assignment. In C and C++ the result of this assignment will always be **true** if **y** is nonzero, and you'll probably get an infinite loop. In Java, the result of this expression is not a **boolean**, but the compiler expects a **boolean** and won't convert from an **int**, so it will conveniently give you a compile-time error and catch the problem



before you ever try to run the program. So the pitfall never happens in Java. (The only time you won't get a compile-time error is when **x** and **y** are **boolean**, in which case **x = y** is a legal expression, and in the preceding example, probably an error.)

A similar problem in C and C++ is using bitwise AND and OR instead

of the logical versions. Bitwise AND and OR use one of the characters (**&** or |) while logical AND and OR use two (**&&** and ||). Just as with = and ==, it's easy to type just one character instead of two. In Java, the compiler again prevents this, because it won't let you cavalierly use one type where it doesn't belong.

Casting Operators

The word *cast* is used in the sense of "casting into a mold." Java will automatically change one type of data into another when appropriate. For instance, if you assign an integral value to a floating point variable, the compiler will automatically convert the **int** to a **float**. Casting makes this type conversion explicit, or forces it when it wouldn't normally happen.

To perform a cast, put the desired data type inside parentheses to the left of any value, as seen here:

```
// operators/Casting.java
public class Casting {
public static void main(String[] args) {
int i = 200;
long lng = (long)i;
lng = i; // "Widening," so a cast is not required
```

```
long lng2 = (long)200;
lng2 = 200;
// A "narrowing conversion":
i = (int)lng2; // Cast required
```

```
}
}
```

Thus, you can cast a numeric value as well as a variable. Casts may be superfluous; for example, the compiler will automatically promote an **int** value to a **long** when necessary. However, you are allowed to use superfluous casts to make a point or to clarify your code. In other situations, a cast might be essential just to get the code to compile.

In C and C++, casting can cause some headaches. In Java, casting is safe, with the exception that when you perform a so-called *narrowing conversion* (that is, when you go from a data type that can hold more information to one that doesn't hold as much), you run the risk of losing information. Here the compiler forces you to use a cast, in effect saying, "This can be a dangerous thing to do—if you want me to do it

anyway you must make the cast explicit." With a *widening conversion* an explicit cast is not needed, because the new type will more than hold the information from the old type so no information is ever lost. Java can cast any primitive type to any other primitive type, except for **boolean**, which doesn't allow any casting at all. Class types do not allow casting. To convert one to the other, there must be special methods. (You'll find out later that objects can be cast within a *family* of types; an **Oak** can be cast to a **Tree** and vice versa, but not to a foreign type such as a **Rock**.)

Truncation and Rounding

When you are performing narrowing conversions, you must pay attention to issues of truncation and rounding. For example, if you cast from a floating point value to an integral value, what does Java do? For example, if you cast the value 29.7 to an **int**, is the resulting value 30 or 29? The answer is seen here:

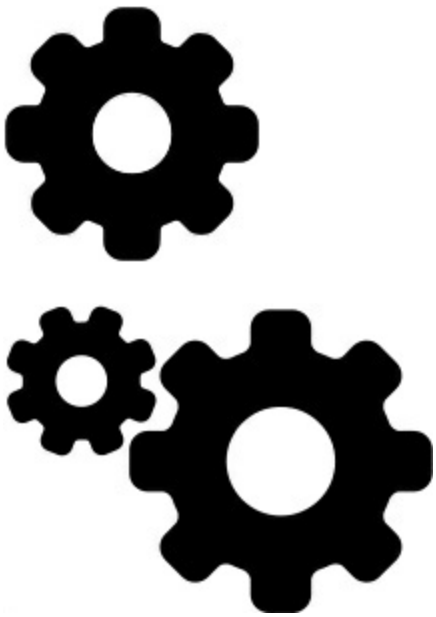
```
// operators/CastingNumbers.java
// What happens when you cast a float
// or double to an integral value?
public class CastingNumbers {
public static void main(String[] args) {
```

```
double above = 0.7, below = 0.4;
float fabove = 0.7f, fbelow = 0.4f;
System.out.println("(int)above: " + (int)above);
System.out.println("(int)below: " + (int)below);
System.out.println("(int)fabove: " + (int)fabove);
System.out.println("(int)fbelow: " + (int)fbelow);
}
}
/* Output:
(int)above: 0
(int)below: 0
(int)fabove: 0
(int)fbelow: 0
*/
```

So the answer is that casting from a **float** or **double** to an integral value always truncates the number. If instead you want the result rounded, use the **round()** methods in **java.lang.Math**:

```
// operators/RoundingNumbers.java
// Rounding floats and doubles
public class RoundingNumbers {
```

```
public static void main(String[] args) {
double above = 0.7, below = 0.4;
float fabove = 0.7f, fbelow = 0.4f;
System.out.println(
"Math.round(above): " + Math.round(above));
System.out.println(
"Math.round(below): " + Math.round(below));
System.out.println(
"Math.round(fabove): " + Math.round(fabove));
System.out.println(
"Math.round(fbelow): " + Math.round(fbelow));
}
}
```



/ *Output:*

Math.round(above): 1

Math.round(below): 0

Math.round(fabove): 1

Math.round(fbelow): 0

**/*

Since **round()** is part of **java.lang**, you don't need an extra import to use it.

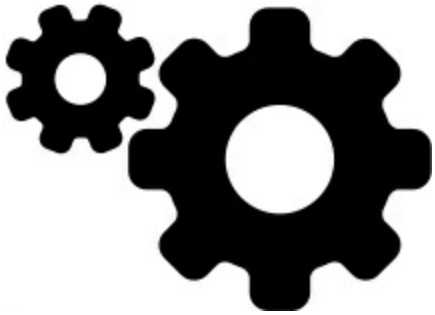
Promotion

You'll discover that if you perform any mathematical or bitwise operations on primitive data types smaller than an **int** (that is, **char**, **byte**, or **short**), those values are promoted to **int** before performing the operations, and the resulting value is of type **int**. To assign back into the smaller type, you use a cast. (And, since you're assigning back into a smaller type, you might be losing information.) In general, the largest data type in an expression is the one that determines the size of the result of that expression. If you multiply a **float** and a **double**, the result is **double**. If you add an **int** and a **long**, the result is **long**.

Java Has No "sizeof"

In C and C++, the **sizeof()** operator tells you the number of bytes

allocated for data items. The most compelling reason for **sizeof()** in C and C++ is for portability. Different data types might be different sizes on different machines, so the programmer must discover how big those types are when performing operations that are sensitive to size. For example, one computer might store integers in 32 bits, whereas another might store integers as 16 bits. Programs could store larger



values in integers on the first machine. As you might imagine, portability is a huge headache for C and C++ programmers.

Java does not need a **sizeof()** operator for this purpose, because all the data types are the same size on all machines. You do not need to think about portability on this level—it is designed into the language.

A Compendium of

Operators

The following example shows which primitive data types can be used with particular operators. Basically, it is the same example repeated over and over, but using different primitive data types. The file will

compile without error because the lines that fail are commented out with a //-.

```
// operators/AllOps.java
// Tests all operators on all primitive data types
// to show which ones are accepted by the Java compiler
public class AllOps {
// To accept the results of a boolean test:
void f(boolean b) {}
void boolTest(boolean x, boolean y) {
// Arithmetic operators:
//- x = x * y;
//- x = x / y;
//- x = x % y;
//- x = x + y;
//- x = x - y;
//- x++;
//- x--;
//- x = +y;
//- x = -y;
// Relational and logical:
```

```
//- f(x > y);
//- f(x >= y);
//- f(x < y);
//- f(x <= y);
f(x == y);
f(x != y);
f(!y);
x = x && y;
x = x || y;
// Bitwise operators:
//- x = ~y;
x = x & y;
x = x | y;
x = x ^ y;
//- x = x << 1;
//- x = x >> 1;
//- x = x >>> 1;
// Compound assignment:
//- x += y;
//- x -= y;
```

```
//- x *= y;
//- x /= y;
//- x %= y;
//- x <<= 1;
//- x >>= 1;
//- x >>>= 1;
x &= y;
x ^= y;
x |= y;
// Casting:
//- char c = (char)x;
//- byte b = (byte)x;
//- short s = (short)x;
//- int i = (int)x;
//- long l = (long)x;
//- float f = (float)x;
//- double d = (double)x;
}
void charTest(char x, char y) {
// Arithmetic operators:
```

```
x = (char)(x * y);

x = (char)(x / y);

x = (char)(x % y);

x = (char)(x + y);

x = (char)(x - y);

x++;

x--;

x = (char) + y;

x = (char) - y;

// Relational and logical:

f(x > y);

f(x >= y);

f(x < y);

f(x <= y);

f(x == y);

f(x != y);

//- f(!x);

//- f(x && y);

//- f(x || y);

// Bitwise operators:
```

```
x= (char)~y;
x = (char)(x & y);
x = (char)(x | y);
x = (char)(x ^ y);
x = (char)(x << 1);
x = (char)(x >> 1);
x = (char)(x >>> 1);
// Compound assignment:
x += y;
x -= y;
x *= y;
x /= y;
x %= y;
x <<= 1;
x >>= 1;
x >>>= 1;
x &= y;
x ^= y;
x |= y;
// Casting:
```

```
//- boolean bl = (boolean)x;
byte b = (byte)x;
short s = (short)x;
int i = (int)x;
long l = (long)x;
float f = (float)x;
double d = (double)x;
}
void byteTest(byte x, byte y) {
// Arithmetic operators:
x = (byte)(x* y);
x = (byte)(x / y);
x = (byte)(x % y);
x = (byte)(x + y);
x = (byte)(x - y);
x++;
x--;
x = (byte) + y;
x = (byte) - y;
// Relational and logical:
```

```
f(x > y);
f(x >= y);
f(x < y);
f(x <= y);
f(x == y);
f(x != y);
//- f(!x);
//- f(x && y);
//- f(x || y);
// Bitwise operators:
x = (byte)~y;
x = (byte)(x & y);
x = (byte)(x | y);
x = (byte)(x ^ y);
x = (byte)(x << 1);
x = (byte)(x >> 1);
x = (byte)(x >>> 1);
// Compound assignment:
x += y;
x -= y;
```

```
x *= y;
x /= y;
x %= y;
x <<= 1;
x >>= 1;
x >>>= 1;
x &= y;
x ^= y;
x |= y;
// Casting:
//- boolean bl = (boolean)x;
char c = (char)x;
short s = (short)x;
int i = (int)x;
long l = (long)x;
float f = (float)x;
double d = (double)x;
}
void shortTest(short x, short y) {
// Arithmetic operators:
```

```
x = (short)(x * y);
x = (short)(x / y);
x = (short)(x % y);
x = (short)(x + y);
x = (short)(x - y);
x++;
x--;
x = (short) + y;
x = (short) - y;
// Relational and logical:
f(x > y);
f(x >= y);
f(x < y);
f(x <= y);
f(x == y);
f(x != y);
//- f(!x);
//- f(x && y);
//- f(x || y);
// Bitwise operators:
```

```
x = (short) ~ y;
x = (short)(x & y);
x = (short)(x | y);
x = (short)(x ^ y);
x = (short)(x << 1);
x = (short)(x >> 1);
x = (short)(x >>> 1);
// Compound assignment:
x += y;
x -= y;
x *= y;
x /= y;
x %= y;
x <<= 1;
x >>= 1;
x >>>= 1;
x &= y;
x ^= y;
x |= y;
// Casting:
```

```
//- boolean bl = (boolean)x;
char c = (char)x;
byte b = (byte)x;
int i = (int)x;
long l = (long)x;
float f = (float)x;
double d = (double)x;
}
void intTest(int x, int y) {
// Arithmetic operators:
x = x * y;
x = x / y;
x = x % y;
x = x + y;
x = x - y;
x++;
x--;
x = +y;
x = -y;
// Relational and logical:
```

```
f(x > y);

f(x >= y);

f(x < y);

f(x <= y);

f(x == y);

f(x != y);

//- f(!x);

//- f(x && y);

//- f(x || y);

// Bitwise operators:

x = ~y;

x = x & y;

x = x | y;

x = x ^ y;

x = x << 1;

x = x >> 1;

x = x >>> 1;

// Compound assignment:

x += y;

x -= y;
```

```
x *= y;
x /= y;
x %= y;
x <<= 1;
x >>= 1;
x >>>= 1;
x &= y;
x ^= y;
x |= y;
// Casting:
//- boolean bl = (boolean)x;
char c = (char)x;
byte b = (byte)x;
short s = (short)x;
long l = (long)x;
float f = (float)x;
double d = (double)x;
}
void longTest(long x, long y) {
// Arithmetic operators:
```

```
x = x * y;
x = x / y;
x = x % y;
x = x + y;
x = x - y;
x++;
x--;
x = +y;
x = -y;
// Relational and logical:
f(x > y);
f(x >= y);
f(x < y);
f(x <= y);
f(x == y);
f(x != y);
//- f(!x);
//- f(x && y);
//- f(x || y);
// Bitwise operators:
```

```
x = ~y;

x = x & y;

x = x | y;

x = x ^ y;

x = x << 1;

x = x >> 1;

x = x >>> 1;

// Compound assignment:

x += y;

x -= y;

x *= y;

x /= y;

x %= y;

x <<= 1;

x >>= 1;

x >>>= 1;

x &= y;

x ^= y;

x |= y;

// Casting:
```

```
//- boolean bl = (boolean)x;
char c = (char)x;
byte b = (byte)x;
short s = (short)x;
int i = (int)x;
float f = (float)x;
double d = (double)x;
}
void floatTest(float x, float y) {
// Arithmetic operators:
x = x * y;
x = x / y;
x = x % y;
x = x + y;
x = x - y;
x++;
x--;
x = +y;
x = -y;
// Relational and logical:
```

```
f(x > y);

f(x >= y);

f(x < y);

f(x <= y);

f(x == y);

f(x != y);

//- f(!x);

//- f(x && y);

//- f(x || y);

// Bitwise operators:

//- x = ~y;

//- x = x & y;

//- x = x | y;

//- x = x ^ y;

//- x = x << 1;

//- x = x >> 1;

//- x = x >>> 1;

// Compound assignment:

x += y;

x -= y;
```

```
x *= y;
x /= y;
x %= y;
//- x <<= 1;
//- x >>= 1;
//- x >>>= 1;
//- x &= y;
//- x ^= y;
//- x |= y;
// Casting:
//- boolean bl = (boolean)x;
char c = (char)x;
byte b = (byte)x;
short s = (short)x;
int i = (int)x;
long l = (long)x;
double d = (double)x;
}
void doubleTest(double x, double y) {
// Arithmetic operators:
```

```
x = x * y;

x = x / y;

x = x % y;

x = x + y;

x = x - y;

x++;

x--;

x = +y;

x = -y;
// Relational and logical:

f(x > y);

f(x >= y);

f(x < y);

f(x <= y);

f(x == y);

f(x != y);

//- f(!x);

//- f(x && y);
```

//- f(x || y);

// Bitwise operators:

//- x = ~y;

//- x = x & y;

//- x = x | y;

//- x = x ^ y;

//- x = x << 1;

//- x = x >> 1;

//- x = x >>> 1;

// Compound assignment:

x += y;

x -= y;

x *= y;

x /= y;

x %= y;

//- x <<= 1;

//- x >>= 1;

//- x >>>= 1;

//- x &= y;

//- x ^= y;

```
//- x |= y;
// Casting:
//- boolean bl = (boolean)x;
char c = (char)x;
byte b = (byte)x;
short s = (short)x;
int i = (int)x;
long l = (long)x;
float f = (float)x;
}
}
```

Note that **boolean** is limited. You can assign to it the values **true** and **false**, and you can test it for truth or falsehood, but you cannot add Booleans or perform any other type of operation on them.

In **char**, **byte**, and **short**, you see the effect of promotion with the arithmetic operators. Each arithmetic operation on any of those types produces an **int** result, which must be explicitly cast back to the original type (a narrowing conversion that might lose information) to assign back to that type. With **int** values, however, you do not need a cast, because everything is already an **int**. Don’t be lulled into

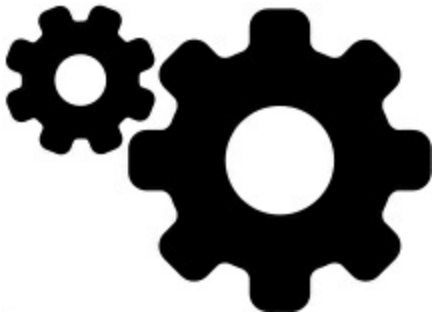
thinking everything is safe, though. If you multiply two **int**s that are big enough, you'll overflow the result. The following example demonstrates this:

```
// operators/Overflow.java
// Surprise! Java lets you overflow
public class Overflow {
public static void main(String[] args) {
int big = Integer.MAX_VALUE;
System.out.println("big = " + big);
int bigger = big * 4;
System.out.println("bigger = " + bigger);
}
}
/* Output:
big = 2147483647
bigger = -4
*/
```

You get no errors or warnings from the compiler, and no exceptions at run time. Java is good, but it's not *that* good.

Compound assignments do *not* require casts for **char**, **byte**, or

short, even though they are performing promotions that have the



same results as the direct arithmetic operations. On the other hand, the lack of a cast certainly simplifies the code.

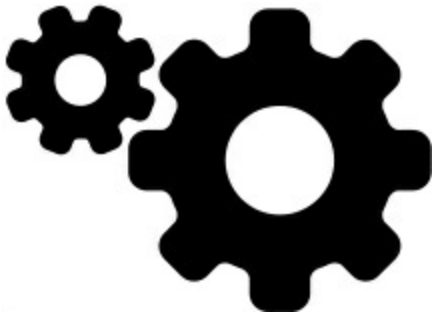
Except for **boolean**, any primitive type can be cast to any other primitive type. Again, you must be aware of the effect of a narrowing conversion when casting to a smaller type; otherwise, you might unknowingly lose information during the cast.

Summary

If you've had experience with any languages that use C-like syntax, you see that the operators in Java are so similar there is virtually no learning curve. If you found this chapter challenging, make sure you view the multimedia presentation *Thinking in C*, freely available at www.OnJava8.com.

1. As an undergraduate, I attended Pomona College for two years, where the number 47 was considered a "magic number." See the Wikipedia article.↩

2. John Kirkham writes, “I started computing in 1962 using FORTRAN II on an IBM 1620. At that time, and throughout the 1960s and into the 1970s, FORTRAN was an all uppercase language. This probably started because many of the early input devices were old teletype units that used 5 bit Baudot code, which had no lowercase capability. The **E** in the exponential notation was also always uppercase and was never confused with the natural logarithm base **e**, which is always lowercase. The **E** simply stood for exponential, which was for the base of the number system used—usually 10. At the time octal was also widely used by programmers. Although I never saw it used, if I had seen an octal number in exponential notation I would have considered it to be base 8. The first time I remember seeing an exponential using a lowercase **e** was in the late 1970s and I also found it confusing. The problem arose as lowercase crept into FORTRAN, not at its beginning. We actually had functions to use if you really wanted to use the natural logarithm base, but they were all uppercase.” ↩



Control Flow

A program manipulates its world and

makes choices. In Java you make choices

with execution control statements.

Java uses all of C's execution control statements, so if you've

programmed with C or C++, most of what you see is familiar. Most

procedural programming languages have some kind of control

statements, and there is often overlap among languages. In Java, the

keywords include **if-else**, **while**, **do-while**, **for**, **return**, **break**, and a selection statement called **switch**. Java does not,

however, support the much-maligned **goto** (which can still be the

most expedient way to solve certain types of problems). You can still

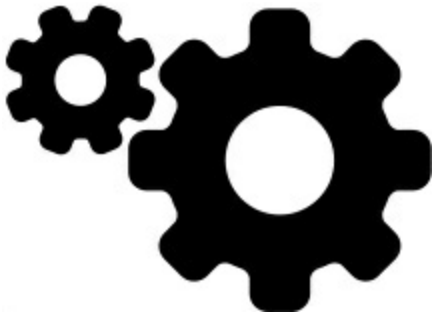
do a **goto**-like jump, but it is much more constrained than **goto** in

other languages.

true and false

All conditional statements use the truth or falsehood of a conditional

expression to determine the execution path. An example of a



conditional expression is **a == b**. This uses the conditional operator == to see if the value of **a** is equivalent to the value of **b**. The expression returns **true** or **false**. If you display the result of a conditional expression, it produces the strings “true” and “false” representing the **boolean** values:

```
// control/TrueFalse.java
public class TrueFalse {
public static void main(String[] args) {
System.out.println(1 == 1);
System.out.println(1 == 2);
}
}
/* Output:
true
false
```

*/

Any of the relational operators you've seen in the previous chapter can produce a conditional statement. Note that Java doesn't allow you to use a number as a **boolean**, even though it's allowed in C and C++ (where truth is nonzero and falsehood is zero). To use a non-**boolean** in a **boolean** test, such as **if(a)**, you must first convert it to a **boolean** value by using a conditional expression, such as **if(a != 0)**.

if-else

The **if-else** statement is the most basic way to control program flow. The **else** is optional, so you can use **if** in two forms:

if(Boolean-expression)

statement

or

if(Boolean-expression)

statement

else

statement

The *Boolean-expression* must produce a **boolean** result. The *statement* is either a simple statement terminated by a semicolon, or a

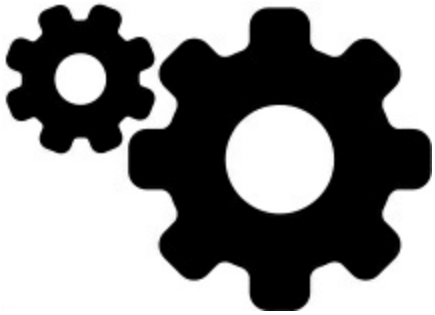
compound statement: a group of simple statements enclosed in braces.

Whenever the word "*statement*" is used, it always implies that the statement can be simple or compound.

As an example of **if-else**, here is a **test()** method that tells whether a guess is above, below, or equivalent to a target number:

```
// control/IfElse.java
public class IfElse {
static int result = 0;
static void test(int testval, int target) {
if(testval > target)
result = +1;
else if(testval < target) // [1]
result = -1;
else
result = 0; // Match
}
public static void main(String[] args) {
test(10, 5);
System.out.println(result);
test(5, 10);
```

```
System.out.println(result);
test(5, 5);
System.out.println(result);
}
}
/* Output:
1
-1
0
```



```
*/
```

[1] “**else if**” is not a new keyword, but just an **else** followed by a new **if** statement.

Although Java, like C and C++ before it, is a “free-form” language, it is conventional to indent the body of a control flow statement so the reader can easily determine where it begins and ends.

Iteration Statements

Looping is controlled by **while**, **do-while** and **for**, which are sometimes called *iteration statements*. Such statements repeat until the controlling *Boolean-expression* evaluates to **false**. The form for a **while** loop is:

while(Boolean-expression)

statement

The *Boolean-expression* is evaluated once at the beginning of the loop and again before each further iteration of the statement.

This generates random numbers until a particular condition is met:

```
// control/WhileTest.java
// Demonstrates the while loop
public class WhileTest {
static boolean condition() {
boolean result = Math.random() < 0.99;
System.out.print(result + ", ");
return result;
}
public static void main(String[] args) {
while(condition())
System.out.println("Inside 'while'");
```

```
System.out.println("Exited 'while'");

}

}

/* Output: (First and Last 5 Lines)

true, Inside 'while'

true, Inside 'while'

true, Inside 'while'

true, Inside 'while'

true, Inside 'while'

...________...________...________...________...

true, Inside 'while'

true, Inside 'while'

true, Inside 'while'

true, Inside 'while'

false, Exited 'while'

*/
```

The **condition()** method uses the **static** method **random()** in

the **Math** library, which generates a **double** value between 0 and 1 (It includes 0, but not 1). The **result** value comes from the comparison operator < , which produces a **boolean** result. The conditional expression for the **while** says: “repeat the statements in the body as long as **condition()** returns **true**.”

do-while

The form for **do-while** is

do

statement

while(Boolean-expression);

The sole difference between **while** and **do-while** is that the statement of the **do-while** always executes at least once, even if the expression evaluates to **false** the first time. In a **while**, if the

conditional is **false** the first time the statement never executes. In practice, **do-while** is less common than **while**.

for

A **for** loop is perhaps the most commonly used form of iteration. This

loop performs initialization before the first iteration. Then it performs conditional testing and, at the end of each iteration, some form of "stepping." The form of the **for** loop is:

for(initialization; Boolean-expression; step)

statement

Any of the expressions *initialization*, *Boolean-expression* or *step* can be empty. The expression is tested before each iteration, and as soon as it evaluates to **false**, execution will continue at the line following the **for** statement. At the end of each loop, the *step* executes.

for loops are often used for "counting" tasks:

```
// control/ListCharacters.java
// List all the lowercase ASCII letters
public class ListCharacters {
public static void main(String[] args) {
for(char c = 0; c < 128; c++)
if(Character.isLowerCase(c))
System.out.println("value: " + (int)c +
" character: " + c);
}
}
/* Output: (First 10 Lines)
```

value: 97 character: a

value: 98 character: b

value: 99 character: c

value: 100 character: d

value: 101 character: e

value: 102 character: f

value: 103 character: g

value: 104 character: h

value: 105 character: i

value: 106 character: j

...

**/*

Note that the variable **c** is defined when it is used, inside the control expression of the **for** loop, rather than at the beginning of **main()**.

The scope of **c** is the statement controlled by the **for**.

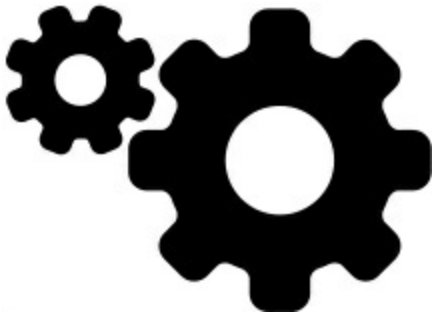
Traditional procedural languages like C require that all variables be defined at the beginning of a block. When the compiler creates a block,

it can allocate space for those variables. In Java and C++, you can spread your variable declarations throughout the block, defining them when you need them. This allows a more natural coding style and makes code easier to understand.1

This program uses the **java.lang.Character** "wrapper" class, which not only wraps the primitive **char** type in an object, but also provides other utilities. Here, **static isLowerCase()** detects whether the character in question is a lowercase letter.

The Comma Operator

The comma *operator* (not the comma *separator*, used to separate definitions and method arguments) has only one use in Java: in the control expression of a **for** loop. In both the initialization and step portions of the control expression, you can have a number of statements separated by commas, and those statements are evaluated sequentially.



Using the comma operator, you can define multiple variables within a

for statement, but they must be of the same type:

```
// control/CommaOperator.java

public class CommaOperator {

public static void main(String[] args) {

for(int i = 1, j = i + 10; i < 5; i++, j = i * 2) {

System.out.println("i = " + i + " j = " + j);

}

}

}

/* Output:

i = 1 j = 11

i = 2 j = 4

i = 3 j = 6

i = 4 j = 8

*/
```

The **int** definition in the **for** statement covers both **i** and **j**. The initialization portion can have any number of definitions *of one type*.

The ability to define variables in a control expression is limited to the

for loop. You cannot use this approach with any of the other selection

or iteration statements.

In both the initialization and step portions, the statements are

evaluated in sequential order.

For-in Syntax

Java 5 introduced a more succinct **for** syntax, for use with arrays and collections (you'll learn more about these in the Arrays and Collections chapters). This is sometimes called the *enhanced for*, and much of the documentation you'll see call this the *for-each syntax*, but Java 8 has added **forEach()** which is heavily used. This confuses the terminology, and so I take some license and instead call it *for-in* (in Python, for example, you actually say **for x in sequence**, so there is reasonable precedent). Just keep in mind you might see it termed differently elsewhere.

The *for-in* produces each item for you, automatically, so you don't create an **int** to count through a sequence of items. For example, suppose you have an array of **float** and you'd like to select each element in that array:

```
// control/ForInFloat.java
import java.util.*;
public class ForInFloat {
public static void main(String[] args) {
Random rand = new Random(47);
```

```
float[] f = new float[10];
for(int i = 0; i < 10; i++)
f[i] = rand.nextFloat();
for(float x : f)
System.out.println(x);
}
}
/* Output:
0.72711575
0.39982635
0.5309454
0.0534122
0.16020656
0.57799757
0.18847865
0.4170137
0.51660204
0.73734957
*/
```

The array is populated using the old **for** loop, because it must be

accessed with an index. You see the *for-in* syntax in the line:

for(float x : f) {

This defines a variable **x** of type **float** and sequentially assigns each element of **f** to **x**.

Any method that returns an array is a *for-in* candidate. For example,

the **String** class has a method **toCharArray()** that returns an

array of **char**, so you can easily iterate through the characters in a

String:

```
// control/ForInString.java

public class ForInString {

public static void main(String[] args) {

for(char c : "An African Swallow".toCharArray())

System.out.print(c + " ");

}

}

/* Output:

A n A f r i c a n S w a l l o w

*/
```

As you'll see in the Collections chapter, *for-in* also works with any object that is **Iterable**.

Many **for** statements involve stepping through a sequence of integral

values, like this:

```
for(int i = 0; i < 100; i++)
```

For these, the *for-in* syntax won't work unless you create an array of **int** first. To simplify this task, I've created a method called **range()** in **onjava.Range** that automatically generates the appropriate array.

The Implementation Hiding chapter introduces *static import* s. However, you don't need to know those details to begin using this library. You see the **static import** syntax in the **import** line here:

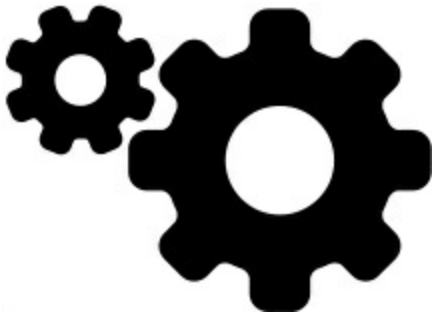
```
// control/ForInInt.java
import static onjava.Range.*;
public class ForInInt {
public static void main(String[] args) {
for(int i : range(10)) // 0..9
System.out.print(i + " ");
System.out.println();
for(int i : range(5, 10)) // 5..9
System.out.print(i + " ");
System.out.println();
```

```
for(int i : range(5, 20, 3)) // 5..20 step 3
System.out.print(i + " ");
System.out.println();
for(int i : range(20, 5, -3)) // Count down
System.out.print(i + " ");
System.out.println();
}
}
/* Output:
0 1 2 3 4 5 6 7 8 9
5 6 7 8 9
5 8 11 14 17
20 17 14 11 8
*/
```

The **range()** method is *overloaded*, which means the same method name can be used with different argument lists (you'll learn about overloading soon). The first overloaded form of **range()** just starts at zero and produces values up to but not including the top end of the range. The second form starts at the first value and goes until one less than the second, and the third form has a step value so it increases by

that value. The fourth form shows you can also count down. **range()** is a simple version of what's called a *generator*, which you'll see later in the book.

range() allows *for-in* syntax in more places, and thus arguably



increases readability.

Notice that **System.out.print()** does not emit a newline, so you can output a line in pieces.

The *for-in* syntax doesn't just save time when writing code. More importantly, it is far easier to read and says *what* you are trying to do (get each element of the array) rather than giving the details of *how* you are doing it ("I'm creating this index so I can use it to select each of the array elements."). The *for-in* syntax is preferred in this book.

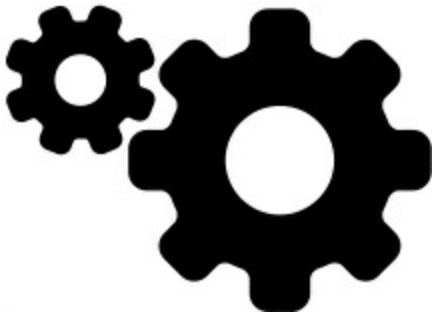
return

Several keywords represent *unconditional branching*, which means the branch happens without any test. These include **return**, **break**, **continue**, and a way to jump to a labeled statement, similar to

goto in other languages.

The **return** keyword has two purposes: It specifies what value a method will return (if it doesn't have a **void** return value) and it causes the current method to exit, returning that value. The **test()** method from **IfElse.java** can be rewritten to take advantage of this:

```
// control/TestWithReturn.java
public class TestWithReturn {
static int test(int testval, int target) {
if(testval > target)
return +1;
if(testval < target)
return -1;
return 0; // Match
}
```



```
public static void main(String[] args) {
```

```
System.out.println(test(10, 5));
System.out.println(test(5, 10));
System.out.println(test(5, 5));
}
}
/* Output:
1
-1
0
*/
```

There’s no need for **else**, because the method will not continue after executing a **return**.

If you do not have a **return** statement in a method that returns **void**, there’s an implicit **return** at the end of that method, so it’s not always necessary to include a **return** statement. However, if your method states it will return anything other than **void**, you must ensure every code path will return a value.

break and continue

You can also control the flow of the loop inside the body of any of the iteration statements by using **break** and **continue**. **break** quits

the loop without executing the rest of the statements in the loop.

continue stops the execution of the current iteration and goes back to the beginning of the loop to begin the next iteration.

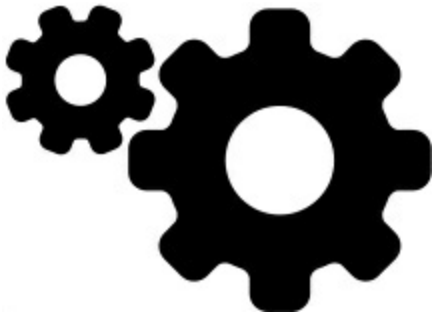
Here you see **break** and **continue** within **for** and **while** loops:

```
// control/BreakAndContinue.java
// Break and continue keywords
import static onjava.Range.*;
public class BreakAndContinue {
public static void main(String[] args) {
for(int i = 0; i < 100; i++) { // [1]
if(i == 74) break; // Out of for loop
if(i % 9 != 0) continue; // Next iteration
System.out.print(i + " ");
}
System.out.println();
// Using for-in:
for(int i : range(100)) { // [2]
if(i == 74) break; // Out of for loop
if(i % 9 != 0) continue; // Next iteration
System.out.print(i + " ");
```

```
}
System.out.println();
int i = 0;
// An "infinite loop":
while(true) { // [3]
i++;
int j = i * 27;
if(j == 1269) break; // Out of loop
if(i % 10 != 0) continue; // Top of loop
System.out.print(i + " ");
}
}
}
/* Output:
0 9 18 27 36 45 54 63 72
0 9 18 27 36 45 54 63 72
10 20 30 40
*/
```

[1] The value of **i** never gets to 100 because the **break** statement breaks out of the loop when **i** is 74. Normally, you use a **break**

like this only if you don’t know when the terminating condition occurs. The **continue** statement takes execution back to the top of the iteration loop (thus incrementing **i**) whenever **i** is not evenly divisible by 9. When it is, the value is displayed.



[2] *For-in* produces the same results.

[3] The “infinite” **while** loop could continue forever because its conditional expression is always **true**, but the **break** breaks out of the loop. Notice the **continue** statement moves control back to the top of the loop without completing anything after the **continue**. Thus, display occurs only when the value of **i** is divisible by **10**. In the output, the value **0** is shown because **0 % 9** produces **0**.

Another form of the infinite loop is **for(;;)**. The compiler treats both **while(true)** and **for(;;)** the same way, so the one you use is a matter of programming taste.

The Infamous “Goto”

The **goto** keyword was present in programming languages from the beginning. Indeed, **goto** was the genesis of program control in assembly language: "If condition A, then jump here; otherwise, jump there." If you read the assembly code that is ultimately generated by virtually any compiler, you'll see that program control contains many jumps (the Java compiler produces its own "assembly code," but this code is run by the Java Virtual Machine rather than directly on a hardware CPU).

A **goto** is a jump at the source-code level, and that's what brought it into disrepute. If a program will always jump from one point to another, isn't there some way to reorganize the code so the flow of control is not so jumpy? **goto** fell into true disfavor with the publication of the famous "Goto considered harmful" paper by Edsger Dijkstra, and since then **goto**-bashing is a popular sport, with advocates of the cast-out keyword scurrying for cover.

As is typical in situations like this, the middle ground is the most fruitful. The problem is not **goto**, but the overuse of **goto**; in rare situations **goto** is actually the best way to structure control flow.

Although **goto** is a reserved word in Java, it is not used in the language—Java has no **goto**. However, it does have something that looks a bit like a jump tied in with the **break** and **continue**

keywords. It’s not a jump but rather a way to break out of an iteration statement. The reason it’s often thrown in with discussions of **goto** is because it uses the same mechanism: a label.

A label is an identifier followed by a colon, like this:

label1:

The *only* place a label is useful in Java is right before an iteration statement. And that means *right* before—it does no good to put any other statement between the label and the iteration. And the sole reason to put a label before an iteration is if you’re going to nest another iteration or a **switch** (which you’ll learn about shortly) inside it. That’s because the **break** and **continue** keywords will normally interrupt only the current loop, but when used with a label, they’ll interrupt the loops up to where the label exists:

label1:

outer-iteration {

inner-iteration {

// ...

break; *// [1]*

// ...

continue; *// [2]*

// ...

continue label1; *// [3]*

// ...

break label1; *// [4]*

}

}

[1] The **break** breaks out of the inner iteration and you end up in the outer iteration.

[2] The **continue** moves back to the beginning of the inner iteration.

[3] The **continue label1** breaks out of the inner iteration *and* the outer iteration, all the way back to **label1**. Then it does in fact continue the iteration, but starting at the outer iteration.

[4] The **break label1** also breaks all the way out to **label1**, but it does not reenter the iteration. It actually does break out of both iterations.

Labeled **break** and labeled **continue** can also be used with **for** loops:

// control/LabeledFor.java

// For loops with "labeled break"/"labeled continue."

```
public class LabeledFor {
public static void main(String[] args) {
int i = 0;
outer: // Can't have statements here
for(; true ;) { // infinite loop
inner: // Can't have statements here
for(; i < 10; i++) {
System.out.println("i = " + i);
if(i == 2) {
System.out.println("continue");
continue;
}
if(i == 3) {
System.out.println("break");
i++; // Otherwise i never
// gets incremented.
break;
}
if(i == 7) {
System.out.println("continue outer");
```

```
i++; // Otherwise i never
// gets incremented.
continue outer;
}
if(i == 8) {
System.out.println("break outer");
break outer;
}
for(int k = 0; k < 5; k++) {
if(k == 3) {
System.out.println("continue inner");
continue inner;
}
}
}
}
// Can't break or continue to labels here
}
}
/* Output:
```

i = 0

continue inner

i = 1

continue inner

i = 2

continue

i = 3

break

i = 4

continue inner

i = 5

continue inner

i = 6

continue inner

i = 7

continue outer

i = 8

break outer

**/*

Note that **break** breaks out of the **for** loop, and that the increment expression doesn't occur until the end of the pass through the **for**

loop. Since **break** skips the increment expression, the increment is performed directly in the case of **i == 3**. The **continue outer** statement in the case of **i == 7** also goes to the top of the loop and also skips the increment, so it too is incremented directly.

Without the **break outer** statement, there's no way to get out of the outer loop from within an inner loop, since **break** by itself can only break out of the innermost loop. (The same is true for **continue**.)

In cases where breaking out of a loop also exits the method, you can simply use a **return**.

This demonstrates labeled **break** and **continue** statements with **while** loops:

```
// control/LabeledWhile.java
// "While" with "labeled break" and "labeled continue."
public class LabeledWhile {
public static void main(String[] args) {
int i = 0;
outer:
while(true) {
System.out.println("Outer while loop");
```

```
while(true) {
i++;
System.out.println("i = " + i);
if(i == 1) {
System.out.println("continue");
continue;
}
if(i == 3) {
System.out.println("continue outer");
continue outer;
}
if(i == 5) {
System.out.println("break");
break;
}
if(i == 7) {
System.out.println("break outer");
break outer;
}
}
```

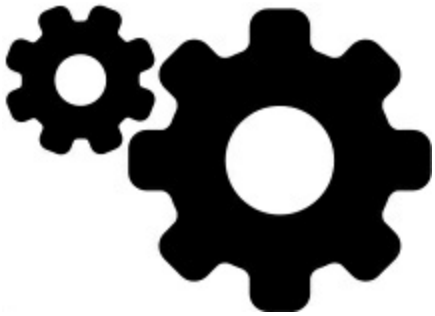
```
}

}

}

/* Output:

Outer while loop

i = 1

continue

i = 2

i = 3

continue outer

Outer while loop

i = 4

i = 5

break

Outer while loop

i = 6

i = 7

break outer

*/
```

The same rules hold true for **while**:

1. A plain **continue** goes to the top of the innermost loop and continues.

2. A labeled **continue** goes to the label and reenters the loop right after that label.

3. A **break** “drops out of the bottom” of the loop.



4. A labeled **break** drops out of the bottom of the end of the loop denoted by the label.

It’s important to remember that the *only* reason to use labels in Java is when you have nested loops and you must **break** or **continue** through more than one nested level.

Labeled **break** and labeled **continue** have turned out to be speculative features (with little or no precedent in preceding languages) that are relatively unused, so you rarely see them in code. In Dijkstra’s “Goto considered harmful” paper, what he specifically objected to was the labels, not the **goto**. He observed that the number of bugs seems to increase with the number of labels in a program, 2

and that labels and **goto**s make programs difficult to analyze. Note that Java labels don't suffer from this problem, since they are constrained in their placement and can't be used to transfer control in an ad hoc manner. This is a case where a language feature is made more valuable by restricting its use.

switch

The **switch** is sometimes called a *selection statement*. A **switch** selects from among pieces of code based on the value of an integral expression. Its general form is:

switch(integral-selector) {

case integral-value1 : statement; **break**;

case integral-value2 : statement; **break**;

case integral-value3 : statement; **break**;

case integral-value4 : statement; **break**;

case integral-value5 : statement; **break**;

// ...

default: statement;

}

Integral-selector is an expression that produces an integral value. The **switch** compares the result of *integral-selector* to each *integral-value*. If it finds a match, the corresponding *statement* (a single

statement or multiple statements; braces are not required) executes. If no match occurs, the **default** *statement* executes.

Notice in the preceding definition that each **case** ends with a **break**. This jumps to the end of the **switch** body. The example shows the conventional way to build a **switch** statement, but the **break** is optional. If it is missing, the code for the following **case** statements executes until a **break** is encountered. Although you don't usually want this kind of behavior, it can be useful to an experienced programmer. Note that the last statement, following the **default**, doesn't have a **break** because the execution just falls through to where the **break** would have taken it anyway. You can put a **break** at the end of the **default** statement with no harm if you considered it important for style's sake.

The **switch** statement is a clean way to implement multiway selection (i.e., selecting from among a number of different execution paths), but before Java 7 it only worked with a selector that evaluates to an integral value, such as **int** or **char**. For non-integral types (except **String** in Java 7 and beyond), you must use a series of **if** statements. At the end of the next chapter, you'll see that the **enum** feature helps ease this restriction, as **enum**s are designed to work

nicely with **switch**.

Here’s an example that creates letters randomly and determines whether they’re vowels or consonants:

```
// control/VowelsAndConsonants.java
// Demonstrates the switch statement
import java.util.*;
public class VowelsAndConsonants {
public static void main(String[] args) {
Random rand = new Random(47);
for(int i = 0; i < 100; i++) {
int c = rand.nextInt(26) + 'a';
System.out.print((char)c + ", " + c + ": ");
switch(c) {
case 'a':
case 'e':
case 'i':
case 'o':
case 'u': System.out.println("vowel");
break;
case 'y':
```

case 'w': System.out.println("Sometimes vowel");

break;

default: System.out.println("consonant");

}

}

}

}

/ *Output: (First 13 Lines)*

y, 121: Sometimes vowel

n, 110: consonant

z, 122: consonant

b, 98: consonant

r, 114: consonant

n, 110: consonant

y, 121: Sometimes vowel

g, 103: consonant

c, 99: consonant

f, 102: consonant

o, 111: vowel

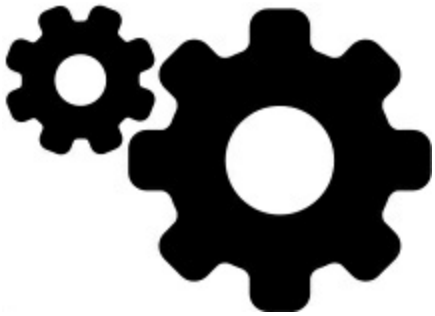
w, 119: Sometimes vowel

z, 122: consonant

...

*/

Since **Random.nextInt(26)** generates a value between 0 and 25, you need only add an offset of **a** to produce the lowercase letters. The



single-quoted characters in the **case** statements also produce integral values used for comparison.

Notice how the **case**s can be “stacked” on top of each other to provide multiple matches for a particular piece of code. It’s essential to put the **break** statement at the end of a particular case; otherwise, control will drop through and continue processing on the next case.

In the statement:

int c = rand.nextInt(26) + 'a';

Random.nextInt() produces a random **int** value from 0 to 25, which is added to the value of **a**. This means **a** is automatically converted to an **int** to perform the addition.

To print **c** as a character, it must be cast to **char**; otherwise, you'll produce integral output.

Switching on Strings

Java 7 added the ability to switch on **String**s as well as integral values. This example shows both the old way you would choose from a set of **String** possibilities, and the new way, using **switch**:

```
// control/StringSwitch.java
public class StringSwitch {
public static void main(String[] args) {
String color = "red";
// Old way: using if-then
if("red".equals(color)) {
System.out.println("RED");
} else if("green".equals(color)) {
System.out.println("GREEN");
} else if("blue".equals(color)) {
System.out.println("BLUE");
} else if("yellow".equals(color)) {
System.out.println("YELLOW");
} else {
```

```
System.out.println("Unknown");
}
// New way: Strings in switch
switch(color) {
case "red":
System.out.println("RED");
break;
case "green":
System.out.println("GREEN");
break;
case "blue":
System.out.println("BLUE");
break;
case "yellow":
System.out.println("YELLOW");
break;
default:
System.out.println("Unknown");
break;
}
```

```
}
}
/* Output:
RED
RED
*/
```

Once you understand **switch**, this syntax is a logical extension. The result is cleaner and easier to understand and maintain.

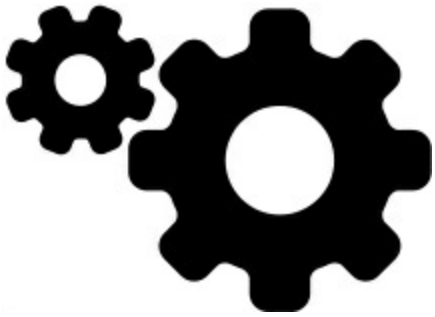
As a second example of switching on **String**s, let's revisit **Math.random()**. Does it produce a value from zero to one, inclusive or exclusive of the value "1"? In math lingo, is it (0,1), or [0,1], or (0,1] or [0,1)? (The square bracket means "includes," whereas the parenthesis means "doesn't include.")

Here's a test program that *might* provide the answer. All command-line arguments are passed as **String** objects, so we can **switch** on the argument to decide what to do. There's one problem: the user might not provide any arguments, so indexing into the **args** array would cause the program to fail. To fix this, we check the **length** of the array and, if it's zero, we use an empty **String**, otherwise we select the first element in the **args** array:

```
// control/RandomBounds.java
// Does Math.random() produce 0.0 and 1.0?
// {java RandomBounds lower}
import onjava.*;
public class RandomBounds {
public static void main(String[] args) {
new TimedAbort(3);
switch(args.length == 0 ? "" : args[0]) {
case "lower":
while(Math.random() != 0.0)
; // Keep trying
System.out.println("Produced 0.0!");
break;
case "upper":
while(Math.random() != 1.0)
; // Keep trying
System.out.println("Produced 1.0!");
break;
default:
System.out.println("Usage:");
```

```
System.out.println("\tRandomBounds lower");
System.out.println("\tRandomBounds upper");
System.exit(1);
}
}
}
```

To run the program, you type a command line of either:



```
java RandomBounds lower
```

or

```
java RandomBounds upper
```

Using the **TimedAbort** class from the **onjava** package, the program aborts after three seconds, so it would appear that **Math.random()** never produces either 0.0 or 1.0. But this is where such an experiment can be deceiving. If you consider the number of different double fractions between 0 and 1, the likelihood of reaching any one value experimentally might exceed the lifetime of one

computer, or even one experimenter. It turns out 0.0 *is* included in the output of **Math.random()**, while 1.0 is not. In math lingo, it is [0,1). You must be careful to analyze your experiments and to understand their limitations.

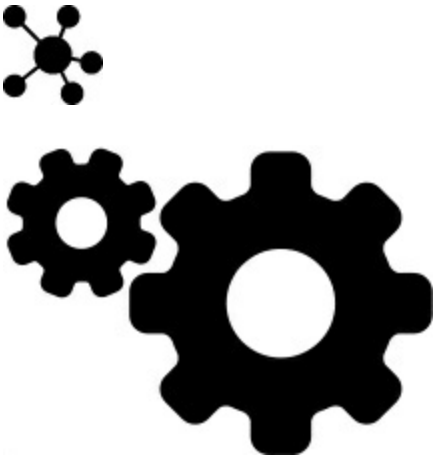
Summary

This chapter concludes our exploration of fundamental features that appear in most programming languages: calculation, operator precedence, type casting, and selection and iteration. Now you're ready to begin taking steps that move you closer to the world of object-oriented and functional programming. The next chapter will cover the important issues of initialization and cleanup of objects, followed in the subsequent chapter by the essential concept of implementation hiding.

1. In earlier languages, a large number of decisions were based on making life easier for the compiler writers. You'll see that in modern languages, most design decisions make life easier for the *users* of the language, although at times there are compromises—which usually end up becoming regrets on the part of the language designers.↩

2. Note that this seems a hard assertion to support, and may very

well be an example of the cognitive bias called the correlation-causation fallacy↩



Housekeeping

“Unsafe” programming is one of the major culprits that makes programming expensive.

Two of these safety issues are *initialization* and *cleanup*. Many C bugs occur when the programmer forgets to initialize a variable. This is especially true with libraries when users don’t know how to initialize a library component, or even that they must. Cleanup is a special problem because it’s easy to forget about an element when you’re done with it, since it no longer concerns you. Thus, the resources used by that element are retained and you can easily end up running out of resources (most notably, memory).

C++ introduced the concept of a *constructor*, a special method automatically called when an object is created. Java adopted the constructor, and also has a *garbage collector* that automatically releases memory resources when they're no longer used. This chapter examines the issues of initialization and cleanup, and their support in Java.

Guaranteed Initialization with the Constructor

You can imagine creating a method called **initialize()** for every class you write. The name is a hint it should be called before using the object. Unfortunately, this means the user must remember to call that method. In Java, the class designer can guarantee initialization of every object by writing a *constructor*. If a class has a constructor, Java automatically calls that constructor when an object is created, before users can even get their hands on it. So initialization is guaranteed.

The next challenge is what to name this method. There are two issues. The first is that any name you use could clash with a name you might like to use as an element in the class. The second is that because the compiler is responsible for calling the constructor, it must always

know which method to call. The C++ solution seems the easiest and most logical, so it’s also used in Java: The name of the constructor is the name of the class. It makes sense that such a method is called automatically during initialization.

Here’s a simple class with a constructor:

```
// housekeeping/SimpleConstructor.java
// Demonstration of a simple constructor
class Rock {
Rock() { // This is the constructor
System.out.print("Rock ");
}
}
public class SimpleConstructor {
public static void main(String[] args) {
for(int i = 0; i < 10; i++)
new Rock();
}
}
/* Output:
Rock Rock Rock Rock Rock Rock Rock Rock Rock Rock
```

*/

Now, when an object is created:

new Rock();

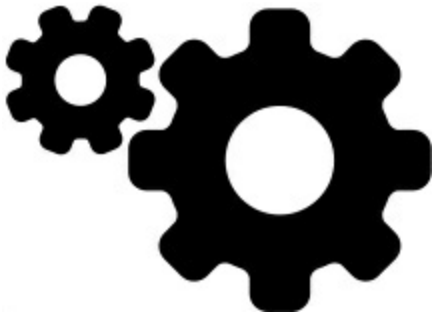
storage is allocated and the constructor is called. The constructor guarantees that the object is properly initialized before you can get your hands on it.

Note that the coding style of making the first letter of all methods lowercase does not apply to constructors, since the name of the constructor must match the name of the class *exactly*.

In C++, a constructor that takes no arguments is called the *default constructor*. This term was in use for many years before Java appeared, but for some reason the Java designers decided to use the term *no-arg* constructor, which I found very awkward and unnecessary, so I resisted and attempted to continue using “default constructor.” Java 8 has introduced the use of **default** as a keyword for method definitions, so I must relent, choke down a bit of bile, and use *no-arg*.

Like any method, the constructor can have arguments that specify how an object is created. The preceding example can easily be changed so the constructor takes an argument:

```
// housekeeping/SimpleConstructor2.java
// Constructors can have arguments
class Rock2 {
Rock2(int i) {
System.out.print("Rock " + i + " ");
}
}
public class SimpleConstructor2 {
```



```
public static void main(String[] args) {
for(int i = 0; i < 8; i++)
new Rock2(i);
}
}
/* Output:
Rock 0 Rock 1 Rock 2 Rock 3 Rock 4 Rock 5 Rock 6 Rock 7
*/
```

If a class **Tree** has a constructor that takes a single integer argument denoting the height of the tree, you create a **Tree** object like this:

Tree t = **new** Tree(12); *// 12-foot tree*

If **Tree(int)** is your only constructor, the compiler won't let you create a **Tree** object any other way.

Constructors eliminate an important class of problems and make the code easier to read. In the preceding code fragment, for example, you don't see an explicit call to some **initialize()** method that is conceptually separate from creation. In Java, creation and initialization are unified concepts—you can't have one without the other.

The constructor is an unusual type of method because it has no return value. This is distinctly different from a **void** return value, where the method returns nothing but you still have the option to make it return something else. Constructors return nothing and you don't have an option (the **new** expression does return a reference to the newly created object, but the constructor itself has no return value). If there were a return value, and if you could select your own, the compiler would somehow need to know what to do with that return value.

Method Overloading

Names are an important feature in any programming language. When you create an object, you give a name to a region of storage. A method is a name for an action. You refer to all objects, fields, and methods by using names. Well-chosen names create a system that is easier for people to understand and change. It's a lot like writing prose—the goal is to communicate with your readers.

A problem arises when mapping the concept of *nuance* in human language onto a programming language. Often, the same word expresses a number of different meanings—it's *overloaded*. This is useful, especially when it comes to trivial differences. You say, "Wash the shirt," "Wash the car," and "Wash the dog." It would be silly to be forced to say, "shirtWash the shirt," "carWash the car," and "dogWash the dog" just so the listener doesn't have to make any distinction about the action performed. Most human languages are redundant, so even if you miss a few words, you can still determine the meaning. You don't need unique identifiers—you can deduce meaning from context. Most programming languages (C in particular) require a unique identifier for each method (often called *functions* in those languages). So you could *not* have a function called **print()** for printing integers and another called **print()** for printing floats—each function

requires a unique name.

In Java (and C++), another factor forces the overloading of method names: the constructor. Because the constructor's name is predetermined by the name of the class, there can be only one constructor name. But how do you create an object in more than one way? For example, suppose you build a class that can initialize itself in a standard way or by reading information from a file. You need two constructors, the no-arg constructor and one that takes a **String** as an argument, which is the name of the file from which to initialize the object. Both are constructors, so they must have the same name—the name of the class. Thus, *method overloading* is necessary to allow the same method name with different argument types. And although method overloading is essential for constructors, it's a general convenience and can be used with any method.

Here's an example that shows both overloaded constructors and overloaded methods:

```
// housekeeping/Overloading.java
// Both constructor and ordinary method overloading
class Tree {
int height;
```

```
Tree() {
System.out.println("Planting a seedling");
height = 0;
}
Tree(int initialHeight) {
height = initialHeight;
System.out.println("Creating new Tree that is " +
height + " feet tall");
}
void info() {
System.out.println(
"Tree is " + height + " feet tall");
}
void info(String s) {
System.out.println(
s + ": Tree is " + height + " feet tall");
}
}
public class Overloading {
public static void main(String[] args) {
```

```
for(int i = 0; i < 5; i++) {
Tree t = new Tree(i);
t.info();
t.info("overloaded method");
}
// Overloaded constructor:
new Tree();
}
}
/* Output:
Creating new Tree that is 0 feet tall
```

```
Tree is 0 feet tall
overloaded method: Tree is 0 feet tall
Creating new Tree that is 1 feet tall
Tree is 1 feet tall
overloaded method: Tree is 1 feet tall
Creating new Tree that is 2 feet tall
```

Tree is 2 feet tall

overloaded method: Tree is 2 feet tall

Creating new Tree that is 3 feet tall

Tree is 3 feet tall

overloaded method: Tree is 3 feet tall

Creating new Tree that is 4 feet tall

Tree is 4 feet tall

overloaded method: Tree is 4 feet tall

Planting a seedling

*/

A **Tree** object can be created either as a seedling, with no argument, or as a plant grown in a nursery, with an existing height. To support this, there is a no-arg constructor, plus a constructor that takes the existing height.

You might also want to call the **info()** method in more than one way. For example, if you have an extra message you want printed, you can use **info(String)**. If you have nothing more to say, you just use **info()**. It would seem strange to give two separate names to what is obviously the same concept. With method overloading, you use the same name for both.

Distinguishing Overloaded

Methods

If methods have the same name, how can Java know which method you mean? There’s a simple rule: Each overloaded method must take a unique list of argument types.

If you think about this for a second, it makes sense. How else could a programmer tell the difference between two methods that have the same name, other than by the types of their arguments?

Even differences in the ordering of arguments are sufficient to distinguish two methods, although you don’t normally take this approach because it produces difficult-to-maintain code:

```
// housekeeping/OverloadingOrder.java
// Overloading based on the order of the arguments
public class OverloadingOrder {
static void f(String s, int i) {
System.out.println("String: " + s + ", int: " + i);
}
```

```
static void f(int i, String s) {
System.out.println("int: " + i + ", String: " + s);
}
public static void main(String[] args) {
f("String first", 11);
f(99, "Int first");
}
}
/* Output:
String: String first, int: 11
int: 99, String: Int first
*/
```

The two **f()** methods have identical arguments, but the order is different, and that's what makes them distinct.

Overloading with Primitives

A primitive can be automatically *promoted* from a smaller type to a larger one, and this can be slightly confusing in combination with overloading. Here's a demonstration of what happens when a primitive is handed to an overloaded method:

```
// housekeeping/PrimitiveOverloading.java
```

```
// Promotion of primitives and overloading
public class PrimitiveOverloading {
void f1(char x) { System.out.print("f1(char) "); }
void f1(byte x) { System.out.print("f1(byte) "); }
void f1(short x) { System.out.print("f1(short) "); }
void f1(int x) { System.out.print("f1(int) "); }
void f1(long x) { System.out.print("f1(long) "); }
void f1(float x) { System.out.print("f1(float) "); }
void f1(double x) { System.out.print("f1(double) "); }
void f2(byte x) { System.out.print("f2(byte) "); }
void f2(short x) { System.out.print("f2(short) "); }
void f2(int x) { System.out.print("f2(int) "); }
void f2(long x) { System.out.print("f2(long) "); }
void f2(float x) { System.out.print("f2(float) "); }
void f2(double x) { System.out.print("f2(double) "); }
void f3(short x) { System.out.print("f3(short) "); }
void f3(int x) { System.out.print("f3(int) "); }
void f3(long x) { System.out.print("f3(long) "); }
void f3(float x) { System.out.print("f3(float) "); }
void f3(double x) { System.out.print("f3(double) "); }
```

```
void f4(int x) { System.out.print("f4(int) "); }
void f4(long x) { System.out.print("f4(long) "); }
void f4(float x) { System.out.print("f4(float) "); }
void f4(double x) { System.out.print("f4(double) "); }
void f5(long x) { System.out.print("f5(long) "); }
void f5(float x) { System.out.print("f5(float) "); }
void f5(double x) { System.out.print("f5(double) "); }
void f6(float x) { System.out.print("f6(float) "); }
void f6(double x) { System.out.print("f6(double) "); }
void f7(double x) { System.out.print("f7(double) "); }
void testConstVal() {
System.out.print("5: ");
f1(5);f2(5);f3(5);f4(5);f5(5);f6(5);f7(5);
System.out.println();
}
void testChar() {
char x = 'x';
System.out.print("char: ");
f1(x);f2(x);f3(x);f4(x);f5(x);f6(x);f7(x);
System.out.println();
```

```
}
void testByte() {
byte x = 0;
System.out.print("byte: ");
f1(x);f2(x);f3(x);f4(x);f5(x);f6(x);f7(x);
System.out.println();
}
void testShort() {
short x = 0;
System.out.print("short: ");
f1(x);f2(x);f3(x);f4(x);f5(x);f6(x);f7(x);
System.out.println();
}
void testInt() {
int x = 0;
System.out.print("int: ");
f1(x);f2(x);f3(x);f4(x);f5(x);f6(x);f7(x);
System.out.println();
}
void testLong() {
```

```
long x = 0;
System.out.print("long: ");
f1(x);f2(x);f3(x);f4(x);f5(x);f6(x);f7(x);
System.out.println();
}
void testFloat() {
float x = 0;
System.out.print("float: ");
f1(x);f2(x);f3(x);f4(x);f5(x);f6(x);f7(x);
System.out.println();
}
void testDouble() {
double x = 0;
System.out.print("double: ");
f1(x);f2(x);f3(x);f4(x);f5(x);f6(x);f7(x);
System.out.println();
}
public static void main(String[] args) {
PrimitiveOverloading p =
new PrimitiveOverloading();
```

```
p.testConstVal();
p.testChar();
p.testByte();
p.testShort();
p.testInt();
p.testLong();
p.testFloat();
p.testDouble();
}
}
/* Output:
5: f1(int) f2(int) f3(int) f4(int) f5(long) f6(float)
f7(double)
char: f1(char) f2(int) f3(int) f4(int) f5(long)
f6(float) f7(double)
byte: f1(byte) f2(byte) f3(short) f4(int) f5(long)
f6(float) f7(double)
short: f1(short) f2(short) f3(short) f4(int) f5(long)
f6(float) f7(double)
int: f1(int) f2(int) f3(int) f4(int) f5(long) f6(float)
```

f7(double)

long: f1(long) f2(long) f3(long) f4(long) f5(long)

f6(float) f7(double)

float: f1(float) f2(float) f3(float) f4(float)

f5(float) f6(float) f7(double)

double: f1(double) f2(double) f3(double) f4(double)

f5(double) f6(double) f7(double)

**/*

The constant value 5 is treated as an **int**, so if an overloaded method is available that takes an **int**, it is used. In all other cases, if you have a data type that is smaller than the argument in the method, that data type is promoted. **char** produces a slightly different effect, since if it doesn't find an exact **char** match, it is promoted to **int**.

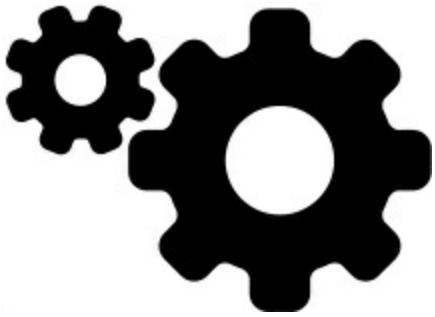
What happens if your argument is *bigger* than the argument expected by the method? An example gives the answer:

```
// housekeeping/Demotion.java
// Demotion of primitives
public class Demotion {
void f1(double x) {
System.out.println("f1(double)");
```

```
}
void f2(float x) { System.out.println("f2(float)"); }
void f3(long x) { System.out.println("f3(long)"); }
void f4(int x) { System.out.println("f4(int)"); }
void f5(short x) { System.out.println("f5(short)"); }
void f6(byte x) { System.out.println("f6(byte)"); }
void f7(char x) { System.out.println("f7(char)"); }
void testDouble() {
double x = 0;
System.out.println("double argument:");
f1(x);
f2((float)x);
f3((long)x);
f4((int)x);
f5((short)x);
f6((byte)x);
f7((char)x);
}
public static void main(String[] args) {
Demotion p = new Demotion();
```

```
p.testDouble();
}
}
/* Output:
double argument:
f1(double)
f2(float)
f3(long)
f4(int)
f5(short)
f6(byte)
f7(char)
*/
```

If your argument is wider than what the method expects, you must



perform a narrowing conversion with a cast. If you don’t do this, the compiler will issue an error message.

Overloading on Return Values

It is common to wonder, “Why only class names and method argument lists? Why not distinguish between methods based on their return values?” For example, these two methods, which have the same name and arguments, are easily distinguished from each other:

```
void f() {}
int f() { return 1; }
```

This might work fine as long as the compiler could unequivocally determine the meaning from the context, as in **int x = f()**.

However, you can also call a method and ignore the return value. This is *calling a method for its side effect*, since you don’t care about the return value, but instead want the other effects of the method call. So if you call the method this way:

f();

how can Java determine which **f()** should be called? And how could someone reading the code see it? Because of this sort of problem, you cannot use return value types to distinguish overloaded methods. To support new features, Java 8 has added better guessing in some specialized situations, but in general it doesn't work.

No-arg Constructors

As mentioned previously, a no-arg constructor is one without arguments, used to create a "default object." If you create a class that has no constructors, the compiler will automatically create a no-arg constructor for you. For example:

```
// housekeeping/DefaultConstructor.java
class Bird {}
public class DefaultConstructor {
public static void main(String[] args) {
Bird b = new Bird(); // Default!
}
}
```

The expression

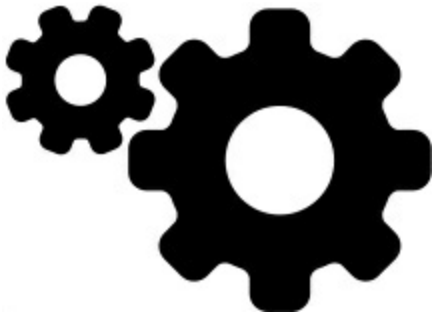
```
new Bird()
```

creates a new object and calls the no-arg constructor, even though one was not explicitly defined. Without it, you have no method call to build the object. However, if you define any constructors (with or without arguments), the compiler will *not* synthesize one for you:

```
// housekeeping/NoSynthesis.java
class Bird2 {
Bird2(int i) {}
Bird2(double d) {}
}
public class NoSynthesis {
public static void main(String[] args) {
//- Bird2 b = new Bird2(); // No default
Bird2 b2 = new Bird2(1);
Bird2 b3 = new Bird2(1.0);
}
}
```

If you say:

```
new Bird2()
```



the compiler complains it cannot find a constructor that matches.

When you don't put in any constructors, it's as if the compiler says, "You are bound to need *some* constructor, so let me make one for you." But if you write a constructor, the compiler says, "You've written a constructor so you know what you're doing; if you didn't put in a default it's because you meant to leave it out."

The this Keyword

For two objects of the same type called **a** and **b**, you might wonder how you can call a method **peel()** for both those objects:

```
// housekeeping/BananaPeel.java
class Banana { void peel(int i) { /* ... */ } }
public class BananaPeel {
public static void main(String[] args) {
Banana a = new Banana(),
b = new Banana();
a.peel(1);
```

```
b.peel(2);
}
}
```

If there's only one method called **peel()**, how can that method know whether it's called for the object **a** or **b**?

The compiler does some undercover work so you can write code this way. There's a secret first argument passed to the method **peel()**, and that argument is the reference to the object that's being manipulated. So the two method calls become something like:

```
Banana.peel(a, 1);
Banana.peel(b, 2);
```

This is internal and you can't write these expressions and get the compiler to accept them, but it gives you an idea of what's happening. Suppose you're inside a method and you'd like to get the reference to the current object. However, that reference is passed *secretly* by the compiler—it's not in the argument list. Conveniently, there's a keyword: **this**. The **this** keyword can be used only inside a non-**static** method. When you call a method on an object, **this** produces a reference to that object. You can treat the reference just like any other object reference. If you're calling a method of your class

from within another method of your class, don't use **this**. Simply call the method. The current **this** reference is automatically used for the other method. Thus you can say:

```
// housekeeping/Apricot.java
public class Apricot {
void pick() { /* ... */ }
void pit() { pick(); /* ... */ }
}
```

Inside **pit()**, you *could* say **this.pick()** but there's no need.1 The compiler does it for you automatically. The **this** keyword is used only for those special cases where you must explicitly use the reference to the current object. For example, it's often used in **return** statements for returning the reference to the current object:

```
// housekeeping/Leaf.java
// Simple use of the "this" keyword
public class Leaf {
int i = 0;
Leaf increment() {
i++;
return this;
```

```
}
void print() {
System.out.println("i = " + i);
}
public static void main(String[] args) {
Leaf x = new Leaf();
x.increment().increment().increment().print();
}
}
/* Output:
i = 3
*/
```

Because **increment()** returns the reference to the current object via the **this** keyword, multiple operations can easily be performed on the same object.

The **this** keyword is also useful for passing the current object to another method:

```
// housekeeping/PassingThis.java
class Person {
public void eat(Apple apple) {
```

```
Apple peeled = apple.getPeeled();
System.out.println("Yummy");
}
}
class Peeler {
static Apple peel(Apple apple) {
// ... remove peel
return apple; // Peeled
}
}
class Apple {
Apple getPeeled() { return Peeler.peel(this); }
}
public class PassingThis {
public static void main(String[] args) {
new Person().eat(new Apple());
}
```

}

/ *Output:*

Yummy

**/*

Apple calls **Peeler.peel()**, a foreign utility method to perform an operation that, for some reason, must be external to **Apple** (perhaps the external method can be applied across many different classes, and you don't want to repeat the code). To pass itself to the foreign method, it must use **this**.

Calling Constructors from Constructors

When you write several constructors for a class, there are times when you'd like to call one constructor from another to avoid duplicating code. You can make such a call by using the **this** keyword. Normally, when you say **this**, it is in the sense of "this object" or "the current object," and by itself it produces the reference to the current object. Inside a constructor, the **this** keyword takes on a different meaning when you give it an argument list. It makes an explicit call to the constructor that matches that argument list, and so is a straightforward way to call other constructors:

```
// housekeeping/Flower.java
// Calling constructors with "this"
public class Flower {
int petalCount = 0;
String s = "initial value";
Flower(int petals) {
petalCount = petals;
System.out.println(
"Constructor w/ int arg only, petalCount= "
+ petalCount);
}
Flower(String ss) {
System.out.println(
"Constructor w/ String arg only, s = " + ss);
s = ss;
}
Flower(String s, int petals) {
this(petals);
//- this(s); // Can't call two!
this.s = s; // Another use of "this"
```

```
System.out.println("String & int args");
}
Flower() {
this("hi", 47);
System.out.println("no-arg constructor");
}
void printPetalCount() {
//- this(11); // Not inside non-constructor!
System.out.println(
"petalCount = " + petalCount + " s = "+ s);
}
public static void main(String[] args) {
Flower x = new Flower();
x.printPetalCount();
}
}
/* Output:
Constructor w/ int arg only, petalCount= 47
String & int args
no-arg constructor
```

petalCount = 47 s = hi

/

The constructor **Flower(String s, int petals)** shows that,

while you can call one constructor using **this**, you cannot call two. In addition, the constructor call must be the first thing you do, or you'll get a compiler error message.

This example also shows another way you'll see **this** used. Since the

name of the argument **s** and the name of the member data **s** are the same, there's an ambiguity. You can resolve it using **this.s**, to say that you're referring to the member data. You'll often see this form used in Java code, and it's used in numerous places in this book.

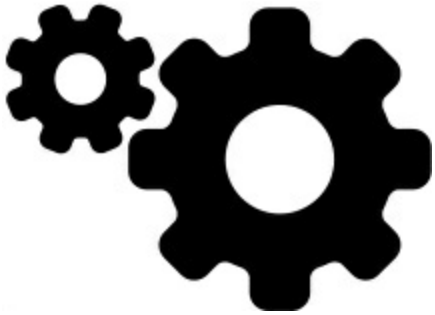
In **printPetalCount()**, the compiler won't let you call a constructor from inside any method other than a constructor.

The Meaning of static

With the **this** keyword in mind, you can more fully understand what it means to make a method **static**: There is no **this** for that particular method. You cannot call non-**static** methods from inside

static methods2 (although the reverse is possible), and you can call a **static** method for the class itself, without any object. In fact, that's the primary purpose of a **static** method. It's as if you're creating the equivalent of a global method. However, global methods are not permitted in Java, and putting the **static** method inside a class allows it access to other **static** methods and to **static** fields.

Some people argue that **static** methods are not object-oriented, since they do have the semantics of a global method; with a **static** method, you don't send a message to an object, since there's no **this**. This is a fair argument, and if you find yourself using a *lot* of **static** methods, rethink your strategy. However, **static**s are pragmatic, and there are times when you genuinely need them, so whether or not they are "proper OOP" should be left to the theoreticians.



Cleanup: Finalization and Garbage Collection

Programmers know the importance of initialization, but often forget the importance of cleanup. After all, who cleans up an **int**? But "letting go" of an object once you're done with it is not always safe. Java does have the garbage collector to reclaim the memory of objects that are no longer used. But now consider an unusual case: Suppose your object allocates "special" memory without using **new**. The garbage collector only knows how to release memory allocated *with* **new**, so it won't know how to release the object's "special" memory. To handle this case, Java provides a method called **finalize()** you can define for your class.

Here's how it's *supposed* to work: When the garbage collector is ready to release the storage used for your object, it first calls **finalize()**, and only on the next garbage-collection pass will it reclaim the object's memory. So if you choose to use **finalize()**, it gives you the ability to perform some important cleanup *at the time of garbage collection*.

finalize() is a potential programming pitfall because some programmers, especially C++ programmers, might initially mistake it for the *destructor* in C++, a function that is *always* called when an object is destroyed. It is important to distinguish between C++ and Java here, because in C++, *objects always get destroyed* (in a bug-free

program), whereas in Java, objects do not always get garbage collected. Or, put another way:

1. Your objects might not get garbage

collected.

2. Garbage collection is not destruction.

If there is some activity to perform before you no longer need an object, you must perform that activity yourself. Java has no destructor or similar concept, so you must create an ordinary method to perform this cleanup. For example, suppose that in the process of creating your object, it draws itself on the screen. If you don't explicitly erase its image from the screen, it might never get cleaned up. If you put some kind of erasing functionality inside **finalize()**, then if an object is garbage collected and **finalize()** is called (and there's no guarantee this will happen), the image will first be removed from the screen, but if it isn't, the image will remain.

You might find that the storage for an object never gets released because your program never nears the point of running out of storage.

If your program completes and the garbage collector never gets around to releasing the storage for any of your objects, that storage is returned to the operating system *en masse* as the program exits. This is a good thing, because garbage collection has some overhead, and if you never do it, you never incur that expense.

What is finalize() for?

So, if you can't use **finalize()** as a general-purpose cleanup method, what good is it?

A third point to remember is:

3. Garbage collection is only about memory.

That is, the sole reason for the existence of the garbage collector is to

recover memory your program is no longer using. So any activity associated with garbage collection, most notably your **finalize()** method, must also be only about memory and its deallocation.

Does this mean that if your object contains other objects, **finalize()** should explicitly release those objects? Well, no—the

garbage collector takes care of the release of all object memory regardless of how the object is created. The need for **finalize()** is limited to special cases where your object can allocate storage in some way other than creating an object. But, you might observe, everything in Java is an object, so how can this be?

It would seem that **finalize()** is in place because you might do something C-like by allocating memory using a mechanism other than the normal one in Java. This can happen primarily through *native methods*, which are a way to call non-Java code from Java (Native methods are covered in Appendix B of the electronic 2nd edition of *Thinking in Java*, available at www.OnJava8.com). C and C++ are the only languages currently supported by native methods, but since those languages can call subprograms in other languages, you can effectively call anything. Inside the non-Java code, C's **malloc()** family of functions might be called to allocate storage, and unless you call **free()**, that storage is not released, causing a memory leak.

However, **free()** is a C and C++ function, so you'd call it in a native method inside your **finalize()**.

After reading this, you probably get the idea you won't use **finalize()** much. [3] You're correct; it is not the appropriate place for normal cleanup to occur. So where should normal cleanup be

performed?

You Must Perform Cleanup

To clean up an object, the user of that object must call a cleanup method when cleanup is desired. This sounds pretty straightforward, but it collides a bit with the C++ concept of the destructor. In C++, all objects are destroyed. Or rather, all objects *should be* destroyed. If the C++ object is created as a local (i.e., on the stack—not possible in Java), the destruction happens at the closing curly brace of the scope where the object was created. If the object was created using **new** (like in Java), the destructor is called when the programmer calls the C++ operator **delete** (which doesn't exist in Java). If the C++ programmer forgets to call **delete**, the destructor is never called, and you have a memory leak, plus the other parts of the object never get cleaned up. This kind of bug can be very difficult to track down, and is one of the compelling reasons to move from C++ to Java.
In contrast, Java doesn't allow you to create local objects—you must always use **new**. But in Java, there's no "delete" for releasing the

object, because the garbage collector releases the storage for you. So from a simplistic standpoint, you can say that because of garbage collection, Java has no destructor. You'll see as this book progresses, however, that the presence of a garbage collector does not remove the need for or the utility of destructors. (And never call **finalize()** directly, so that's not a solution.) If you want some kind of cleanup performed other than storage release, you must *still* explicitly call an appropriate method in Java: the equivalent of a C++ destructor but without the convenience.

Remember that neither garbage collection nor finalization is guaranteed. If the JVM isn't close to running out of memory, it might not waste time recovering memory through garbage collection.

The Termination Condition

In general, you can't rely on **finalize()** being called, and you must create separate "cleanup" methods and call them explicitly. So it appears that **finalize()** is only useful for obscure memory cleanup that most programmers will never use. However, there is an interesting use of **finalize()** that does not rely on it being called every time. This is the verification of the *termination condition*[4] of an object. When you're no longer interested in an object—when it's ready to be

cleaned up—that object should be in a state whereby its memory can be safely released. For example, if the object represents an open file, that file should be closed by the programmer before the object is garbage collected. If any portions of the object are not properly cleaned up, you have a bug in your program that can be very difficult to find. **finalize()** can eventually discover this condition, even if it isn't always called. If one of the finalizations happens to reveal the bug, you discover the problem, which is all you really care about. Here's a simple example of how you might use it:

```
// housekeeping/TerminationCondition.java
// Using finalize() to detect an object that
// hasn't been properly cleaned up
import onjava.*;
class Book {
boolean checkedOut = false;
Book(boolean checkOut) {
checkedOut = checkOut;
}
void checkIn() {
checkedOut = false;
```

```
}
@Override
public void finalize() {
if(checkedOut)
System.out.println("Error: checked out");
// Normally, you'll also do this:
// super.finalize(); // Call the base-class version
}
}
public class TerminationCondition {
public static void main(String[] args) {
Book novel = new Book(true);
// Proper cleanup:
novel.checkIn();
// Drop the reference, forget to clean up:
new Book(true);
// Force garbage collection & finalization:
System.gc();
new Nap(1); // One second delay
}
```

}

/ *Output:*

Error: checked out

**/*

The termination condition says that all **Book** objects must be checked in before they are garbage collected, but **main()** doesn't check in one of the books. Without **finalize()** to verify the termination condition, this can be a difficult bug to find.

You see here the use of **@Override**. The **@** indicates an *annotation*, which is extra information about the code. Here, it tells the compiler you aren't *accidentally* redefining the **finalize()** method that is in every object—you know you're doing it. The compiler makes sure you haven't misspelled the method name, and that the method actually exists in the base class. The annotation is also a reminder to the reader. **@Override** was introduced in Java 5, and modified in Java 7, and I use it throughout the book.

Note that **System.gc()** is used to force finalization. But even if it isn't, it's highly probable that the errant **Book** will eventually be discovered through repeated executions of the program (assuming the program allocates enough storage to cause the garbage collector to

execute).

Assume that the base-class version of **finalize()** does something important, and call it using **super**, as you see in **Book.finalize()**. It is commented because it requires exception handling, which we haven't covered yet.

How a Garbage Collector Works

If you come from a programming language where allocating objects on the heap is expensive, you might naturally assume that Java's scheme of allocating everything (except primitives) on the heap is also expensive. However, the garbage collector can significantly *increase* the speed of object creation. This might sound a bit odd at first—that storage release affects storage allocation—but it's the way some JVMs work, and it means allocating storage for heap objects in Java can be nearly as fast as creating storage *on the stack* in other languages.

For example, you can think of the C++ heap as a yard where each object stakes out its own piece of turf. This real estate can become

abandoned sometime later and must be reused. In some JVMs, the Java heap is different; it's more like a conveyor belt that moves forward every time you allocate a new object. This means object storage allocation is remarkably rapid. The "heap pointer" is simply moved forward into virgin territory, so it's effectively the same as C++'s stack allocation. (There's some extra overhead for bookkeeping, but it's nothing like searching for storage.)

You might observe that the heap isn't in fact a conveyor belt, and if you treat it that way, you'll start paging memory—moving it on and off disk, so it appears there's more memory than actually exists. Paging significantly impacts performance. Eventually, after you create enough objects, you'll run out of memory. The trick is that the garbage collector steps in and collects the garbage. While it does this, it also compacts all the objects in the heap so you've effectively moved the "heap pointer" closer to the beginning of the conveyor belt and farther away from a page fault. The garbage collector rearranges things and makes it possible for the high-speed, infinite-free-heap model while allocating storage.

To understand garbage collection in Java, it's helpful to learn how garbage-collection schemes work in other systems. A simple but slow

garbage-collection technique is called *reference counting*. This means each object contains a reference counter, and every time a reference is attached to that object, the reference count is increased. Every time a reference goes out of scope or is set to **null**, the reference count is decreased. Thus, managing reference counts is a small but constant overhead that happens throughout the lifetime of your program. The garbage collector moves through the entire list of objects, and when it finds one with a reference count of zero it releases that storage (however, reference counting schemes often release an object as soon as the count goes to zero). The one drawback is that if objects circularly refer to each other they can have nonzero reference counts while still being garbage. Locating such self-referential groups requires significant extra work for the garbage collector. Reference counting is commonly used to explain one kind of garbage collection, but it doesn't seem to be in any JVM implementations.

Faster schemes do not use reference counting, but are based instead on the idea that any non-dead object must ultimately be traceable back to a reference that lives either on the stack or in static storage. The chain might go through several layers of objects. Thus, if you start in the stack and in the static storage area and walk through all the

references, you'll find all the live objects. For each reference you find, you must trace into the object that it points to, then follow all the references in *that* object, tracing into the objects they point to, etc., until you've moved through the entire web that originated with the reference on the stack or in static storage. Each object you move through must still be alive. Note there is no problem with detached self-referential groups—these are simply not found, and are therefore automatically garbage.

In the approach described here, the JVM uses an *adaptive* garbage-collection scheme, and what it does with the live objects it locates depends on the variant currently used. One of these variants is *stop-and-copy*. This means—for reasons that become apparent—the program is first stopped (this is not a background collection scheme). Then, each live object is copied from one heap to another, leaving behind all the garbage. In addition, as the objects are copied into the new heap, they are packed end-to-end, thus compacting the new heap (and allowing new storage to be reeled off the end as previously described).

When an object is moved from one place to another, all references that point to the object must be changed. The reference that goes from the

stack or the static storage area to the object can be changed right away, but there can be other references pointing to this object encountered later during the “walk.” These are fixed up as they are found (imagine a table that maps old addresses to new ones).

There are two issues that make these so-called “copy collectors” inefficient. The first is the idea that you have two heaps and you slosh all the memory back and forth between these two separate heaps, maintaining twice as much memory as you actually need. Some JVMs deal with this by allocating the heap in chunks as needed and copying from one chunk to another.

The second issue is the copying process itself. Once your program becomes stable, it might be generating little or no garbage. Despite that, a copy collector will still copy all the memory from one place to another, which is wasteful. To prevent this, some JVMs detect that no new garbage is generated and switch to a different variant (this is the “adaptive” part). This other variant is called *mark-and-sweep*, and it’s what earlier versions of Sun’s JVM used all the time. For general use, mark-and-sweep is fairly slow, but when you know you’re generating little or no garbage, it’s fast.

Mark-and-sweep follows the same logic of starting from the stack and

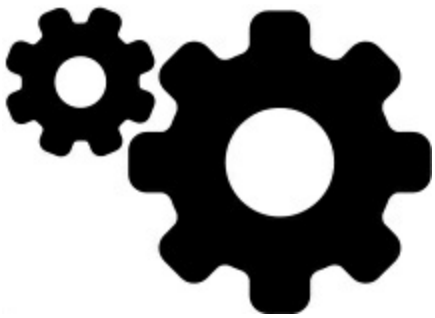
static storage, and tracing through all the references to find live objects. However, each time it finds a live object, that object is marked by setting a flag in it—the object isn't collected yet. Only when the marking process is finished does the sweep occur. During the sweep, the dead objects are released. However, no copying happens, so if the collector chooses to compact a fragmented heap, it does so by shuffling objects around.

"Stop-and-copy" refers to the idea that this type of garbage collection is *not* done in the background; instead, the program is stopped while the garbage collection occurs. In the Oracle literature you'll find many references to garbage collection as a low-priority background process, but garbage collection was not implemented that way in earlier versions of the JVM. Instead, the garbage collector stopped the program when memory got low. Mark-and-sweep also requires that the program be stopped.

As previously mentioned, in the JVM described here memory is allocated in big blocks. If you allocate an especially large object, it gets its own block. Strict stop-and-copy requires copying every live object from the source heap to a new heap before you can free the old one, which translates to lots of memory. With blocks, the garbage collection

can typically copy objects to dead blocks as it collects. Each block has a *generation count* to keep track of whether it's alive. In the normal case, only the blocks created since the last garbage collection are compacted; all other blocks get their generation count bumped if they are referenced from somewhere. This handles the normal case of lots of short-lived temporary objects. Periodically, a full sweep is made—large objects are still not copied (they just get their generation count bumped), and blocks containing small objects are copied and compacted. The JVM monitors the efficiency of garbage collection and if it becomes a waste of time because all objects are long-lived, it switches to mark-and-sweep. Similarly, the JVM keeps track of how successful mark-and-sweep is, and if the heap starts to become fragmented, it switches back to stop-and-copy. This is where the "adaptive" part comes in, so you end up with a mouthful: "Adaptive generational stop-and-copy mark-and-sweep."

There are a number of additional speedups possible in a JVM. An



especially important one involves the operation of the loader and what is called a *just-in-time* (JIT) compiler. A JIT compiler partially or fully converts a program into native machine code so it doesn't need interpretation by the JVM and thus runs much faster. When a class must be loaded (typically, the first time you create an object of that class), the **.class** file is located, and the bytecodes for that class are brought into memory. You could simply JIT compile all the loaded code, but this has two drawbacks: It takes a little more time, which, compounded throughout the life of the program, can add up; and it increases the size of the executable (bytecodes are significantly more compact than expanded JIT code), and this might cause paging, which definitely slows down a program. An alternative approach is *lazy evaluation*, which means the code is not JIT compiled until necessary. Thus, code that never gets executed might never be JIT compiled. The Java HotSpot technologies in recent JDKs take a similar approach by increasingly optimizing a piece of code each time it is executed, so the more the code is executed, the faster it gets.

Member Initialization

Java goes out of its way to guarantee that variables are properly initialized before they are used. In the case of a method's local

variables, this guarantee comes in the form of a compile-time error. So

if you say:

```
void f() {
int i;
i++;
}
```

you'll get an error message that says that **i** might not be initialized.

The compiler could give **i** a default value, but an uninitialized local

variable is probably a programmer error, and a default value would

cover that up. Forcing the programmer to provide an initialization

value is more likely to catch a bug.

If a primitive is a field in a class, however, things are a bit different. As you saw in the Objects Everywhere chapter, each primitive field of a class is guaranteed to get an initial value. Here's a program that

verifies this, and shows the values:

```
// housekeeping/InitialValues.java
// Shows default initial values
public class InitialValues {
boolean t;
char c;
byte b;
```

```
short s;
int i;
long l;
float f;
double d;
InitialValues reference;
void printInitialValues() {
System.out.println("Data type Initial value");
System.out.println("boolean " + t);
System.out.println("char [" + c + "]");
System.out.println("byte " + b);
System.out.println("short " + s);
System.out.println("int " + i);
System.out.println("long " + l);
System.out.println("float " + f);
System.out.println("double " + d);
System.out.println("reference " + reference);
}
public static void main(String[] args) {
new InitialValues().printInitialValues();
```

```
}
}
/* Output:
Data type Initial value
boolean false
char [NUL]
byte 0
short 0
int 0
long 0
```

```
float 0.0
double 0.0
reference null
*/
```

Even though the values are not specified, they automatically get initialized (the **char** value is a zero, which my output verification system translates to **NUL**). So at least there's no threat of working with

uninitialized variables.

When you define an object reference inside a class without initializing it to a new object, that reference is given a special value of **null**.

Specifying Initialization

How do you give a variable an initial value? One direct way to do this is to assign the value when you define the variable in the class. Here the field definitions in class **InitialValues** are changed to provide initial values:

```
// housekeeping/InitialValues2.java
// Providing explicit initial values
public class InitialValues2 {
boolean bool = true;
char ch = 'x';
byte b = 47;
short s = 0xff;
int i = 999;
long lng = 1;
float f = 3.14f;
double d = 3.14159;
}
```

You can also initialize non-primitive objects in this same way. If **Depth** is a class, you can create a variable and initialize it like so:

```
// housekeeping/Measurement.java
class Depth {}
public class Measurement {
Depth d = new Depth();
// ...
}
```

If you haven't given **d** an initial value and you try to use it anyway, you'll get a runtime error called an *exception* (covered in the Exceptions chapter).

You can call a method to provide an initialization value:

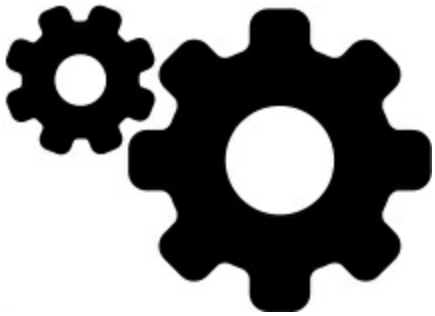
```
// housekeeping/MethodInit.java
public class MethodInit {
int i = f();
int f() { return 11; }
}
```

This method can have arguments, but those arguments cannot be other class members that haven't been initialized yet. Thus, you can do this:

```
// housekeeping/MethodInit2.java
public class MethodInit2 {
int i = f();
int j = g(i);
int f() { return 11; }
int g(int n) { return n * 10; }
}
```

But you cannot do this:

```
// housekeeping/MethodInit3.java
public class MethodInit3 {
//- int j = g(i); // Illegal forward reference
int i = f();
int f() { return 11; }
int g(int n) { return n * 10; }
}
```



The compiler appropriately complains about forward referencing, since it is about the order of initialization and not the way the program is compiled.

This approach to initialization is simple and straightforward. It has the limitation that *every* object of type **InitialValues** will get these

same initialization values. Sometimes this is exactly what you need, but at other times you need more flexibility.

Constructor

Initialization

The constructor performs initialization, and this gives you greater flexibility in your programming because you can call methods at run time to determine initial values. However, you aren't precluding automatic initialization, which happens before the constructor is entered. So, for example, if you say:

```
// housekeeping/Counter.java
public class Counter {
int i;
Counter() { i = 7; }
// ...
}
```

then **i** will first be initialized to 0, then to 7. This is true with all the primitive types and with object references, including those given explicit initialization at the point of definition. For this reason, the compiler doesn't try to force you to initialize elements in the constructor at any particular place, or before they are used—

initialization is already guaranteed.

Order of Initialization

The order variables are defined within a class determines the order of initialization. The variable definitions can be scattered throughout and in between method definitions, but the variables are initialized before any methods can be called—even the constructor. For example:

```
// housekeeping/OrderOfInitialization.java
// Demonstrates initialization order
// When the constructor is called to create a
// Window object, you'll see a message:
class Window {
Window(int marker) {
System.out.println("Window(" + marker + ")");
}
}
class House {
Window w1 = new Window(1); // Before constructor
House() {
// Show that we're in the constructor:
System.out.println("House()");
```

```
w3 = new Window(33); // Reinitialize w3
}
Window w2 = new Window(2); // After constructor
void f() { System.out.println("f()"); }
Window w3 = new Window(3); // At end
}
public class OrderOfInitialization {
public static void main(String[] args) {
House h = new House();
h.f(); // Shows that construction is done
}
}
/* Output:
Window(1)
Window(2)
Window(3)
House()
Window(33)
f()
*/
```

In **House**, the definitions of the **Window** objects are intentionally scattered about to prove they'll all get initialized before the constructor is entered or anything else can happen. In addition, **w3** is reinitialized inside the constructor.

The output shows that the **w3** reference gets initialized twice: once before and once during the constructor call (The first object is dropped, so it can be garbage collected later). This might not seem efficient at first, but it guarantees proper initialization. Consider what would happen if an overloaded constructor were defined that did *not* initialize **w3** and there wasn't a "default" initialization for **w3** in its definition.

static Data Initialization

There's only a single piece of storage for a **static**, regardless of how many objects are created. You can't apply the **static** keyword to local variables, so it only applies to fields. If a field is a **static** primitive and you don't initialize it, it gets the standard initial value for its type. If it's a reference to an object, the default initialization value is

null.

To place initialization at the point of definition, it looks the same as for non-**static**s.

This shows *when* **static** storage gets initialized:

```
// housekeeping/StaticInitialization.java
// Specifying initial values in a class definition
class Bowl {
Bowl(int marker) {
System.out.println("Bowl(" + marker + ")");
}
void f1(int marker) {
System.out.println("f1(" + marker + ")");
}
}
class Table {
static Bowl bowl1 = new Bowl(1);
Table() {
System.out.println("Table()");
bowl2.f1(1);
}
```

```
void f2(int marker) {
System.out.println("f2(" + marker + ")");
}
static Bowl bowl2 = new Bowl(2);
}
class Cupboard {
Bowl bowl3 = new Bowl(3);
static Bowl bowl4 = new Bowl(4);
Cupboard() {
System.out.println("Cupboard()");
bowl4.f1(2);
}
void f3(int marker) {
System.out.println("f3(" + marker + ")");
}
static Bowl bowl5 = new Bowl(5);
}
public class StaticInitialization {
public static void main(String[] args) {
System.out.println("main creating new Cupboard()");
```

```
new Cupboard();
System.out.println("main creating new Cupboard()");
new Cupboard();
table.f2(1);
cupboard.f3(1);
}
static Table table = new Table();
static Cupboard cupboard = new Cupboard();
}
/* Output:
Bowl(1)
Bowl(2)
Table()
f1(1)
Bowl(4)
Bowl(5)
Bowl(3)
Cupboard()
f1(2)
main creating new Cupboard()
```

Bowl(3)

Cupboard()

f1(2)

main creating new Cupboard()

Bowl(3)

Cupboard()

f1(2)

f2(1)

f3(1)

**/*

Bowl shows the creation of a class, and **Table** and **Cupboard** have

static members of **Bowl** scattered through their class definitions.

Note that **Cupboard** creates a non-**static Bowl bowl3** prior to

the **static** definitions.

The output shows that **static** initialization occurs only if it's

necessary. If you don't create a **Table** object and you never refer to

Table.bowl1 or **Table.bowl2**, the **static Bowl bowl1** and

bowl2 will never be created. They are initialized only when you create

the *first* **Table** object (or the first **static** access occurs). After that, the **static** objects are not reinitialized.

The order of initialization is **static**s first, if they haven't already

been initialized by a previous object creation, then the non-**static** objects. The evidence is in the output. To execute **main()** (a **static** method), the **StaticInitialization** class must be loaded, and its **static** fields **table** and **cupboard** are then initialized, which causes *those* classes to be loaded, and since they both contain **static** **Bowl** objects, **Bowl** is then loaded. Thus, all the classes in this particular program get loaded before **main()** starts. This is usually not the case, because in typical programs you won't have everything linked together by **static**s as you do in this example.

To summarize the process of creating an object, consider a class called **Dog**:

1. Even though it doesn't explicitly use the **static** keyword, the constructor is actually a **static** method. So the first time you create an object of type **Dog**, *or* the first time you access a **static** method or **static** field of class **Dog**, the Java interpreter must locate **Dog.class**, which it does by searching through the classpath.
2. As **Dog.class** is loaded (creating a **Class** object, which you'll learn about later), all of its **static** initializers are run. Thus, **static** initialization takes place only once, as the **Class** object is loaded for the first time.

3. When you create a **new Dog()**, the construction process for a **Dog** object first allocates enough storage for a **Dog** object on the heap.

4. This storage is wiped to zero, automatically setting all the primitives in that **Dog** object to their default values (zero for numbers and the equivalent for **boolean** and **char**) and the

references to **null**.

5. Any initializations that occur at the point of field definition are executed.

6. Constructors are executed. As you shall see in the Reuse chapter, this might actually involve a fair amount of activity, especially when inheritance is involved.

Explicit static Initialization

You can group other **static** initializations inside a special "**static** clause" (sometimes called a *static block*) in a class. It looks like this:

```
// housekeeping/Spoon.java
public class Spoon {
```

```
static int i;
static {
i = 47;
}
}
```

It looks a little like a method, but it’s just the **static** keyword followed by a block of code. This code, like other **static** initializations, is executed only once: the first time you make an object of that class *or* the first time you access a **static** member of that class (even if you never make an object of that class). For example:

```
// housekeeping/ExplicitStatic.java
// Explicit static initialization with "static" clause
class Cup {
Cup(int marker) {
System.out.println("Cup(" + marker + ")");
}
void f(int marker) {
```

```
System.out.println("f(" + marker + ")");
}
}
class Cups {
static Cup cup1;
static Cup cup2;
static {
cup1 = new Cup(1);
cup2 = new Cup(2);
}
Cups() {
System.out.println("Cups()");
}
}
public class ExplicitStatic {
public static void main(String[] args) {
System.out.println("Inside main()");
Cups.cup1.f(99); // [1]
}
// static Cups cups1 = new Cups(); // [2]
```

// static Cups cups2 = new Cups(); // [2]

}

/ *Output:*

Inside main()

Cup(1)

Cup(2)

f(99)

**/*

The **static** initializers for **Cups** run when either the access of the

static object **cup1** occurs on **[1]**, or if **[1]** is commented out and the lines marked **[2]** are uncommented. If both **[1]** and **[2]** are

commented out, the **static** initialization for **Cups** never occurs.

Also, it doesn't matter if one or both of the lines marked **[2]** are

uncommented; the static initialization only occurs once.

Non-static Instance

Initialization

Java provides a similar syntax, called *instance initialization*, for

initializing non-**static** variables for each object. Here's an example:

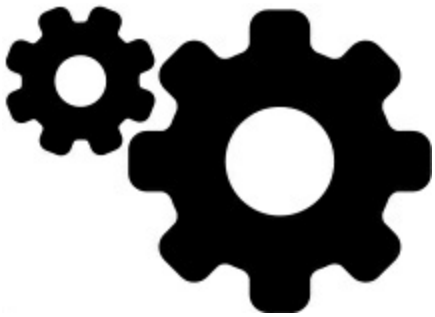
// housekeeping/Mugs.java

// Instance initialization

class Mug {

```
Mug(int marker) {
System.out.println("Mug(" + marker + ")");
}
}
public class Mugs {
Mug mug1;
Mug mug2;
{ // [1]
mug1 = new Mug(1);
mug2 = new Mug(2);
System.out.println("mug1 & mug2 initialized");
}
Mugs() {
System.out.println("Mugs()");
}
Mugs(int i) {
System.out.println("Mugs(int)");
}
public static void main(String[] args) {
System.out.println("Inside main()");
```

```
new Mugs();
System.out.println("new Mugs() completed");
new Mugs(1);
System.out.println("new Mugs(1) completed");
}
}
/* Output:
Inside main()
Mug(1)
Mug(2)
```



```
mug1 & mug2 initialized
Mugs()
new Mugs() completed
Mug(1)
Mug(2)
mug1 & mug2 initialized
```

Mugs(int)

new Mugs(1) completed

*/

[1] The instance initialization clause looks exactly like the static initialization clause except for the missing **static** keyword. This syntax is necessary to support the initialization of *anonymous inner classes* (see the Inner Classes chapter), but you can also guarantee that certain operations occur regardless of which explicit constructor is called.

The output shows that the instance initialization clause is executed before either one of the constructors.

Array Initialization

An array is a sequence of either objects or primitives that are all the same type and are packaged together under one identifier name. Arrays are defined and used with the square-brackets *indexing operator* **[]**. To define an array reference, you follow the type name with empty square brackets:

```
int[] a1;
```

You can also put the square brackets after the identifier to produce exactly the same meaning:

```
int a1[];
```

This conforms to expectations from C and C++ programmers. The former style, however, is probably a more sensible syntax, since it says that the type is “an **int** array.” That style is used in this book.

The compiler doesn’t allow you to tell it how big the array is. This brings us back to that issue of “references.” All you have now is a reference to an array (you’ve allocated enough storage for that reference), and there’s been no space allocated for the array object itself. To create storage for the array, you must write an initialization expression. For arrays, initialization can appear anywhere in your code, but you can also use a special kind of initialization expression that must occur when you create the array. This special initialization is a set of values surrounded by curly braces. The storage allocation (the equivalent of using **new**) is taken care of by the compiler in this case. For example:

```
int[] a1 = { 1, 2, 3, 4, 5 };
```

Why would you ever define an array reference without an array?

```
int[] a2;
```

Well, it’s possible to assign one array to another in Java, so you can say:

```
a2 = a1;
```

What you’re really doing is copying a reference, as demonstrated here:

```
// housekeeping/ArraysOfPrimitives.java
public class ArraysOfPrimitives {
public static void main(String[] args) {
int[] a1 = { 1, 2, 3, 4, 5 };
int[] a2;
a2 = a1;
for(int i = 0; i < a2.length; i++)
a2[i] += 1;
for(int i = 0; i < a1.length; i++)
System.out.println("a1[" + i + "] = " + a1[i]);
}
}
```

```
/* Output:
a1[0] = 2
a1[1] = 3
a1[2] = 4
```

a1[3] = 5

a1[4] = 6

**/*

a1 is given an initialization value but **a2** is not; **a2** is assigned later—here, to another array. Since **a2** and **a1** are then aliased to the same array, the changes made via **a2** are seen in **a1**.

All arrays have an intrinsic member (whether they're arrays of objects or arrays of primitives) you can query—but not change—to tell you how many elements there are in the array. This member is **length**. Since arrays in Java, just like C and C++, start counting from element zero, the largest element you can index is **length - 1**. If you go out of bounds, C and C++ quietly accept this and allow you to stomp all over your memory, which is the source of many infamous bugs. However, Java protects you against such problems by causing a runtime error (an *exception*) if you step out of bounds. 5

Dynamic Array Creation

What if you don't know how many elements you're going to need in your array while you're writing the program? You simply use **new** to create the elements in the array. Here, **new** works even though it's creating an array of primitives (**new** won't create a non-array

primitive):

```
// housekeeping/ArrayNew.java
// Creating arrays with new
import java.util.*;
public class ArrayNew {
public static void main(String[] args) {
int[] a;
Random rand = new Random(47);
a = new int[rand.nextInt(20)];
System.out.println("length of a = " + a.length);
System.out.println(Arrays.toString(a));
}
}
/* Output:
length of a = 18
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]
*/
```

The size of the array is chosen at random by using the **Random.nextInt()** method, which produces a value between zero and that of its argument. Because of the randomness, it’s clear that

array creation is actually happening at run time. In addition, the output of this program shows that array elements of primitive types are automatically initialized to “empty” values. (For numerics and **char**, this is zero, and for **boolean**, it’s **false**.)

The **Arrays.toString()** method, part of the standard **java.util** library, produces a printable version of a one-dimensional array.

The array can also be defined and initialized in the same statement:

int[] a = **new** int[rand.nextInt(20)];

This is the preferred way to do it, if you can.

If you create a non-primitive array, you create an array of references.

Consider the wrapper type **Integer**, which is a class and not a primitive:

```
// housekeeping/ArrayClassObj.java
// Creating an array of nonprimitive objects
import java.util.*;
public class ArrayClassObj {
public static void main(String[] args) {
Random rand = new Random(47);
Integer[] a = new Integer[rand.nextInt(20)];
```

```
System.out.println("length of a = " + a.length);
for(int i = 0; i < a.length; i++)
a[i] = rand.nextInt(500); // Autoboxing
System.out.println(Arrays.toString(a));
}
}
/* Output:
length of a = 18
[55, 193, 361, 461, 429, 368, 200, 22, 207, 288, 128,
51, 89, 309, 278, 498, 361, 20]
*/
```

Here, even after **new** is called to create the array:

```
Integer[] a = new Integer[rand.nextInt(20)];
```

it's only an array of references, and the initialization is not complete until the reference itself is initialized by creating a new **Integer** object (via autoboxing, in this case):

```
a[i] = rand.nextInt(500);
```

If you forget to create the object, however, you'll get an exception at run time when you try to use the empty array location.

It's also possible to initialize arrays of objects by using a curly brace-

enclosed list. There are two forms:

```
// housekeeping/ArrayInit.java
// Array initialization
import java.util.*;
public class ArrayInit {
public static void main(String[] args) {
Integer[] a = {
1, 2,
3, // Autoboxing
};
Integer[] b = new Integer[]{
1, 2,
3, // Autoboxing
};
System.out.println(Arrays.toString(a));
System.out.println(Arrays.toString(b));
}
}
/* Output:
[1, 2, 3]
```

[1, 2, 3]

/

In both cases, the final comma in the list of initializers is optional. (This feature makes for easier maintenance of long lists.)

Although the first form is useful, it's more limited because it can only be used at the point the array is defined. You can use the second and third forms anywhere, even inside a method call. For example, you can create an array of **String** objects to pass to the **main()** of another class, to provide alternate command-line arguments to that **main()**:

```
// housekeeping/DynamicArray.java
// Array initialization
public class DynamicArray {
public static void main(String[] args) {
Other.main(new String[]{ "fiddle", "de", "dum" });
}
}
class Other {
public static void main(String[] args) {
for(String s : args)
System.out.print(s + " ");
```

}

}

/ *Output:*

fiddle de dum

**/*

The array argument for **Other.main()** is created at the point of the method call, so you can even provide alternate arguments at the time of the call.

Variable Argument Lists

You create and call methods in a way that produces an effect similar to C's *variable argument lists* (known as "varargs" in C). These can include unknown quantities of arguments as well as unknown types. Since all classes are ultimately inherited from the common root class **Object** (a subject you learn more about as this book progresses), you can create a method that takes an array of **Object** and call it like this:

// housekeeping/VarArgs.java

// Using array syntax to create variable argument lists

```
class A {}
public class VarArgs {
static void printArray(Object[] args) {
for(Object obj : args)
System.out.print(obj + " ");
System.out.println();
}
public static void main(String[] args) {
printArray(new Object[]{
47, (float) 3.14, 11.11});
printArray(new Object[]{"one", "two", "three" });
printArray(new Object[]{new A(), new A(), new A()});
}
}
/* Output:
47 3.14 11.11
one two three
A@15db9742 A@6d06d69c A@7852e922
*/
```

printArray() takes an array of **Object**, then steps through the

array using the *for-in* syntax and prints each one. The standard Java library classes produce sensible output, but the objects of the classes created here print the class name, followed by an **@** sign and hexadecimal digits. Thus, the default behavior (if you don't define a **toString()** method for your class, which is described later in the book) is to print the class name and the address of the object.

You might see pre-Java 5 code written like the above to produce variable argument lists. In Java 5 this long-requested feature was finally added, so ellipses define a variable argument list, as in **printArray()**:

```
// housekeeping/NewVarArgs.java
// Using array syntax to create variable argument lists
public class NewVarArgs {
static void printArray(Object... args) {
for(Object obj : args)
System.out.print(obj + " ");
System.out.println();
}
public static void main(String[] args) {
// Can take individual elements:
```

```
printArray(47, (float) 3.14, 11.11);
printArray(47, 3.14F, 11.11);
printArray("one", "two", "three");
printArray(new A(), new A(), new A());
// Or an array:
printArray((Object[])new Integer[]{ 1, 2, 3, 4 });
printArray(); // Empty list is OK
}
}
/* Output:
47 3.14 11.11
47 3.14 11.11
one two three
A@15db9742 A@6d06d69c A@7852e922
1 2 3 4
*/
```

With varargs, you no longer explicitly write out the array syntax—the compiler will actually fill it in for you when you specify varargs. You're still getting an array, which is why **printArray()** is able to use *for-in* to iterate through the array. However, it's more than just an

automatic conversion from a list of elements to an array. Notice the second-to-last line in the program, where an array of **Integer** (created using autoboxing) is cast to an **Object** array (to remove a compiler warning) and passed to **printArray()**. Clearly, the compiler sees this is already an array and performs no conversion on it. So if you have a group of items you can pass them in as a list, and if you already have an array it will accept that as the variable argument list.

The last line of the program shows it's possible to pass zero arguments to a vararg list. This is helpful when you have optional trailing arguments:

```
// housekeeping/OptionalTrailingArguments.java
public class OptionalTrailingArguments {
static void f(int required, String... trailing) {
System.out.print("required: " + required + " ");
for(String s : trailing)
System.out.print(s + " ");
System.out.println();
}
public static void main(String[] args) {
```

```
f(1, "one");
f(2, "two", "three");
f(0);
}
}
/* Output:
required: 1 one
required: 2 two three
required: 0
*/
```

This also shows how you can use varargs with a specified type other than **Object**. Here, all the varargs must be **String** objects. It's possible to use any type of argument in varargs, including a primitive type. The following example also shows that the vararg list becomes an array, and if there's nothing in the list it's an array of size zero:

```
// housekeeping/VarargType.java
public class VarargType {
static void f(Character... args) {
System.out.print(args.getClass());
System.out.println(" length " + args.length);
```

```
}
static void g(int... args) {
System.out.print(args.getClass());
System.out.println(" length " + args.length);
}
public static void main(String[] args) {
f('a');
f();
g(1);
g();
System.out.println("int[]: " +
new int[0].getClass());
}
}
/* Output:
class [Ljava.lang.Character; length 1
class [Ljava.lang.Character; length 0
class [I length 1
class [I length 0
int[]: class [I
```

*/

The **getClass()** method is part of **Object**, and is explored fully in

the Type Information chapter. It produces the class of an object, and when you print this class, you see an encoded **String** representing

the class type. The leading **[** indicates this is an array of the type that follows. The **I** is for a primitive **int**; to double-check, I created an

array of **int** in the last line and printed its type. This verifies that

using varargs does not depend on autoboxing, but it actually uses the

primitive types.

Varargs work harmoniously with autoboxing:

```
// housekeeping/AutoboxingVarargs.java

public class AutoboxingVarargs {

public static void f(Integer... args) {

for(Integer i : args)

System.out.print(i + " ");

System.out.println();

}

public static void main(String[] args) {

f(1, 2);

f(4, 5, 6, 7, 8, 9);

f(10, 11, 12);
```

```
}
}
/* Output:
1 2
4 5 6 7 8 9
10 11 12
*/
```

Notice you can mix the types together in a single argument list, and autoboxing selectively promotes the **int** arguments to **Integer**.

Varargs complicate the process of overloading, although it seems safe enough at first:

```
// housekeeping/OverloadingVarargs.java
public class OverloadingVarargs {
static void f(Character... args) {
System.out.print("first");
for(Character c : args)
System.out.print(" " + c);
System.out.println();
}
static void f(Integer... args) {
```

```
System.out.print("second");
for(Integer i : args)
System.out.print(" " + i);
System.out.println();
}
static void f(Long... args) {
System.out.println("third");
}
public static void main(String[] args) {
f('a', 'b', 'c');
f(1);
f(2, 1);
f(0);
f(0L);
//- f(); // Won't compile -- ambiguous
}
}
/* Output:
first a b c
second 1
```

second 2 1

second 0

third

**/*

In each case, the compiler uses autoboxing to match the overloaded method, and calls the most specifically matching method.

But when you call **f()** without arguments, it has no way of knowing which one to call. Although this error is understandable, it will probably surprise the client programmer.

You might try solving the problem by adding a non-vararg argument to one of the methods:

```
// housekeeping/OverloadingVarargs2.java
// {WillNotCompile}
public class OverloadingVarargs2 {
static void f(float i, Character... args) {
System.out.println("first");
}
static void f(Character... args) {
System.out.print("second");
}
```

public static void main(String[] args) {

f(1, 'a');

f('a', 'b');

}

}

The **{WillNotCompile}** comment tag excludes the file from this book's Gradle build.

If you compile it by hand you'll see the error message:

OverloadingVarargs2.java:14: error: reference to f is ambiguous

f('a', 'b');

\^

both method f(float,Character...) in OverloadingVarargs2 and method f(Character...) in OverloadingVarargs2 match

1 error

If you give *both* methods a non-vararg argument, it works:

// housekeeping/OverloadingVarargs3.java

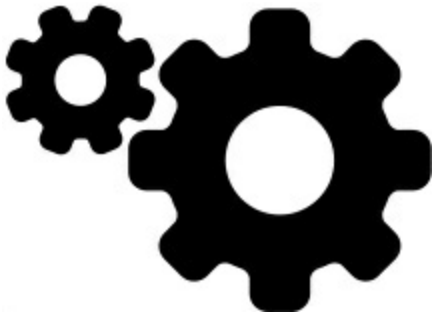
public class OverloadingVarargs3 {

static void f(float i, Character**...** args) {

System.out.println("first");

}

```
static void f(char c, Character... args) {
System.out.println("second");
}
public static void main(String[] args) {
```



```
f(1, 'a');
f('a', 'b');
}
}
/* Output:
first
second
*/
```

As a rule of thumb, only use a variable argument list on one version of an overloaded method. Or consider not doing it at all.

Enumerated Types

A seemingly small addition in Java 5 is the **enum** keyword, which

makes your life much easier when you group together and use a set of *enumerated types*. In the past you created a set of constant integral values, but these do not naturally restrict themselves to your set and thus are riskier and more difficult to use. Enumerated types are a common enough need that C, C++, and a number of other languages have always had them. Before Java 5, programmers were forced to know a lot and be quite careful when they wanted to properly produce the **enum** effect. Now Java has **enum**, too, and it's much more full-featured than what you find in C/C++. Here's a simple example:

```
// housekeeping/Spiciness.java
public enum Spiciness {
NOT, MILD, MEDIUM, HOT, FLAMING
}
```

This creates an enumerated type called **Spiciness** with five named values. Because the instances of enumerated types are constants, they are in all capital letters by convention (if there are multiple words in a name, they are separated by underscores).

To use an **enum**, you create a reference of that type and assign it to an instance:

```
// housekeeping/SimpleEnumUse.java
public class SimpleEnumUse {
```

public static void main(String[] args) {

Spiciness howHot = Spiciness.MEDIUM;

System.out.println(howHot);

}

}

/ *Output:*

MEDIUM

**/*

The compiler automatically adds useful features when you create an **enum**. For example, it creates a **toString()** to easily display the name of an **enum** instance, which is how the print statement above produced its output. The compiler also creates an **ordinal()** method to indicate the declaration order of a particular **enum** constant, and a **static values()** method that produces an array of values of the **enum** constants in the order they were declared:

// housekeeping/EnumOrder.java

public class EnumOrder {

public static void main(String[] args) {

for(Spiciness s : Spiciness.values())

System.out.println(

```
s + ", ordinal " + s.ordinal());
}
}
/* Output:
NOT, ordinal 0
MILD, ordinal 1
MEDIUM, ordinal 2
HOT, ordinal 3
FLAMING, ordinal 4
*/
```

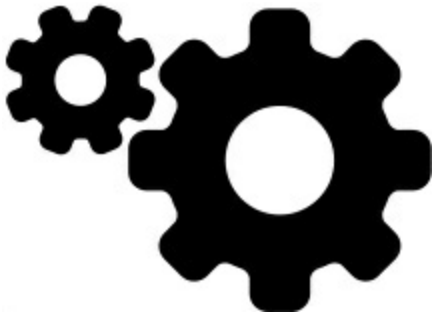
Although **enum**s appear to be a new data type, the keyword only produces some compiler behavior while generating a class for the **enum**, so in many ways you can treat an **enum** as if it were any other class. In fact, **enum**s *are* classes and have their own methods.

An especially nice feature is the way that **enum**s can be used inside **switch** statements:

```
// housekeeping/Burrito.java
public class Burrito {
Spiciness degree;
public Burrito(Spiciness degree) {
```

```
this.degree = degree;
}
public void describe() {
System.out.print("This burrito is ");
switch(degree) {
case NOT: System.out.println(
"not spicy at all.");
break;
case MILD:
case MEDIUM: System.out.println("a little hot.");
break;
case HOT:
case FLAMING:
default: System.out.println("maybe too hot.");
}
}
public static void main(String[] args) {
Burrito
plain = new Burrito(Spiciness.NOT),
greenChile = new Burrito(Spiciness.MEDIUM),
```

```
jalapeno = new Burrito(Spiciness.HOT);
plain.describe();
greenChile.describe();
jalapeno.describe();
}
}
/* Output:
```



```
This burrito is not spicy at all.
This burrito is a little hot.
This burrito is maybe too hot.
*/
```

Since a **switch** is intended to select from a limited set of possibilities, it's an ideal match for an **enum**. Notice how **enum** names can produce a much clearer expression of intent.

In general you can use an **enum** as if it were another way to create a data type, then just put the results to work. That's the point, so you

don’t have to think too hard about them. Before the introduction of **enum**, you went to a lot of effort to make an equivalent enumerated type that was safe to use.

This is enough for you to understand and use basic **enum**s, but we’ll look more deeply at them later in the book—they have their own chapter: Enumerations.

Summary

This seemingly elaborate mechanism for initialization, the constructor, should give you a strong hint about the critical importance placed on initialization in the language. As Bjarne Stroustrup, the inventor of C++, was designing that language, one of the first observations he made about productivity in C was that improper initialization of variables causes a significant portion of programming problems. These kinds of bugs are hard to find, and similar issues apply to improper cleanup. Because constructors allow you to *guarantee* proper initialization and cleanup (the compiler will not allow an object to be created without the proper constructor calls), you get complete control and safety.

In C++, destruction is quite important because objects created with **new** must be explicitly destroyed. In Java, the garbage collector

automatically releases the memory for all objects, so the equivalent cleanup method in Java isn't necessary much of the time (but when it is, you must do it yourself). In cases where you don't need destructor-like behavior, Java's garbage collector greatly simplifies programming and adds much-needed safety in managing memory. Some garbage collectors can even clean up other resources like graphics and file handles. However, the garbage collector does add a runtime cost, the expense of which is difficult to put into perspective because of the historical slowness of Java interpreters. Although Java has had significant performance increases over time, the speed problem has taken its toll on the adoption of the language for certain types of programming problems.

Because of the guarantee that all objects are constructed, there's actually more to the constructor than what is shown here. In particular, when you create new classes using either *composition* or *inheritance*, the guarantee of construction also holds, and some additional syntax is necessary to support this. You'll learn about composition, inheritance, and how they affect constructors in future chapters.

1. Some people will obsessively put **this** in front of every method

call and field reference, arguing that it makes it “clearer and more explicit.” Don’t do it. There’s a reason that we use high-level languages. They do things for us. If you use **this** when it’s not necessary, you confuse and annoy everyone who reads your code, since all the rest of the code they’ve read *won’t* use **this** everywhere. People expect **this** only when it is necessary. Following a consistent and straightforward coding style saves time and money. ↩

2. The one case this is possible is if you pass a reference to an object into the **static** method (the **static** method could also create its own object). Then, via the reference (which is now effectively **this**), you can call non-**static** methods and access non-**static** fields. But typically, to do something like this, you’ll just make an ordinary, non-**static** method. ↩

3. Joshua Bloch goes further in his section titled “avoid finalizers”: “Finalizers are unpredictable, often dangerous, and generally unnecessary.” *Effective Java Programming Language Guide*, p. 20 (Addison-Wesley, 2001).↩

4. A term coined by Bill Venners (*www.Artima.com*) during a seminar that he and I gave together.↩

5. Of course, checking every array access costs time and code and there's no way to turn it off, which means that array accesses might be a source of inefficiency in your program if they occur at a critical juncture. For Internet security and programmer productivity, the Java designers saw that this was a worthwhile trade-off. Although you may be tempted to write code you think might make array accesses more efficient, this is a waste of time because automatic compile-time and runtime optimizations will speed array accesses. ↩

Implementation Hiding

Access control (or *implementation hiding*) is about "not getting it right the first time."

All good writers—including those who write software—know that a piece of work isn't good until it's been rewritten, often many times. If you leave a piece of code in a drawer for a while and come back to it, you might see a much better way to do it. This is one of the prime motivations for *refactoring*, which rewrites working code to make it

more readable, understandable, and thus maintainable. 1

There is a tension, however, in this desire to change and improve your code. There are often consumers (*client programmers*) who rely on some aspect of your code staying the same. So you want to change it; they want it to stay the same. Thus a primary consideration in object-oriented design is to “separate the things that change from the things that stay the same.”

This is particularly important for libraries. Consumers of that library must rely on the part they use, and know they won’t have to rewrite code if a new version of the library comes out. On the flip side, the library creator must have the freedom to make modifications and improvements with the certainty that the client code won’t be affected by those changes.

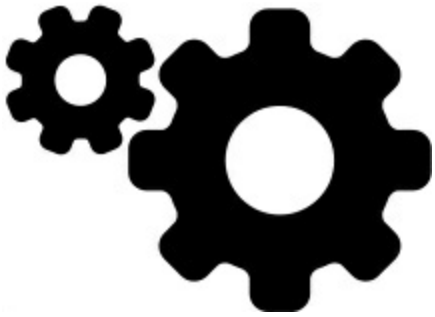
This can be achieved through convention. For example, the library programmer must agree not to remove existing methods when modifying a class in the library, since that would break the client programmer’s code. The reverse situation is more complex. In the case of a field, how can the library creator know which fields were accessed by client programmers? This is also true with methods used only to implement a class, but not meant for direct use by client

programmers. What if the library creator wants to rip out an old implementation and put in a new one? Changing any of those members might break a client programmer's code. Thus the library creator is in a strait jacket and can't change anything.

To solve this problem, Java provides *access specifiers* to allow the library creator to say what is available to the client programmer and what is not. The levels of access control span from "most access" to "least access": **public**, **protected**, *package access* (which has no keyword), and **private**. From the previous paragraph you might think, as a library designer, you'll keep everything as "private" as possible, and expose only the methods you want the client programmer to use. This is generally what you'll do, even though it's often counterintuitive for people who program in other languages (especially C) and who are used to accessing everything without restriction.

The concept of a library of components and the control over who can access the components of that library is not complete, however. There's still the question of how the components are bundled together into a cohesive library unit. This is controlled with the **package** keyword in Java, and the access specifiers are affected by whether a

class is in the same package or in a separate package. So to begin this chapter, you'll learn how library components are placed into packages. Then you can understand the complete meaning of the access specifiers.



package: the Library

Unit

A package contains a group of classes, organized together under a single *namespace*.

For example, there's a utility library that's part of the standard Java distribution, organized under the namespace **java.util**. One of the classes in **java.util** is called **ArrayList**. One way to use an **ArrayList** is to specify the full name **java.util.ArrayList**.

```
// hiding/FullQualification.java
public class FullQualification {
public static void main(String[] args) {
java.util.ArrayList list =
```

```
new java.util.ArrayList();
}
}
```

This rapidly becomes tedious, so you can use the **import** keyword instead. To import a single class, you name that class in the **import** statement:

```
// hiding/SingleImport.java
import java.util.ArrayList;
public class SingleImport {
public static void main(String[] args) {
ArrayList list = new ArrayList();
}
}
```

Now you can use **ArrayList** with no qualification. However, none of the other classes in **java.util** are available. To import everything, you use the ***** as you've been seeing in the rest of the examples in this book:

```
import java.util.*;
```

The reason for all this importing is to provide a mechanism to manage namespaces. The names of all your class members are insulated from each other. A method **f()** inside a class **A** will not clash with an **f()**

that has the same signature in class **B**. But what about the class names? Suppose you create a **Stack** class that is installed on a machine that already has a **Stack** class that's written by someone else? This potential clashing of names is why we need complete control over namespaces in Java. To achieve this, we create a unique identifier combination for each class.

Most of the examples thus far have existed in a single file and are designed for local use, so they haven't bothered with package names. However, an example without a package name is still in a package: the "unnamed" or *default package*. This is certainly an option, and for simplicity's sake this approach is used whenever possible throughout the rest of this book. However, if you're planning to create libraries or programs friendly to other Java programs on the same machine, you must think about preventing class name clashes.

A Java source-code file is called a *compilation unit* (sometimes a *translation unit*). Each compilation unit must have a file name ending in **.java**. Inside the compilation unit there *can* be a **public** class that must have the same name as the file (including capitalization, but excluding the **.java** file name extension). There can be only *one* **public** class in each compilation unit; otherwise, the compiler will

complain. If there are additional classes in that compilation unit, they are hidden from the world outside that package because they're *not* **public**, and they comprise "support" classes for the main **public** class.

Code Organization

When you compile a **.java** file, you get an output file *for each class* in the **.java** file. Each output file has the name of its corresponding class in the **.java** file, but with an extension of **.class**. Thus you can end up with quite a few **.class** files from a small number of **.java** files. If you've programmed with a compiled language, you might be used to the compiler spitting out an intermediate form (usually an "obj" file) that is then packaged together with others of its kind using a linker (to create an executable file) or a librarian (to create a library). That's not how Java works. A working program is a bunch of **.class** files, which can be packaged and compressed into a *Java ARchive* (JAR) file (using the **jar** archiver). The Java interpreter is responsible for finding, loading, and interpreting these

files.

A library is a group of these class files. Each source file usually has a **public** class and any number of non-**public** classes, so there's one **public** component for each source file. To say that all these components belong together, use the **package** keyword.

If you use a **package** statement, it *must* appear as the first non-comment in the file. When you say:

package hiding;

you're stating this compilation unit is part of a library named **hiding**. Put another way, you're saying that the **public** class name within this compilation unit is under the umbrella of the name **hiding**, and anyone who wants to use that name must either fully specify the name or use the **import** keyword in combination with **hiding**, using the choices given previously. (Note that the convention for Java package names is to use all lowercase letters, even for intermediate words.)

For example, suppose the name of a file is **MyClass.java**. This means there can only be one **public** class in that file, and the name of that class must be **MyClass** (including the capitalization):

// hiding/mypackage/MyClass.java

package hiding.mypackage;

public class MyClass {

// ...

}

Now, if someone wants to use **MyClass** or, for that matter, any of the other **public** classes in **hiding.mypackage**, they must use the **import** keyword to make the name or names in **hiding.mypackage** available. The alternative is to give the fully qualified name:

// hiding/QualifiedMyClass.java

public class QualifiedMyClass {

public static void main(String[] args) {

hiding.mypackage.MyClass m =

new hiding.mypackage.MyClass();

}

}

The **import** keyword makes it cleaner:

// hiding/ImportedMyClass.java

import hiding.mypackage.*;

public class ImportedMyClass {

public static void main(String[] args) {

MyClass m = **new** MyClass();

}

}

The **package** and **import** keywords divide up the single global namespace so names don’t clash.

Creating Unique Package Names

You might observe that, since a package never really gets “packaged” into a single file, a package can be made up of many **.class** files, and things could get a bit cluttered. To prevent this, a logical thing to do is to place all the **.class** files for a particular package into a single directory; that is, use the hierarchical file structure of the operating system to your advantage. This is one way that Java references the problem of clutter; you’ll see the other way later when the **jar** utility is introduced.

Collecting the package files into a single subdirectory solves two other

problems: creating unique package names, and finding those classes that might be buried in a directory structure someplace. This is accomplished by encoding the path of the location of the **.class** file into the name of the **package**. By convention, the first part of the **package** name is the reversed Internet domain name of the creator of the class. Since Internet domain names are unique, *if* you follow this convention, your **package** name is also unique and you won't have a name clash. If you don't have your own domain name, you must fabricate an unlikely combination (such as your first and last name) to create unique package names. If you've decided to start publishing Java code, it's worth the relatively small effort to get a domain name.

The second part of this trick is resolving the **package** name into a directory on your machine, so when the Java interpreter must load a **.class** file, it can locate the directory where that **.class** file resides. First, it finds the environment variable CLASSPATH[2] (set via the operating system, and sometimes by the installation program that installs Java or a Java-based tool on your machine). CLASSPATH contains one or more directories that are roots in a search for **.class** files. Starting at that root, the interpreter takes the package name and replaces each dot with a slash to generate a path name off of the CLASSPATH root (so **package foo.bar.baz** becomes

foo\bar\baz or **foo/bar/baz** or possibly something else, depending on your operating system). This is then concatenated with the various entries in the CLASSPATH. That's where it looks for the **.class** file with the name corresponding to the class you're trying to create. (It also searches some standard directories relative to where the Java interpreter resides.)

To understand this, consider my domain name, **MindviewInc.com**. By reversing this and making it all lowercase, **com.mindviewinc** establishes my unique global name for my classes. (The **com**, **edu**, **org**, etc., extensions were formerly capitalized in Java packages, but this was changed in Java 2 so the entire package name is lowercase.) I subdivide this by deciding to create a library named **simple**, yielding:

```
package com.mindviewinc.simple;
```

This package name can be used as an umbrella namespace for the following two files:

```
// com/mindviewinc/simple/Vector.java
// Creating a package
package com.mindviewinc.simple;
public class Vector {
```

```
public Vector() {
System.out.println("com.mindviewinc.simple.Vector");
}
}
```

As mentioned before, the **package** statement must be the first non-comment code in the file. The second file looks much the same:

```
// com/mindviewinc/simple/List.java
// Creating a package
package com.mindviewinc.simple;
public class List {
public List() {
System.out.println("com.mindviewinc.simple.List");
}
}
```

Both of these files are placed in the following subdirectory on my machine:

C:\DOC\Java\com\mindviewinc\simple

(The first comment line in every file in this book establishes the directory location of that file in the source-code tree—this is used by the automatic code-extraction tool for this book.)

If you walk back through this path, you see the package name **com.mindviewinc.simple**, but what about the first portion of the path? That's taken care of by the CLASSPATH environment variable. On my machine, part of the CLASSPATH looks like this:

```
CLASSPATH=.;D:\JAVA\LIB;C:\DOC\Java
```

The CLASSPATH can contain many alternative search paths. There's a variation when using JAR files, however. You must put the actual name of the JAR file in the classpath, not just the path where it's located. So for a JAR named **grape.jar** your classpath would include:

```
CLASSPATH=.;D:\JAVA\LIB;C:\flavors\grape.jar
```

Once the classpath is set up properly, the following file can be placed in any directory:

```
// hiding/LibTest.java
// Uses the library
import com.mindviewinc.simple.*;
public class LibTest {
public static void main(String[] args) {
Vector v = new Vector();
List l = new List();
```

```
}
}
/* Output:
com.mindviewinc.simple.Vector
com.mindviewinc.simple.List
*/
```

When the compiler encounters the **import** statement for the **simple** library, it begins searching at the directories specified by CLASSPATH, looking for subdirectory **com/mindviewinc/simple**, then seeking the compiled files of the appropriate names (**Vector.class** for **Vector**, and **List.class** for **List**). Note that both the classes and the desired methods in **Vector** and **List** must be **public**.

Setting the CLASSPATH is such a trial for beginning Java users (it was for me, when I started) that the JDK for later versions of Java got a bit smarter. You'll find that when you install it, even if you don't set the CLASSPATH, you can compile and run basic Java programs. However, to compile and run the individual examples for this book (available at https://github.com/BruceEckel/OnJava8-examples), you must add the base directory of the book's unpacked code tree to your

CLASSPATH (the **gradlew** command manages its own CLASSPATH, so you only need to set the CLASSPATH if you want to use **javac** and **java** directly, without Gradle).

Collisions

What happens if two libraries are imported via ***** and they include the same names? For example, suppose a program does this:

import com.mindviewinc.simple.*;

import java.util.*;

Since **java.util.*** also contains a **Vector** class, this causes a potential collision. However, as long as you don't write the code that actually causes the collision, everything is OK—this is good, because otherwise you might do a lot of typing to prevent collisions that never happen.

The collision *does* occur if you now try to make a **Vector**:

Vector v = **new** Vector();

Which **Vector** class does this refer to? The compiler can't know, and the reader can't know either. So the compiler complains and forces you to be explicit. For the standard Java **Vector**, you say:

java.util.Vector v = **new** java.util.Vector();

Since this (along with the CLASSPATH) completely specifies the

location of that **Vector**, there's no need for the **import java.util.*** statement unless I use something else from **java.util**.

Alternatively, you can use the single-class import form to prevent clashes—as long as you don't use both colliding names in the same program (in which case you must fall back to fully specifying the names).

A Custom Tool Library

With this knowledge, you can now create your own libraries of tools to reduce or eliminate duplicate code.

Ordinarily, I would package such a utility using my reversed domain name, in something like **com.mindviewinc.util**, but to simplify and reduce some visual noise, I'll reduce this book's utility package name to just **onjava**.

For example, here are the **range()** methods, introduced in the Control Flow chapter, that allow *for-in* syntax for simple integer sequences:

// onjava/Range.java

```
// Array creation methods that can be used without
// qualifiers, using static imports:
package onjava;
public class Range {
// Produce a sequence [0..n)
public static int[] range(int n) {
int[] result = new int[n];
for(int i = 0; i < n; i++)
result[i] = i;
return result;
}
// Produce a sequence [start..end)
public static int[] range(int start, int end) {
int sz = end - start;
int[] result = new int[sz];
for(int i = 0; i < sz; i++)
```

```
result[i] = start + i;
```

```
return result;
}
// Produce sequence [start..end) incrementing by step
public static
int[] range(int start, int end, int step) {
int sz = (end - start)/step;
int[] result = new int[sz];
for(int i = 0; i < sz; i++)
result[i] = start + (i * step);
return result;
}
}
```

The location of this file must be in a directory that starts at one of the CLASSPATH locations, then continues into **onjava**. After compiling, the methods can be used anywhere in your system using an **import static** statement.

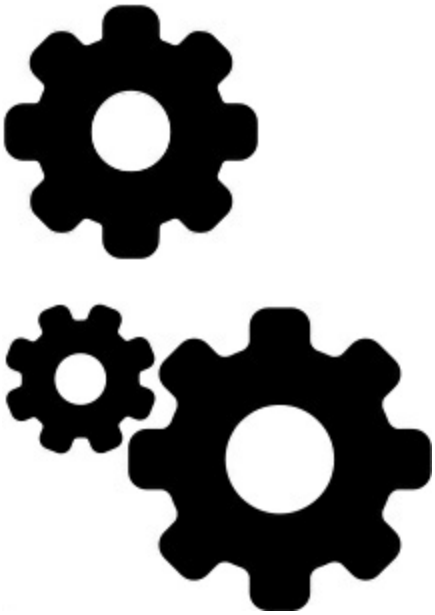
From now on, whenever you come up with a useful new utility, you can add it to your own library. You'll see more components added to the **onjava** library throughout the book.

Using Imports to Change

Behavior

A missing feature in Java is C's *conditional compilation*, where you change a switch and get different behavior without changing any other code. The reason such a feature was left out of Java is probably because it is most often used in C to solve cross-platform issues: Different portions of the code are compiled depending on the target platform. Since Java is intended to be automatically cross-platform, such a feature should not be necessary.

However, there are other valuable uses for conditional compilation. A



very common use is for debugging code. The debugging features are enabled during development and disabled in the shipping product. You can accomplish this by changing the **package** that's imported to change the code used in your program from the debug version to the

production version. This technique can be used for any kind of conditional code.

Package Caveat

When you create a package, you implicitly specify a directory structure when you give the package a name. The package *must* live in the directory indicated by its name, and that directory must be searchable starting from the CLASSPATH. Experimenting with the **package** keyword can be a bit frustrating at first, because unless you adhere to the package-name to directory-path rule, you'll get many mysterious runtime messages about not being able to find a particular class, even if that class is sitting there in the same directory. If you get a message like this, try commenting out the **package** statement, and if it runs, you'll know where the problem lies.

Note that compiled code is often placed in a different directory than source code. This is the standard for many projects, and integrated development environments will usually do it automatically. The path to the compiled code must still be found by the JVM through the CLASSPATH.

Java Access Specifiers

The Java access specifiers **public**, **protected**, and **private** are

placed in front of definitions for members in your class, both fields and methods. Each access specifier only controls the access for that particular definition.

If you don’t provide an access specifier, it means “package access.” So one way or another, everything has some kind of access control. In the following sections, you’ll learn about various kinds of access.

Package Access

All the examples before this chapter have only used the **public** access specifier, or no specifier (*default access*). Default access has no keyword, and is commonly called *package access* (sometimes “friendly”). It means that all the other classes in the current package have access to that member. To all the classes outside of this package, the member appears as **private**. Since a compilation unit—a file—can belong to only a single package, all the classes within a single compilation unit are automatically available to each other via package access.

Package access groups related classes into a package so they can easily

interact with each other. Classes in a package grant mutual access to their package-access members, so you “own” the code in that package. It makes sense that only code you own should have package access to other code you own. Package access is one reason for grouping classes together in a package. In many languages, the way you organize your definitions in files can be arbitrary, but in Java you’re compelled to organize them in a sensible fashion. In addition, you’ll probably exclude classes that shouldn’t have access to the classes defined in the current package.

The class controls the code that has access to its members. Code from another package can’t just come around and say, “Hi, I’m a friend of **Bob**s!” and expect to be shown the **protected**, package-access, and **private** members of **Bob**. The only way to grant access to a member is to:

1. Make the member **public**. Then everybody, everywhere, can

access it.

2. Give the member package access by leaving off any access

specifier, and put the other classes in the same package. Then the other classes in that package can access the member.

3. As you'll see in the Reuse chapter, when inheritance is introduced, an inherited class can access a **protected** member as well as a **public** member (but not **private** members). It can access package-access members only if the two classes are in the same package. But don't worry about inheritance and **protected** right now.

4. Provide "accessor/mutator" methods (also known as "get/set" methods) that read and change the value.

public: Interface Access

When you use the **public** keyword, it means the member declaration that immediately follows **public** is available to everyone, in particular to the client programmer who uses the library. Suppose you define a package **dessert** containing the following compilation unit:

```
// hiding/dessert/Cookie.java
// Creates a library
package hiding.dessert;
public class Cookie {
public Cookie() {
System.out.println("Cookie constructor");
```

```
}
void bite() { System.out.println("bite"); }
}
```

Remember, the class file produced by **Cookie.java** must reside in a subdirectory called **dessert**, in a directory under **hiding** (indicating the Implementation Hiding chapter of this book) that must be under one of the CLASSPATH directories. Don't make the mistake of thinking that Java will always look at the current directory as one of the starting points for searching. If you don't have a **.** as one of the paths in your CLASSPATH, Java won't look there.

Now if you create a program that uses **Cookie**:

```
// hiding/Dinner.java
// Uses the library
import hiding.dessert.*;
public class Dinner {
public static void main(String[] args) {
Cookie x = new Cookie();
//- x.bite(); // Can't access
}
}
/* Output:
```

Cookie constructor

*/

you can create a **Cookie** object, since its constructor is **public** and the class is **public**. (We'll look more at the concept of a **public** class later.) However, the **bite()** member is inaccessible inside **Dinner.java** since **bite()** provides access only within package **dessert**, so the compiler prevents you from using it.

The Default Package

You might be surprised to discover that the following code compiles, even though it appears to break the rules:

// hiding/Cake.java

// Accesses a class in a separate compilation unit

class Cake {

public static void main(String[] args) {

Pie x = **new** Pie();

x.f();

}

```
}
/* Output:
Pie.f()
*/
```

In a second file in the same directory:

```
// hiding/Pie.java
// The other class
class Pie {
void f() { System.out.println("Pie.f()"); }
}
```

Initially, these seem like completely foreign files, and yet **Cake** is able to create a **Pie** object and call its **f()** method. (Note you must have **.** in your CLASSPATH for the files to compile.) You'd typically think **Pie** and **f()** have package access and are therefore not available to **Cake**. They *do* have package access—that part is correct. The reason they are available in **Cake.java** is because they are in the same directory and have no explicit package name. Java treats files like this as implicitly part of the "default package" for that directory, and thus they provide package access to all the other files in that directory.

private: You Can't Touch

That!

The **private** keyword means no one can access that member except the class that contains that member, inside methods of that class. Other classes in the same package cannot access **private** members, so it's as if you're even insulating the class against yourself. On the other hand, it's not unlikely that a package might be created by several people collaborating together. With **private**, you can freely change that member without worrying whether it affects another class in the same package.

Default package access often provides an adequate amount of hiding; remember, a package-access member is inaccessible to the client programmer using the class. This is nice, since default access is the one you normally use (and the one that you'll get if you forget to add any access control). Thus, you'll typically think about access for the members you make **public** for the client programmer. As a result, you might initially think you won't use the **private** keyword very often, since it's tolerable to get away without it. However, the consistent use of **private** is important, especially where multithreading is concerned. (As you'll see in the Concurrent Programming chapter.)

Here’s an example of **private**:

```
// hiding/IceCream.java
// Demonstrates "private" keyword
class Sundae {
private Sundae() {}
static Sundae makeASundae() {
return new Sundae();
}
}
public class IceCream {
public static void main(String[] args) {
//- Sundae x = new Sundae();
Sundae x = Sundae.makeASundae();
}
```

```
}
```

This shows an example where **private** comes in handy: To control how an object is created and prevent someone from directly accessing

a particular constructor (or all of them). In the preceding example, you cannot create a **Sundae** object via its constructor; instead, you must call the **makeASundae()** method to do it for you.3

Any method that you're certain is only a "helper" method for that class can be made **private**, to ensure you don't accidentally use it elsewhere in the package and thus prohibit yourself from changing or removing the method. Making a method **private** retains these options.

The same is true for a **private** field inside a class. Unless you must expose the underlying implementation (less likely than you might think), make fields **private**. However, just because a reference to an object is **private** inside a class doesn't mean that some other object can't have a **public** reference to the same object. (See Appendix: Passing and Returning Objects to learn about aliasing issues.)

protected: Inheritance Access

Understanding the **protected** access specifier requires a jump ahead. First, be aware you don't have to understand this section to continue through this book up through inheritance (the Reuse chapter). But for completeness, here is a brief description and example using **protected**.

The **protected** keyword deals with a concept called *inheritance*, that takes an existing class—which we refer to as the *base class*—and adds new members to that class without touching the existing class. You can also change the behavior of existing members of the class. To inherit from a class, you say that your new class **extends** an existing class, like this:

class Foo **extends** Bar {

The rest of the class definition looks the same.

If you create a new package and inherit from a class in another package, the only members you can access are the **public** members of the original class. (If you perform the inheritance in the *same* package, you can manipulate all the members with package access.) Sometimes the creator of the base class would like to take a particular member and grant access to derived classes but not the world in general. That's what **protected** does. **protected** also gives package access—that is, other classes in the same package can access **protected** elements.

If you refer back to the file **Cookie.java**, the following class *cannot* call the package-access member **bite()**:

// hiding/ChocolateChip.java

```
// Can't use package-access member from another package
import hiding.dessert.*;
public class ChocolateChip extends Cookie {
public ChocolateChip() {
System.out.println("ChocolateChip constructor");
}
public void chomp() {
//- bite(); // Can't access bite
}
public static void main(String[] args) {
ChocolateChip x = new ChocolateChip();
x.chomp();
}
}
/* Output:
Cookie constructor
ChocolateChip constructor
*/
```

If a method **bite()** exists in class **Cookie**, it also exists in any class inherited from **Cookie**. But since **bite()** has package access and is

in a foreign package, it’s unavailable to us in this one. You can make it **public**, but then everyone has access, and maybe that’s not what you want. If you change the class **Cookie** as follows:

```
// hiding/cookie2/Cookie.java
package hiding.cookie2;
public class Cookie {
public Cookie() {
System.out.println("Cookie constructor");
}
protected void bite() {
System.out.println("bite");
}
}
```

bite() becomes accessible to anyone inheriting from **Cookie**:

```
// hiding/ChocolateChip2.java
import hiding.cookie2.*;
public class ChocolateChip2 extends Cookie {
public ChocolateChip2() {
System.out.println("ChocolateChip2 constructor");
}
```

public void chomp() { bite(); } *// Protected method*

public static void main(String[] args) {

ChocolateChip2 x = **new** ChocolateChip2();

x.chomp();

}

}

/ Output:*

Cookie constructor

ChocolateChip2 constructor

bite

**/*

Although **bite()** also has package access, it is *not* **public**.

Package Access vs. Public

Constructors

When you define a class with package access, you can give it a

public constructor without any complaints from the compiler:

// hiding/packageaccess/PublicConstructor.java

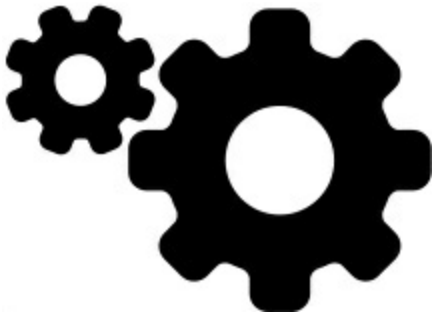
```
package hiding.packageaccess;
class PublicConstructor {
public PublicConstructor() {}
}
```

A tool like Checkstyle, which you can run with the command **gradlew hiding:checkstyleMain**, points out that this is false advertising, and technically an error. You can't actually access this so-called **public** constructor from outside the package:

```
// hiding/CreatePackageAccessObject.java
// {WillNotCompile}
import hiding.packageaccess.*;
public class CreatePackageAccessObject {
public static void main(String[] args) {
new PublicConstructor();
}
}
```

If you compile this file by hand, you'll get a compiler error message:

CreatePackageAccessObject.java:6: error:



PublicConstructor is not public in hiding.packageaccess;

cannot be accessed from outside package

new PublicConstructor();

^

1 error

Thus, declaring a constructor **public** inside a package-access class

doesn’t actually make it **public**, and it should probably be flagged

with a compiler error at the point of declaration.

Interface and

Implementation

Access control is often called *implementation hiding*. Wrapping data

and methods within classes in combination with implementation

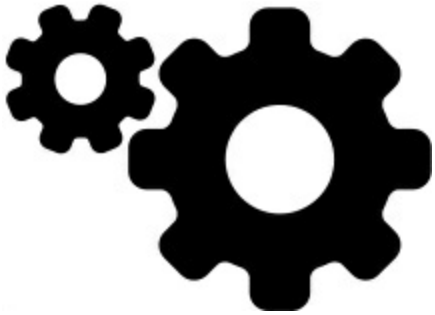
hiding is called *encapsulation*.4 The result is a data type with characteristics and behaviors.

Access control puts boundaries within a data type for two important

reasons. The first is to establish what client programmers can and

cannot use. You build your internal mechanisms into the structure without worrying that the client programmers will accidentally treat the internals as part of the interface they should be using.

This feeds directly into the second reason: to separate interface from implementation. If the structure is used in a set of programs, but client programmers can't do anything but send messages to the **public** interface, you are free to change anything that's *not* **public** (e.g., package access, **protected**, or **private**) without breaking client code.



For clarity, you might prefer a style of creating classes that puts the **public** members at the beginning, followed by the **protected**, package-access, and **private** members. The advantage is that the user of the class can then read down from the top and see first what's important to them (the **public** members, because they can be accessed outside the file), and stop reading when they encounter the non-**public** members, which are part of the internal

implementation:

```
// hiding/OrganizedByAccess.java
public class OrganizedByAccess {
public void pub1() { /* ... */ }
public void pub2() { /* ... */ }
public void pub3() { /* ... */ }
private void priv1() { /* ... */ }
private void priv2() { /* ... */ }
private void priv3() { /* ... */ }
private int i;
// ...
}
```

This makes it only partially easier to read, because the interface and implementation are still mixed together. That is, you still see the source code—the implementation—because it's right there in the class. In addition, the comment documentation supported by Javadoc lessens the importance of code readability by the client programmer. Displaying the interface to the consumer of a class is really the job of the *class browser*, a tool that shows all available classes and what you can do with them (i.e., what members are available). In Java, the JDK

documentation gives the same effect as a class browser.

Class Access

Access specifiers also determine which classes *within* a library are available to the users of that library. If you want a class to be available to a client programmer, you use the **public** keyword on the entire class definition. This controls whether the client programmer can even create an object of the class.

To control access for a class, the specifier must appear before the keyword **class**:

public class Widget {

If the name of your library is **hiding**, any client programmer can access **Widget** by saying:

import hiding.Widget;

or

import hiding.*;

There are additional constraints:

1. There can be only one **public** class per compilation unit (file).

The idea is that each compilation unit has a single public interface represented by that **public** class. It can have as many supporting package-access classes as you want. More than one

public class inside a compilation unit produces a compile-time error message.

2. The name of the **public** class must exactly match the name of the file containing the compilation unit, including capitalization. So for **Widget**, the name of the file must be **Widget.java**, not **widget.java** or **WIDGET.java**. Again, you'll get a compile-time error if they don't agree.

3. It is possible, though not typical, for a compilation unit to lack a **public** class. Here, you can name the file whatever you like (although naming it arbitrarily is confusing to people reading and maintaining the code).

What if you've got a class inside **hiding** that you're only using to accomplish the tasks performed by **Widget** or some other **public** class in **hiding**? You don't want to bother creating documentation for the client programmer, and you think sometime later you might completely change things and rip out your class altogether, substituting a different one. To give you this flexibility, ensure that no client programmers become dependent on your particular implementation details hidden inside **hiding** by leaving the **public** keyword off the class, to give it package access.

When you create a package-access class, it still makes sense to make the fields of the class **private**—you should always make fields as **private** as possible—but it's generally reasonable to give the methods the same access as the class (package access). Since a package-access class is usually used only within the package, you only make the methods of such a class **public** if you're forced, and in those cases, the compiler will tell you.

Note that a class cannot be **private** (that would make it inaccessible to anyone but the class) or **protected**.[5] So you have only two choices for class access: package access or **public**. To prevent access to that class, make all the constructors **private**, thereby prohibiting anyone but you, inside a **static** member of the class, from creating an object of that class:

```
// hiding/Lunch.java
// Demonstrates class access specifiers. Make a class
// effectively private with private constructors:
class Soup1 {
private Soup1() {}
public static Soup1 makeSoup() { // [1]
return new Soup1();
}
```

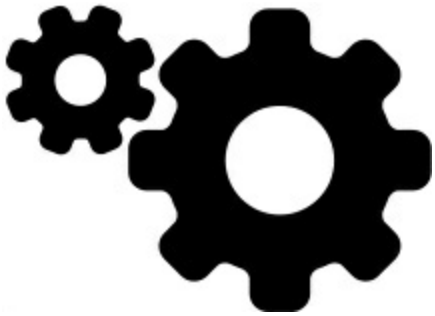
```
}
class Soup2 {
private Soup2() {}
private static Soup2 ps1 = new Soup2(); // [2]
public static Soup2 access() {
return ps1;
}
public void f() {}
}
// Only one public class allowed per file:
public class Lunch {
void testPrivate() {
// Can't do this! Private constructor:
//- Soup1 soup = new Soup1();
}
void testStatic() {
Soup1 soup = Soup1.makeSoup();
}
void testSingleton() {
Soup2.access().f();
```

}

}

You can create an object via a **static** method using **[1]**. You can also create a static object and return a reference when the user requests it, as in **[2]**.

Up to now, most of the methods return either **void** or a primitive type, so the definition in **[1]** might look a little confusing at first. The word **Soup1** before the method name (**makeSoup**) tells what the method returns. So far, this has usually been **void**, which means it returns nothing. But you can also return a reference to an object, which happens here. This method returns a reference to an object of class **Soup1**.



The classes **Soup1** and **Soup2** show how to prevent direct creation of a class by making all the constructors **private**. Remember that if you don’t explicitly create at least one constructor, the no-arg constructor (constructor with no arguments) is created for you. By

writing the no-arg constructor, it won't be created automatically. By making it **private**, no one can create an object of that class. But now how does anyone use this class? The preceding example shows two options. In **Soup1**, a **static** method is created that creates a new **Soup1** and returns a reference to it. This can be useful to perform extra operations on the **Soup1** before returning it, or to keep count of how many **Soup1** objects to create (perhaps to restrict their population).

Soup2 uses what's called a *design pattern*. This particular pattern is called a *Singleton*, because it allows only a single object to ever be created. The object of class **Soup2** is created as a **static private** member of **Soup2**, so there's one and only one, and you can't get at it except through the **public** method **access()**.

Summary

Boundaries are important in any relationship, respected by all parties involved. When you create a library, you establish a relationship with the user of that library—the client programmer—who is another programmer, but one using your library to build an application or a bigger library.

Without rules, client programmers can do anything they want with all

the members of a class, even if you might prefer they don't directly manipulate some of the members. Everything's naked to the world.

This chapter looked at how classes are built to form libraries: first, the way a group of classes is packaged within a library, and second, the way the class controls access to its members.

It is estimated that a C programming project begins to break down somewhere between 50K and 100K lines of code because C has a single namespace, and names begin to collide, causing extra management overhead. In Java, the **package** keyword, the package naming scheme, and the **import** keyword give you complete control over names, so the issue of name collision is easily avoided.

There are two reasons for controlling access to members. The first is to keep users' hands off portions they shouldn't touch. These pieces are necessary for the internal operations of the class, but not part of the interface that the client programmer needs. So making methods and fields **private** is a service to client programmers, because they can easily see what's important to them and what they can ignore. It simplifies their understanding of the class.

The second and most important reason for access control is to allow the library designer to change the internal workings of the class

without worrying it will affect the client programmer. You might, for example, build a class one way at first, then discover that restructuring your code will provide much greater speed. If the interface and implementation are clearly separated and protected, you can accomplish this without forcing client programmers to rewrite their code. Access control ensures that no client programmer becomes dependent on any part of the underlying implementation of a class. When you have the ability to change the underlying implementation, you not only have the freedom to improve your design, you also have the freedom to make mistakes. No matter how carefully you plan and design, you'll make mistakes. Knowing it's relatively safe to make these mistakes means you'll be more experimental, you'll learn more quickly, and you'll finish your project sooner.

The **public** interface to a class is what the user *does* see, so that is the most important part of the class to get "right" during analysis and design. Even that allows you some leeway for change. If you don't get the interface right the first time, you can *add* more methods, as long as you don't remove any that client programmers have already used in their code.

Notice that access control focuses on a relationship—and a kind of

communication—between a library creator and the external clients of that library. There are many situations where this is not the case. For example, if you write all the code yourself, or you work in close quarters with a small team and everything goes into the same package. These situations have a different kind of communication, and rigid adherence to access rules might not be optimal. Default (package) access might be just fine.

1. See *Refactoring: Improving the Design of Existing Code*, by Martin Fowler, et al. (Addison-Wesley, 1999). Occasionally someone will argue against refactoring, suggesting that code which works is perfectly good and it's a waste of time to refactor it. The problem with this way of thinking is that the lion's share of a project's time and money is not in the initial writing of the code, but in maintaining it. Making code easier to understand translates into very significant dollars. ↩

2. When referring to the environment variable, capital letters are used (e.g. CLASSPATH).↩

3. There's another effect here: Since the no-arg constructor is the only one defined, and it's **private**, it will prevent *inheritance* of this class. (A subject to be introduced later.)↩

4. However, people often refer to implementation hiding alone as encapsulation. ↩

5. Actually, an *inner class* can be private or protected, but that's a special case. These are introduced in the Inner Classes chapter.↩

Reuse

One of the most compelling reasons for object-oriented programming is code reuse.

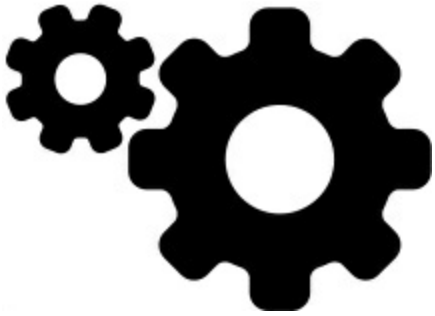
In procedural languages like C, "reuse" often means "copying code," and this is equally easy to do in any language. But it doesn't work very well. Like everything in Java, the solution revolves around the class. You reuse code by creating new classes, but instead of creating them from scratch, you use existing classes that someone has already built and debugged.

The trick is to use the classes without soiling the existing code. In this chapter you'll see two ways to accomplish this. The first is straightforward: You create objects of your existing class inside the new class. This is called *composition*, because the new class is

composed of objects of existing classes. You're reusing the functionality of the code, not its form.

The second approach is more subtle. It creates a new class as a *type of* an existing class. You literally take the form of the existing class and add code to it without modifying the existing class. This technique is called *inheritance*, and the compiler does most of the work.

Inheritance is one of the cornerstones of object-oriented



programming, and has additional implications explored in the Polymorphism chapter.

Much syntax and behavior are similar for both composition and inheritance (which makes sense because they are both ways of making new types from existing types). In this chapter, you'll learn about these code reuse mechanisms.

Composition Syntax

Composition has been used frequently in the examples you've already seen. You simply place object references inside new classes. For

example, suppose you'd like an object that holds several **String** objects, a couple of primitives, and an object of another class. For the non-primitive objects, you put references inside your new class, but you define the primitives directly:

```
// reuse/SprinklerSystem.java
// Composition for code reuse
class WaterSource {
private String s;
WaterSource() {
System.out.println("WaterSource()");
s = "Constructed";
}
@Override
public String toString() { return s; }
}
public class SprinklerSystem {
private String valve1, valve2, valve3, valve4;
private WaterSource source = new WaterSource();
private int i;
private float f;
```

```
@Override
public String toString() {
return
"valve1 = " + valve1 + " " +
"valve2 = " + valve2 + " " +
"valve3 = " + valve3 + " " +
"valve4 = " + valve4 + "\n" +
"i = " + i + " " + "f = " + f + " " +
"source = " + source; // [1]
}
public static void main(String[] args) {
SprinklerSystem sprinklers = new SprinklerSystem();
System.out.println(sprinklers);
}
}
/* Output:
WaterSource()
valve1 = null valve2 = null valve3 = null valve4 = null
i = 0 f = 0.0 source = Constructed
*/
```

One of the methods defined in both classes is special: **toString()**. Every non-primitive object has a **toString()** method, and it's called in special situations when the compiler wants a **String** but it has an object. So in **[1]**,the compiler sees you trying to "add" a **String** object ("**source =**") to a **WaterSource**. Because you can only add a **String** to another **String**, it says, "I'll turn **source** into a **String** by calling **toString()**." Then it can combine the two **String**s and pass the resulting **String** to **System.out.println()**. To allow this behavior with any class you create, you need only write a **toString()** method.

The **@Override** annotation is used on **toString()** to tell the compiler to make sure we are overriding properly. **@Override** is optional, but it helps verify you don't misspell (or, more subtly, mis-type uppercase or lowercase letters), or make other common mistakes.

Primitive fields in a class are automatically initialized to zero, as noted in the Objects Everywhere chapter. But the object references are initialized to **null**, and if you try to call methods for any of them, you'll get an exception—a runtime error. Conveniently, you can still print a **null** reference without throwing an exception.

It makes sense that the compiler doesn't just create a default object for every reference, because that would incur unnecessary overhead in

many cases. There are four ways to initialize references:

1. When the objects are defined. This means they'll always be initialized before the constructor is called.

2. In the constructor for that class.

3. Right before you actually use the object. This is often called *lazy initialization*. It can reduce overhead in situations where object creation is expensive and the object doesn't need to be created every time.

4. Using *instance initialization*.

All four approaches are shown here:

```
// reuse/Bath.java
// Constructor initialization with composition
class Soap {
private String s;
Soap() {
System.out.println("Soap()");
s = "Constructed";
}
@Override
public String toString() { return s; }
```

```
}
public class Bath {
private String // Initializing at point of definition:
s1 = "Happy",
s2 = "Happy",
s3, s4;
private Soap castille;
private int i;
private float toy;
public Bath() {
System.out.println("Inside Bath()");
s3 = "Joy";
toy = 3.14f;
castille = new Soap();
}
// Instance initialization:
{ i = 47; }
@Override
public String toString() {
if(s4 == null) // Delayed initialization:
```

```
s4 = "Joy";
return
"s1 = " + s1 + "\n" +
"s2 = " + s2 + "\n" +
"s3 = " + s3 + "\n" +
"s4 = " + s4 + "\n" +
"i = " + i + "\n" +
"toy = " + toy + "\n" +
"castille = " + castille;
}
public static void main(String[] args) {
Bath b = new Bath();
System.out.println(b);
}
}
/* Output:
Inside Bath()
Soap()
s1 = Happy
s2 = Happy
```

s3 = Joy

s4 = Joy

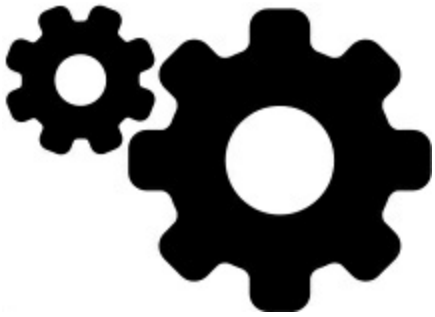
i = 47

toy = 3.14

castille = Constructed

**/*

In the **Bath** constructor, a statement is executed before any of the



initializations take place. When you don’t initialize at the point of definition, there’s still no guarantee that you’ll perform any initialization before you send a message to an object reference—an un-initialized reference will produce a runtime exception if you try to call a method on it.

When **toString()** is called it fills in **s4** so all the fields are properly initialized by the time they are used.

Inheritance Syntax

Inheritance is an integral part of all object-oriented languages. It turns

out you’re always inheriting when you create a class, because unless you explicitly inherit from some other class, you implicitly inherit from Java’s standard root class **Object**.

The syntax for composition is obvious, but inheritance uses a special syntax. When you inherit, you say, “This new class is like that old class.” You state this in code before the opening brace of the class body, using the keyword **extends** followed by the name of the *base class*. When you do this, you automatically get all the fields and methods in the base class. Here’s an example:

```
// reuse/Detergent.java
// Inheritance syntax & properties
class Cleanser {
private String s = "Cleanser";
public void append(String a) { s += a; }
public void dilute() { append(" dilute()"); }
public void apply() { append(" apply()"); }
public void scrub() { append(" scrub()"); }
@Override
public String toString() { return s; }
public static void main(String[] args) {
```

```
Cleanser x = new Cleanser();
x.dilute(); x.apply(); x.scrub();
System.out.println(x);
}
}
public class Detergent extends Cleanser {
// Change a method:
@Override
public void scrub() {
append(" Detergent.scrub()");
super.scrub(); // Call base-class version
}
// Add methods to the interface:
public void foam() { append(" foam()"); }
// Test the new class:
public static void main(String[] args) {
Detergent x = new Detergent();
x.dilute();
x.apply();
x.scrub();
```

```
x.foam();
System.out.println(x);
System.out.println("Testing base class:");
Cleanser.main(args);
}
}
/* Output:
Cleanser dilute() apply() Detergent.scrub() scrub()
foam()
Testing base class:
Cleanser dilute() apply() scrub()
*/
```

This demonstrates a number of features. First, in the **Cleanser** **append()** method, **String**s are concatenated to **s** using the **+=** operator, one of the operators (along with **+**) that the Java designers "overloaded" to work with **String**s.

Second, both **Cleanser** and **Detergent** contain a **main()** method. You can create a **main()** for each of your classes; this allows easy testing for each class. You don't need to remove the **main()** when you're finished; you can leave it in for later testing. Even if you have many classes in a program, the only **main()** that runs is the one

invoked on the command line. So here, when you say **java Detergent**, **Detergent.main()** is called. But you can also say **java Cleanser** to invoke **Cleanser.main()**, even though **Cleanser** is not a **public** class. Even if a class has package access, a **public main()** is accessible.

Here, **Detergent.main()** calls **Cleanser.main()** explicitly, passing it the same arguments from the command line (of course, you can pass it any **String** array).

All methods in **Cleanser** are **public**. Remember that if you leave off any access specifier, the member defaults to package access, which allows access only to package members. Thus, *within this package*, anyone could use those methods if there were no access specifier. **Detergent** would have no trouble, for example. However, if a class from some other package were to inherit from **Cleanser**, it could access only **public** members. So to allow for inheritance, as a general rule make all fields **private** and all methods **public**.

(**protected** members also allow access by derived classes; you'll learn about this later.) In particular cases you must make adjustments, but this is a useful guideline.

Cleanser has a set of methods in its interface: **append()**, **dilute()**, **apply()**, **scrub()**, and **toString()**. Because **Detergent** is *derived from* **Cleanser** (via the **extends** keyword), it automatically gets all these methods in its interface, even though you don't see them all explicitly defined in **Detergent**. You

can think of inheritance, then, as reusing the class.

As seen in **scrub()**, it's possible to take a method that's been defined in the base class and modify it. Here, you might call the method from the base class inside the new version. But inside **scrub()**, you cannot simply call **scrub()**, since that would produce a recursive call. To solve this problem, Java's **super** keyword refers to the "superclass" (base class) that the current class inherits. Thus the expression **super.scrub()** calls the base-class version of the

method **scrub()**.

When inheriting, you're not restricted to using the methods of the base class. You can also add new methods to the derived class exactly the way you add any method to a class: Just define it. The method **foam()** is an example.

In **Detergent.main()** you see that for a **Detergent** object, you can call all the methods available in **Cleanser** as well as in **Detergent** (such as **foam()**).

Initializing the Base Class

There are now two classes involved: the base class and the derived class. It can be confusing to imagine the resulting object produced by a derived class. From the outside, it looks like the new class has the same interface as the base class and maybe some additional methods and fields. But inheritance doesn't just copy the interface of the base class. When you create an object of the derived class, it contains within it a *subobject* of the base class. This subobject is the same as if you had created an object of the base class by itself. It's just that from the outside, the subobject of the base class is wrapped within the derived-class object.

It's essential that the base-class subobject be initialized correctly, and there's only one way to guarantee this: Perform the initialization in the

constructor by calling the base-class constructor, which has all the appropriate knowledge and privileges to perform the base-class initialization. Java automatically inserts calls to the base-class constructor in the derived-class constructor. The following example shows this with three levels of inheritance:

```
// reuse/Cartoon.java
// Constructor calls during inheritance
class Art {
Art() {
System.out.println("Art constructor");
}
}
class Drawing extends Art {
Drawing() {
System.out.println("Drawing constructor");
}
}
public class Cartoon extends Drawing {
public Cartoon() {
System.out.println("Cartoon constructor");
```

```
}
public static void main(String[] args) {
Cartoon x = new Cartoon();
}
}
/* Output:
Art constructor
Drawing constructor
Cartoon constructor
*/
```

The construction happens from the base “outward,” so the base class is initialized before the derived-class constructors can access it. Even if you don’t create a constructor for **Cartoon**, the compiler will synthesize a no-arg constructor for you that calls the base-class constructor. Try removing the **Cartoon** constructor to see this.

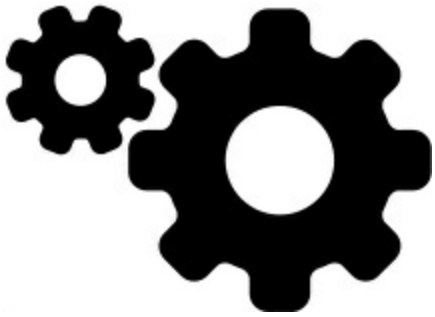
Constructors with Arguments

The preceding example has all no-arg constructors; that is, they have no arguments. It’s easy for the compiler to call these because there’s no question about what arguments to pass. If there isn’t a no-arg base-class constructor, or if you must call a base-class constructor that has

arguments, you must explicitly write a call to the base-class constructor using the **super** keyword and the appropriate argument list:

```
// reuse/Chess.java
// Inheritance, constructors and arguments
class Game {
Game(int i) {
System.out.println("Game constructor");
}
}
class BoardGame extends Game {
BoardGame(int i) {
super(i);
System.out.println("BoardGame constructor");
}
}
public class Chess extends BoardGame {
Chess() {
super(11);
System.out.println("Chess constructor");
```

```
}
public static void main(String[] args) {
Chess x = new Chess();
}
}
/* Output:
Game constructor
```



```
BoardGame constructor
Chess constructor
*/
```

If you don’t call the base-class constructor inside the **BoardGame** constructor, the compiler will complain it can’t find a constructor of the form **Game()**. In addition, the call to the base-class constructor *must* be the first action inside the derived-class constructor. (The compiler reminds you if you get it wrong.)

Delegation

A third relationship, not directly supported by Java, is called *delegation*. This is midway between inheritance and composition, because you place a member object in the class you're building (like composition), but at the same time you expose all the methods from the member object in your new class (like inheritance). For example, a spaceship needs a control module:

```
// reuse/SpaceShipControls.java
public class SpaceShipControls {
void up(int velocity) {}
void down(int velocity) {}
void left(int velocity) {}
void right(int velocity) {}
void forward(int velocity) {}
void back(int velocity) {}
void turboBoost() {}
}
```

One way to build a space ship is to use inheritance:

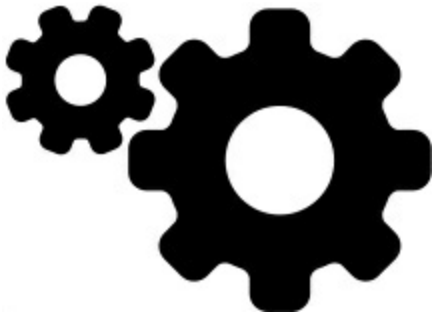
```
// reuse/DerivedSpaceShip.java
public class
DerivedSpaceShip extends SpaceShipControls {
```

```
private String name;
public DerivedSpaceShip(String name) {
this.name = name;
}
@Override
public String toString() { return name; }
public static void main(String[] args) {
DerivedSpaceShip protector =
new DerivedSpaceShip("NSEA Protector");
protector.forward(100);
}
}
```

However, a **DerivedSpaceShip** isn't really "a type of" **SpaceShipControls**, even if, for example, you "tell" a **DerivedSpaceShip** to go **forward()**. It's more accurate to say that a space ship *contains* **SpaceShipControls**, and at the same time all the methods in **SpaceShipControls** are exposed in a space ship. Delegation solves the dilemma:

```
// reuse/SpaceShipDelegation.java
public class SpaceShipDelegation {
```

```
private String name;
private SpaceShipControls controls =
new SpaceShipControls();
public SpaceShipDelegation(String name) {
this.name = name;
}
// Delegated methods:
public void back(int velocity) {
controls.back(velocity);
}
public void down(int velocity) {
controls.down(velocity);
}
public void forward(int velocity) {
controls.forward(velocity);
}
public void left(int velocity) {
```



```
controls.left(velocity);
}
public void right(int velocity) {
controls.right(velocity);
}
public void turboBoost() {
controls.turboBoost();
}
public void up(int velocity) {
controls.up(velocity);
}
public static void main(String[] args) {
SpaceShipDelegation protector =
new SpaceShipDelegation("NSEA Protector");
protector.forward(100);
}
```

}

The methods are forwarded to the underlying **controls** object, and the interface is thus the same as it is with inheritance. However, you have more control with delegation because you can choose to provide only a subset of the methods in the member object.

Although the Java language doesn’t support delegation, development tools often do. The above example, for instance, was automatically generated using the JetBrains Idea IDE.

Combining Composition and Inheritance

You’ll often use composition and inheritance together. The following example shows the creation of class using both inheritance and composition, along with the necessary constructor initialization:

```
// reuse/PlaceSetting.java
// Combining composition & inheritance
class Plate {
Plate(int i) {
System.out.println("Plate constructor");
}
```

```
}
class DinnerPlate extends Plate {
DinnerPlate(int i) {
super(i);
System.out.println("DinnerPlate constructor");
}
}
class Utensil {
Utensil(int i) {
System.out.println("Utensil constructor");
}
}
class Spoon extends Utensil {
Spoon(int i) {
super(i);
System.out.println("Spoon constructor");
}
}
class Fork extends Utensil {
Fork(int i) {
```

```
super(i);
System.out.println("Fork constructor");
}
}
class Knife extends Utensil {
Knife(int i) {
super(i);
System.out.println("Knife constructor");
}
}
// A cultural way of doing something:
class Custom {
Custom(int i) {
System.out.println("Custom constructor");
}
}
public class PlaceSetting extends Custom {
private Spoon sp;
private Fork frk;
private Knife kn;
```

```
private DinnerPlate pl;
public PlaceSetting(int i) {
super(i + 1);
sp = new Spoon(i + 2);
frk = new Fork(i + 3);
kn = new Knife(i + 4);
pl = new DinnerPlate(i + 5);
System.out.println("PlaceSetting constructor");
}
public static void main(String[] args) {
PlaceSetting x = new PlaceSetting(9);
}
}
/* Output:
Custom constructor
Utensil constructor
Spoon constructor
Utensil constructor
Fork constructor
Utensil constructor
```

Knife constructor

Plate constructor

DinnerPlate constructor

PlaceSetting constructor

*/

Although the compiler forces you to initialize the base classes, and requires you do it right at the beginning of the constructor, it doesn't watch over you to make sure you initialize the member objects. Notice how cleanly the classes are separated. You don't even need the

source code for the methods to reuse the code. At most, you just import a package. (This is true for both inheritance and composition.)

Guaranteeing Proper Cleanup

Java doesn't have the C++ concept of a *destructor*, a method that is automatically called when an object is destroyed. The reason is probably that in Java, the practice is simply to forget about objects rather than to destroy them, allowing the garbage collector to reclaim memory as necessary.

Often this is fine, but there are times when your class might perform some activities during its lifetime that require cleanup. The Housekeeping chapter explained that you can't know when the garbage collector is called, or even *if* it is called. So if you want something cleaned up for a class, you must explicitly write a special method to do it, and make sure the client programmer knows they must call this method. On top of this—as described in the Exceptions chapter—you must guard against an exception by putting such cleanup in a **finally** clause.

Consider an example of a computer-aided design system that draws pictures on the screen:

```
// reuse/CADSystem.java
// Ensuring proper cleanup
// {java reuse.CADSystem}
package reuse;
class Shape {
Shape(int i) {
System.out.println("Shape constructor");
}
void dispose() {
```

```
System.out.println("Shape dispose");
}
}
class Circle extends Shape {
Circle(int i) {
super(i);
System.out.println("Drawing Circle");
}
@Override
void dispose() {
System.out.println("Erasing Circle");
super.dispose();
}
}
class Triangle extends Shape {
Triangle(int i) {
super(i);
System.out.println("Drawing Triangle");
}
@Override
```

```
void dispose() {
System.out.println("Erasing Triangle");
super.dispose();
}
}
class Line extends Shape {
private int start, end;
Line(int start, int end) {
super(start);
this.start = start;
this.end = end;
System.out.println(
"Drawing Line: " + start + ", " + end);
}
@Override
void dispose() {
System.out.println(
"Erasing Line: " + start + ", " + end);
super.dispose();
}
```

```
}
public class CADSystem extends Shape {
private Circle c;
private Triangle t;
private Line[] lines = new Line[3];
public CADSystem(int i) {
super(i + 1);
for(int j = 0; j < lines.length; j++)
lines[j] = new Line(j, j*j);
c = new Circle(1);
t = new Triangle(1);
System.out.println("Combined constructor");
}
@Override
public void dispose() {
System.out.println("CADSystem.dispose()");
// The order of cleanup is the reverse
// of the order of initialization:
t.dispose();
c.dispose();
```

```
for(int i = lines.length - 1; i >= 0; i--)
lines[i].dispose();
super.dispose();
}
public static void main(String[] args) {
CADSystem x = new CADSystem(47);
try {
// Code and exception handling...
} finally {
x.dispose();
}
}
}
/* Output:
Shape constructor
Shape constructor
Drawing Line: 0, 0
Shape constructor
Drawing Line: 1, 1
Shape constructor
```

Drawing Line: 2, 4

Shape constructor

Drawing Circle

Shape constructor

Drawing Triangle

Combined constructor

CADSystem.dispose()

Erasing Triangle

Shape dispose

Erasing Circle

Shape dispose

Erasing Line: 2, 4

Shape dispose

Erasing Line: 1, 1

Shape dispose

Erasing Line: 0, 0

Shape dispose

Shape dispose

/

Everything in this system is some kind of **Shape** (itself a kind of

Object, since it's implicitly inherited from the root class). Each class overrides **Shape**s **dispose()** method in addition to calling the base-class version of that method using **super**. The specific **Shape** classes—**Circle**, **Triangle**, and **Line**—all have constructors that "draw," although any method called during the lifetime of the object can be responsible for doing something that needs cleanup. Each class has its own **dispose()** method to restore non-memory things back to the way they were before the object existed.

In **main()**, there are two keywords you haven't seen before, and won't be explained in detail until the Exceptions chapter: **try** and **finally**. The **try** keyword indicates that the block that follows (delimited by curly braces) is a *guarded region*, which means it is given special treatment. One of these special treatments is that the code in the **finally** clause following this guarded region is *always* executed, no matter how the **try** block exits. (With exception handling, it's possible to leave a **try** block in a number of non-ordinary ways.) Here, the **finally** clause is saying, "Always call

dispose() for **x**, no matter what happens."

In your cleanup method (**dispose()**, in this case), you must also pay attention to the calling order for the base-class and member-object cleanup methods in case one subobject depends on another. First perform all cleanup work specific to your class, in the reverse order of creation. (In general, this requires that base-class elements still be viable.) Then call the base-class cleanup method, as demonstrated here.

There are many cases where the cleanup issue is not a problem; you just let the garbage collector do the work. But when you must perform explicit cleanup, diligence and attention are required, because there's not much you can rely on when it comes to garbage collection. The garbage collector might never be called. If it is, it can reclaim objects in any order it wants. You can't rely on garbage collection for anything but memory reclamation. If you want cleanup to take place, make your own cleanup methods and don't use **finalize()**.

Name Hiding

If a Java base class has a method name that's overloaded several times, redefining that method name in the derived class will *not* hide any of the base-class versions. Overloading works regardless of

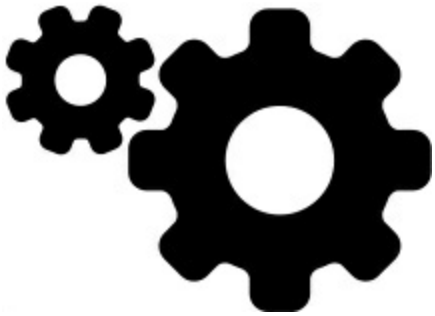
whether the method was defined at this level or in a base class:

```
// reuse/Hide.java
// Overloading a base-class method name in a derived
// class does not hide the base-class versions
class Homer {
char doh(char c) {
System.out.println("doh(char)");
return 'd';
}
float doh(float f) {
System.out.println("doh(float)");
return 1.0f;
}
}
class Milhouse {}
class Bart extends Homer {
void doh(Milhouse m) {
System.out.println("doh(Milhouse)");
}
}
```

```
public class Hide {
public static void main(String[] args) {
Bart b = new Bart();
b.doh(1);
b.doh('x');
b.doh(1.0f);
b.doh(new Milhouse());
}
}
/* Output:
doh(float)
doh(char)
doh(float)
doh(Milhouse)
*/
```

All the overloaded methods of **Homer** are available in **Bart**, even though **Bart** introduces a new overloaded method. As you'll see in the next chapter, it's far more common to override methods of the same name, using exactly the same signature and return type as in the base class. Otherwise it can be confusing.

You’ve been seeing the Java 5 **@Override** annotation, which is not a keyword but can be used as if it were. When you mean to override a method, you can choose to add this annotation and the compiler will produce an error message if you accidentally overload instead of overriding:



```
// reuse/Lisa.java
// {WillNotCompile}
class Lisa extends Homer {
@Override void doh(Milhouse m) {
System.out.println("doh(Milhouse)");
}
}
```

The **{WillNotCompile}** tag excludes the file from this book’s Gradle build, but if you compile it by hand you’ll see:

```
method does not override a method from its superclass
```

The **@Override** annotation prevents you from accidentally

overloading.

Choosing Composition

vs. Inheritance

Both composition and inheritance allow you to place subobjects inside your new class (composition explicitly does this—with inheritance it's implicit). You might wonder about the difference between the two, and when to choose one over the other.

Use composition when you want the functionality of an existing class inside your new class, but not its interface. That is, embed a (usually **private**) object to implement features in your new class. The user of your new class sees the interface you've defined for the new class rather than the interface from the embedded object.

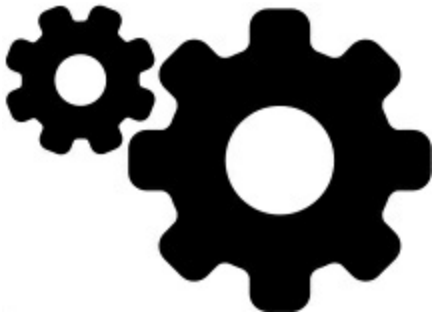
Sometimes it makes sense to allow the class user to directly access the composition of your new class. For this, make the member objects **public** (you can think of this as a kind of "semi-delegation"). The member objects use implementation hiding themselves, so this is safe. When the user knows you're assembling a bunch of parts, it makes the interface easier to understand. A **car** object is a good example:

// reuse/Car.java

// Composition with public objects

```
class Engine {
public void start() {}
public void rev() {}
public void stop() {}
}
class Wheel {
public void inflate(int psi) {}
}
class Window {
public void rollup() {}
public void rolldown() {}
}
class Door {
public Window window = new Window();
public void open() {}
public void close() {}
}
public class Car {
public Engine engine = new Engine();
public Wheel[] wheel = new Wheel[4];
```

```
public Door
left = new Door(),
right = new Door(); // 2-door
public Car() {
for(int i = 0; i < 4; i++)
wheel[i] = new Wheel();
}
public static void main(String[] args) {
Car car = new Car();
car.left.window.rollup();
car.wheel[0].inflate(72);
```



```
}
}
```

The composition of a car is part of the analysis of the problem (and not part of the underlying design). Making the members **public** assists the client programmer's understanding of how to use the class and

requires less code complexity for the creator of the class. However, keep in mind this is a special case. In general, make fields **private**.

When you inherit, you take an existing class and make a special version of it. This usually means taking a general-purpose class and specializing it for a particular need. With a little thought, you'll see it would make no sense to compose a car using a vehicle object—a car doesn't contain a vehicle, it *is* a vehicle. The *is-a* relationship is expressed with inheritance, and the *has-a* relationship is expressed with composition.

protected

Now that you've been introduced to inheritance, the keyword **protected** becomes meaningful. In an ideal world, the **private** keyword would be enough. In real projects, there are times when you hide something from the world at large and yet allow access for members of derived classes.

The **protected** keyword is a nod to pragmatism. It says, "This is **private** as far as the class user is concerned, but available to anyone who inherits from this class or anyone else in the same package." (**protected** also provides package access.)

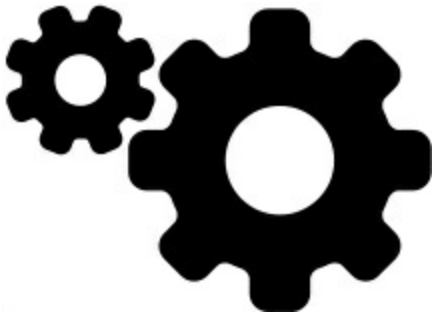
Although it's possible to create **protected** fields, the best approach

is to leave the fields **private** and always preserve your right to change the underlying implementation. You can then allow controlled access to inheritors of your class through **protected** methods:

```
// reuse/Orc.java
// The protected keyword
class Villain {
private String name;
protected void set(String nm) { name = nm; }
Villain(String name) { this.name = name; }
@Override
public String toString() {
return "I'm a Villain and my name is " + name;
}
}
public class Orc extends Villain {
private int orcNumber;
public Orc(String name, int orcNumber) {
super(name);
this.orcNumber = orcNumber;
}
```

```
public void change(String name, int orcNumber) {
set(name); // Available because it's protected
this.orcNumber = orcNumber;
}
@Override
public String toString() {
return "Orc " + orcNumber + ": " + super.toString();
}
public static void main(String[] args) {
Orc orc = new Orc("Limburger", 12);
System.out.println(orc);
orc.change("Bob", 19);
System.out.println(orc);
}
}
/* Output:
Orc 12: I'm a Villain and my name is Limburger
Orc 19: I'm a Villain and my name is Bob
*/
```

change() has access to **set()** because it's **protected**. Notice the



way **Orc**s **toString()** method is defined in terms of the base-class version of **toString()**.

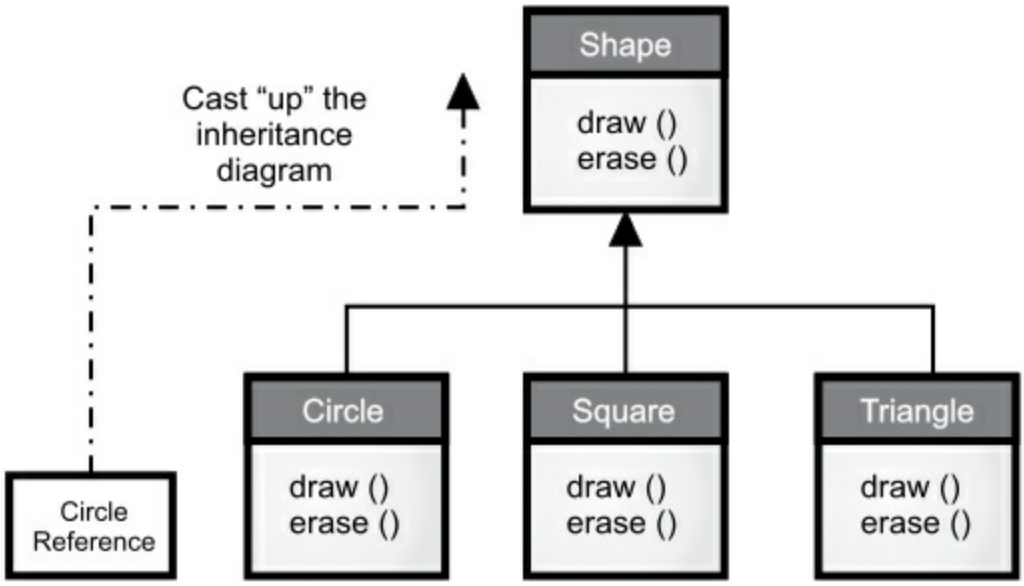
Upcasting

The most important aspect of inheritance is not that it provides methods for the new class. It’s the relationship expressed between the new class and the base class. This relationship can be summarized by saying, “The new class *is a type of* the existing class.”

This description is not just a fanciful way of explaining inheritance—it’s supported directly by the language. As an example, consider a base class called **Instrument** that represents musical instruments, and a derived class called **Wind**. Because inheritance guarantees that all methods in the base class are also available in the derived class, any message you can send to the base class can also be sent to the derived class. If the **Instrument** class has a **play()** method, so will **Wind** instruments. This means you can accurately say that a **Wind** object is also a type of **Instrument**. The following example shows how the

compiler supports this notion:

```
// reuse/Wind.java
// Inheritance & upcasting
class Instrument {
public void play() {}
static void tune(Instrument i) {
// ...
i.play();
}
}
// Wind objects are instruments
// because they have the same interface:
public class Wind extends Instrument {
```



public static void main(String[] args) {

Wind flute = **new** Wind();

Instrument.tune(flute); *// Upcasting*

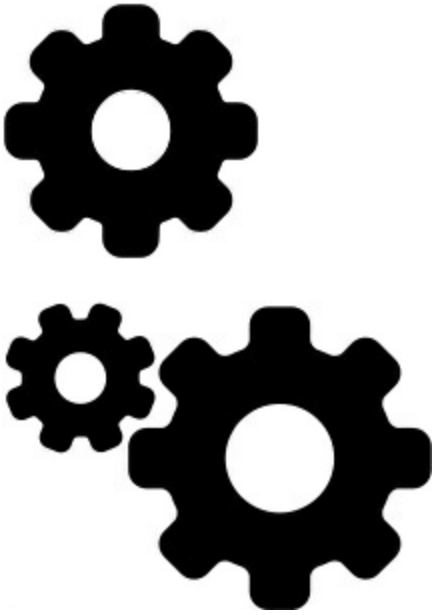
}

}

The **tune()** method accepts an **Instrument** reference. However, in **Wind.main()** the **tune()** method is handed a **Wind** reference. Given that Java is particular about type checking, it seems strange that a method that accepts one type will readily accept another type, until you realize that a **Wind** object is also an **Instrument** object, and there’s no method that **tune()** could call for an **Instrument** that isn’t also in **Wind**. Inside **tune()**, the code works for **Instrument**

and anything derived from **Instrument**, and the act of converting a **Wind** reference into an **Instrument** reference is called *upcasting*. The term is based on the way that class inheritance diagrams have traditionally been drawn: with the root at the top of the page, growing downward. (Of course, you can draw your diagrams any way you find helpful.) The inheritance diagram for **Wind.java** is then:

Casting from a derived type to a base type moves *up* on the inheritance



diagram, so it's commonly called *upcasting*. Upcasting is always safe because you're going from a more specific type to a more general type. That is, the derived class is a superset of the base class. It might contain more methods than the base class, but it must contain *at least* the methods in the base class. During the upcast, the class interface can only lose methods, not gain them. This is why the compiler allows

upcasting without any explicit casts or other special notation.

You can also perform the reverse of upcasting, called *downcasting*, but this involves a dilemma that is examined further in the next chapter, and in the Type Information chapter.

Composition vs. Inheritance Revisited

In object-oriented programming, the most likely way to create and use code is by packaging data and methods together into a class, and using objects of that class. You'll also use existing classes to build new classes with composition. Less frequently, you'll use inheritance. So although inheritance gets a lot of emphasis when teaching OOP, it doesn't mean you should use it everywhere you possibly can. On the contrary, use it sparingly, only when it's clear that inheritance is useful. One of the clearest ways to determine whether to use composition or inheritance is to ask whether you'll ever upcast from your new class to the base class. If you must upcast, inheritance is necessary, but if you don't upcast, look closely at whether you need inheritance. The Polymorphism chapter provides one of the most compelling reasons for upcasting, but if you remember to ask, "Do I need to upcast?" you'll have a good tool for deciding between composition and inheritance.

The final Keyword

Java's **final** keyword has slightly different meanings depending on context, but in general it says, "This cannot be changed." You can prevent changes for two reasons: design or efficiency. Because these two reasons are quite different, it's possible to misuse the **final** keyword.

The following sections discuss the three places where **final** can be used: for data, methods, and classes.

final Data

Many programming languages have a way to tell the compiler that a piece of data is "constant." A constant is useful for two reasons:

1. It can be a *compile-time constant* that won't ever change.
2. It can be a value initialized at run time that you don't want changed.

In the case of a compile-time constant, the compiler is allowed to "fold" the constant value into calculations; that is, the calculation can be performed at compile time, eliminating some runtime overhead. In

Java, these sorts of constants must be primitives and are expressed with the **final** keyword. You must provide a value when the constant is defined.

A field that is both **static** and **final** has only one piece of storage that cannot be changed.

When **final** is used with object references rather than primitives, the meaning can be confusing. With a primitive, **final** makes the *value* a constant, but with an object reference, **final** makes the *reference* a constant. Once the reference is initialized to an object, it can never be changed to point to another object. However, the object itself can be modified; Java does not provide a way to make any arbitrary object a constant. (You can, however, write your class so objects have the effect of being constant.) This restriction includes arrays, which are also objects.

Here's an example that demonstrates **final** fields:

```
// reuse/FinalData.java
// The effect of final on fields
import java.util.*;
class Value {
int i; // Package access
```

```
Value(int i) { this.i = i; }
}
public class FinalData {
private static Random rand = new Random(47);
private String id;
public FinalData(String id) { this.id = id; }
// Can be compile-time constants:
private final int valueOne = 9;
private static final int VALUE_TWO = 99;
// Typical public constant:
public static final int VALUE_THREE = 39;
// Cannot be compile-time constants:
private final int i4 = rand.nextInt(20);
static final int INT_5 = rand.nextInt(20);
private Value v1 = new Value(11);
private final Value v2 = new Value(22);
private static final Value VAL_3 = new Value(33);
// Arrays:
private final int[] a = { 1, 2, 3, 4, 5, 6 };
@Override
```

```
public String toString() {
return id + ": " + "i4 = " + i4
+ ", INT_5 = " + INT_5;
}
public static void main(String[] args) {
FinalData fd1 = new FinalData("fd1");
//- fd1.valueOne++; // Error: can't change value
fd1.v2.i++; // Object isn't constant!
fd1.v1 = new Value(9); // OK -- not final
for(int i = 0; i < fd1.a.length; i++)
fd1.a[i]++; // Object isn't constant!
//- fd1.v2 = new Value(0); // Error: Can't
//- fd1.VAL_3 = new Value(1); // change reference
//- fd1.a = new int[3];
System.out.println(fd1);
System.out.println("Creating new FinalData");
FinalData fd2 = new FinalData("fd2");
System.out.println(fd1);
System.out.println(fd2);
}
```

}

/ *Output:*

fd1: i4 = 15, INT_5 = 18

Creating new FinalData

fd1: i4 = 15, INT_5 = 18

fd2: i4 = 13, INT_5 = 18

**/*

Since **valueOne** and **VALUE_TWO** are **final** primitives with compile-time values, they can both be used as compile-time constants and are not different in any important way. **VALUE_THREE** is the more typical way you'll see such constants defined: **public** so they're usable outside the package, **static** to emphasize there's only one, and **final** to say it's a constant.

By convention, **final static** primitives with constant initial values (that is, compile-time constants) are named with all capitals, with words separated by underscores. (This is just like C constants, which is where that style originated.)

Just because something is **final** doesn't mean its value is known at compile time. This is demonstrated by initializing **i4** and **INT_5** at run time using randomly generated numbers. This portion of the

example also shows the difference between making a **final** value **static** or non-**static**. This difference shows up only when the values are initialized at run time, since the compile-time values are treated the same by the compiler. (And presumably optimized out of existence.) The difference is shown when you run the program. Note that the values of **i4** for **fd1** and **fd2** are unique, but the value for **INT_5** is not changed by creating the second **FinalData** object. That's because it's **static** and is initialized once upon loading and not each time you create a new object.

The variables **v1** through **VAL_3** demonstrate the meaning of a **final** reference. As you see in **main()**, just because **v2** is **final** doesn't mean you can't change its value. Because it's a reference, **final** just means you cannot rebind **v2** to a new object. The same meaning holds true for an array, which is just another kind of reference. (There is no way I know of to make the array references themselves **final**.) Making references **final** seems less useful than making primitives **final**.

Blank finals

Blank finals are **final** fields without initialization values. The compiler ensures that blank **final**s are initialized before use. A

final field inside a class can now be different for each object while retaining its immutable quality:

```
// reuse/BlankFinal.java
// "Blank" final fields
class Poppet {
private int i;
Poppet(int ii) { i = ii; }
}
public class BlankFinal {
private final int i = 0; // Initialized final
private final int j; // Blank final
private final Poppet p; // Blank final reference
// Blank finals MUST be initialized in constructor:
public BlankFinal() {
j = 1; // Initialize blank final
p = new Poppet(1); // Init blank final reference
}
public BlankFinal(int x) {
j = x; // Initialize blank final
p = new Poppet(x); // Init blank final reference
```

```
}
public static void main(String[] args) {
new BlankFinal();
new BlankFinal(47);
}
}
```

You’re forced to perform assignments to **final**s either with an expression at the point of definition of the field or in every constructor. This guarantees that the **final** field is always initialized before use.

final Arguments

You make arguments **final** by declaring them as such in the argument list. This means that inside the method you cannot change what the argument reference points to:

```
// reuse/FinalArguments.java
// Using "final" with method arguments
class Gizmo {
public void spin() {}
}
```

```
public class FinalArguments {
void with(final Gizmo g) {
//- g = new Gizmo(); // Illegal -- g is final
}
void without(Gizmo g) {
g = new Gizmo(); // OK -- g not final
g.spin();
}
// void f(final int i) { i++; } // Can't change
// You can only read from a final primitive:
int g(final int i) { return i + 1; }
public static void main(String[] args) {
FinalArguments bf = new FinalArguments();
bf.without(null);
bf.with(null);
}
}
```

The methods **f()** and **g()** show what happens when primitive arguments are **final**. You can read the argument, but you can't change it. This feature is primarily used to pass data to anonymous inner classes, which you'll learn about in the Inner Classes chapter.

final Methods

There are two reasons for **final** methods. The first is to put a "lock" on the method to prevent an inheriting class from changing that method's meaning by overriding it. This is done for design reasons when you want to make sure that a method's behavior is retained during inheritance.

The second reason **final** methods were suggested in the past is efficiency. In earlier implementations of Java, if you made a method **final**, you allowed the compiler to turn any calls to that method into *inline* calls. When the compiler saw a **final** method call, it could (at its discretion) skip the normal approach of inserting code to perform the method call mechanism (push arguments on the stack, hop over to the method code and execute it, hop back and clean off the stack arguments, and deal with the return value) and instead replace the method call with a copy of the actual code in the method body. This eliminates the overhead of the method call. However, if a method is

big, your code begins to bloat, and you probably wouldn't see performance gains from inlining, since any speedups in the call and return were dwarfed by the amount of time spent inside the method. Relatively early in the history of Java, the virtual machine (in particular, the *hotspot* technologies) began detecting these situations and optimizing away the extra indirection. For a long time, using **final** to help the optimizer has been discouraged. You should let the compiler and JVM handle efficiency issues and make a method **final** only to explicitly prevent overriding.1

final and private

Any **private** methods in a class are implicitly **final**. Because you can't access a **private** method, you can't override it. You can add the **final** specifier to a **private** method, but it doesn't give that method any extra meaning.

This can be confusing, because if you try to override a **private** method (which is implicitly **final**), it seems to work, and the compiler doesn't give an error message:

```
// reuse/FinalOverridingIllusion.java
// It only looks like you can override
// a private or private final method
```

```
class WithFinals {
// Identical to "private" alone:
private final void f() {
System.out.println("WithFinals.f()");
}
// Also automatically "final":
private void g() {
System.out.println("WithFinals.g()");
}
}
class OverridingPrivate extends WithFinals {
private final void f() {
System.out.println("OverridingPrivate.f()");
}
private void g() {
System.out.println("OverridingPrivate.g()");
}
}
class OverridingPrivate2 extends OverridingPrivate {
public final void f() {
```

```
System.out.println("OverridingPrivate2.f()");
}
public void g() {
System.out.println("OverridingPrivate2.g()");
}
}
public class FinalOverridingIllusion {
public static void main(String[] args) {
OverridingPrivate2 op2 = new OverridingPrivate2();
op2.f();
op2.g();
// You can upcast:
OverridingPrivate op = op2;
// But you can't call the methods:
//- op.f();
//- op.g();
// Same here:
WithFinals wf = op2;
//- wf.f();
//- wf.g();
```

```
}
}
```

```
/* Output:
OverridingPrivate2.f()
OverridingPrivate2.g()
*/
```

“Overriding” can only occur if something is part of the base-class interface. That is, you must upcast an object to its base type and call the same method (the point of this becomes clear in the next chapter). If a method is **private**, it isn’t part of the base-class interface. It is just code that’s hidden away inside the class, and it just happens to have that name. But if you create a **public**, **protected**, or package-access method with the same name in the derived class, there’s no connection to the method that might happen to have that name in the base class. You haven’t overridden the method, you’ve just created a new method. Since a **private** method is unreachable and effectively invisible, it doesn’t factor into anything except for the code

organization of the class for which it was defined.

final Classes

When you say that an entire class is **final** (by preceding its definition with the **final** keyword), you're preventing all inheritance from this class. You do this because, for some reason, the design of your class is such that there is never a need to make any changes, or for safety or security reasons you don't want subclassing.

```
// reuse/Jurassic.java
// Making an entire class final
class SmallBrain {}
final class Dinosaur {
int i = 7;
int j = 1;
SmallBrain x = new SmallBrain();
void f() {}
```

```
}
//- class Further extends Dinosaur {}
```

```
// error: Cannot extend final class 'Dinosaur'
public class Jurassic {
public static void main(String[] args) {
Dinosaur n = new Dinosaur();
n.f();
n.i = 40;
n.j++;
}
}
```

The fields of a **final** class can be **final** or not, as you choose. The same rules apply to **final** for fields regardless of whether the class is defined as **final**. However, because it prevents inheritance, all *methods* in a **final** class are implicitly **final**, since there's no way to override them. You can include the **final** specifier to a method in a **final** class, but it doesn't add any meaning.

final Caution

It can seem sensible to make a method **final** while you're designing a class. You might feel that no one could possibly want to override that method. Sometimes this is true.

But be careful with your assumptions. In general, it's difficult to

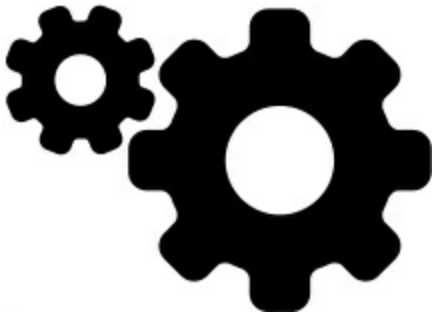
anticipate how a class can be reused, especially a general-purpose class. If you define a method as **final**, you might prevent the possibility of reusing your class through inheritance in some other programmer's project simply because you can't imagine it being used that way.

The standard Java library is a good example of this. In particular, the Java 1.0/1.1 **Vector** class was commonly used and might be even more useful if, in the name of efficiency (which was almost certainly an illusion), all the methods hadn't been made **final**. It's easily conceivable you might inherit and override with such a fundamentally useful class, but the designers somehow decided this wasn't appropriate. This is ironic for two reasons. First, **Stack** inherits **Vector**, which says that a **Stack** *is* a **Vector**, which isn't really true from a logical standpoint. Nonetheless, it's a case where the Java designers themselves inherited **Vector**. When they created **Stack** this way, they should have realized that **final** methods were too restrictive.

Second, many of the most important methods of **Vector**, such as **addElement()** and **elementAt()**, are **synchronized**. The Concurrent Programming chapter shows that this imposes a significant performance overhead that probably wipes out any gains

provided by **final**. This lends credence to the theory that programmers are consistently bad at guessing where optimizations should occur. It's too bad that such a clumsy design made it into the standard library, where everyone had to cope with it. Fortunately, the modern Java collection library supersedes **Vector** with **ArrayList**, which behaves much more civilly. Unfortunately, there's still new code that uses the old collection library, including **Vector**.

Hashtable, another important Java 1.0/1.1 standard library class (later superseded by **HashMap**), does *not* have any **final** methods. As mentioned elsewhere in this book, it's obvious that different classes were designed by different people. The method names in **Hashtable** are much briefer compared to those in **Vector**, another piece of evidence. This is precisely the sort of thing that should *not* be obvious to consumers of a class library. When things are inconsistent, it just makes more work for the user—yet another paean to the value of



design and code walkthroughs.

Initialization and

Class Loading

In more traditional languages, programs are loaded all at once, as part of the startup process. This is followed by initialization, then the program begins. The process of initialization in these languages must be carefully controlled so the order of initialization of **static**s doesn’t cause trouble. C++, for example, has problems if one **static** expects another **static** to be valid before the second one is initialized.

Java doesn’t have this problem because it takes a different approach to loading. This is one of the activities that become easier because everything in Java is an object. Remember that the compiled code for each class exists in its own separate file. That file isn’t loaded until the code is needed. In general, you can say that “class code is loaded at the point of first use.” This is usually when the first object of that class is constructed, but loading also occurs when a **static** field or **static**

method is accessed. The constructor is also a **static** method even though the **static** keyword is not explicit. So to be precise, a class is first loaded when any one of its **static** members is accessed.

The point of first use is also when **static** initialization takes place.

All **static** objects and **static** code blocks are initialized in textual order (the order you write them in the class definition), at load time.

The **static**s are initialized only once.

Initialization with

Inheritance

It’s helpful to look at the whole initialization process, including inheritance, to get a full picture of what happens. Consider the following example:

```
// reuse/Beetle.java
// The full process of initialization
class Insect {
private int i = 9;
protected int j;
Insect() {
System.out.println("i = " + i + ", j = " + j);
j = 39;
}
private static int x1 =
printInit("static Insect.x1 initialized");
static int printInit(String s) {
System.out.println(s);
return 47;
}
}
public class Beetle extends Insect {
```

```
private int k = printInit("Beetle.k initialized");
public Beetle() {
System.out.println("k = " + k);
System.out.println("j = " + j);
}
private static int x2 =
printInit("static Beetle.x2 initialized");
public static void main(String[] args) {
System.out.println("Beetle constructor");
Beetle b = new Beetle();
}
}
/* Output:
static Insect.x1 initialized
static Beetle.x2 initialized
Beetle constructor
```

$i = 9, j = 0$

Beetle.k initialized

k = 47

j = 39

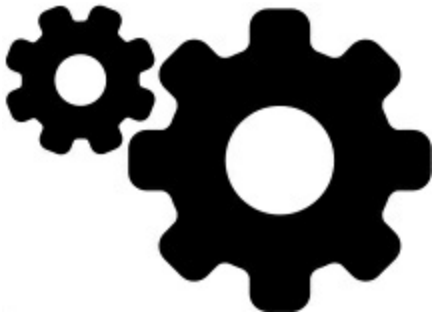
**/*

When you run **java Beetle**, you first try to access **Beetle.main()** (a **static** method), so the loader goes out and finds the compiled code for the **Beetle** class, in the file **Beetle.class**. While loading that, the loader notices there's a base class, which it also loads. This happens whether or not you make an object of that base class. (Try commenting out the object creation to prove it to yourself.)

If the base class has its own base class, that second base class will also be loaded, and so on. Next, the **static** initialization in the root base class (in this case, **Insect**) is performed, then the next derived class, and so on. This is important because the derived-class **static** initialization might depend on the base-class member being initialized properly.

Now the necessary classes have all been loaded, so the object can be created. First, all the primitives in this object are set to their default values and the object references are set to **null**—this happens in one

fell swoop by setting the memory in the object to binary zero. Then the base-class constructor is called. Here the call is automatic, but you can also specify the base-class constructor call (as the first operation in the **Beetle** constructor) by using **super**. The base-class constructor goes through the same process in the same order as the derived-class constructor. After the base-class constructor completes, the instance variables are initialized in textual order. Finally, the rest of the body of the constructor is executed.



Summary

Both inheritance and composition create new types from existing types. Composition reuses existing types as part of the underlying implementation of the new type, and inheritance reuses the interface. With inheritance, the derived class has the base-class interface, so it can be *upcast* to the base, which is critical for polymorphism, as you'll see in the next chapter.

Despite the strong emphasis on inheritance in object-oriented

programming, when you start a design, prefer composition (or possibly delegation) during the first cut and use inheritance only when it is clearly necessary. Composition tends to be more flexible. In addition, by using the added artifice of inheritance with your member type, you can change the exact type, and thus the behavior, of those member objects at run time. Therefore, you can change the behavior of the composed object at run time.

When designing a system, your goal is to find or create a set of classes where each class has a specific use and is neither too big (encompassing so much functionality it's unwieldy to reuse) nor annoyingly small (you can't use it by itself or without adding functionality). If your designs become too complex, it's often helpful to add more objects by breaking existing objects into smaller parts.

When you start designing a system, remember that program development is an incremental process, just like human learning. It relies on experimentation; you can do as much analysis as you want, but you still won't know all the answers when you set out on a project. You'll have much more success—and more immediate feedback—if you start out to "grow" your project as an organic, evolutionary creature, rather than constructing it all at once like a glass-box skyscraper.

Inheritance and composition are two of the most fundamental tools in object-oriented programming that allow you to perform such experiments.

1. Don’t listen to the sirens of premature optimization. If you get your system working and it’s too slow, it’s doubtful you can fix it with the **final** keyword. Profiling, however, *can* be helpful in speeding up your program. ↩

Polymorphism

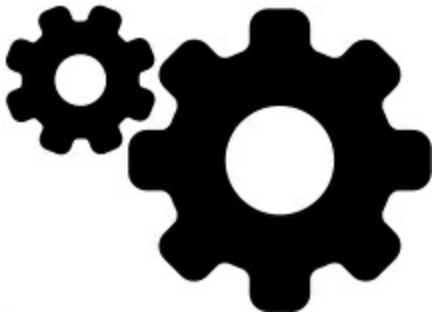
“I have been asked, ‘Pray, Mr. Babbage, if
you put into the machine wrong figures,
will the right answers come out?’ I am not
able to rightly apprehend the kind of
confusion of ideas that could provoke
such a question.”— *Charles Babbage*
(1791-1871)

Polymorphism is the third essential feature of an object-oriented programming language, after data

abstraction and inheritance.

It provides another dimension of separation of interface from implementation, to decouple *what* from *how*. Polymorphism improves code organization and readability as well as the creation of *extensible* programs that can be “grown” not only during the original creation of the project, but also when new features are desired.

Encapsulation creates new data types by combining characteristics and behaviors. Implementation hiding separates the interface from



the implementation by making the details **private**. This sort of mechanical organization makes ready sense to someone with a procedural programming background. But polymorphism deals with decoupling in terms of *types*. In the previous chapter, inheritance enabled you to treat an object as its own type *or* its base type. This treats many types (derived from the same base type) as if they were one type, and a single piece of code works on all those different types equally. The polymorphic method call allows one type to express its

distinction from another, similar type, as long as they're both derived from the same base type. This distinction is expressed through differences in behavior of the methods you can call through the base class.

In this chapter, you'll learn about polymorphism (also called *dynamic binding* or *late binding* or *runtime binding*) starting from the basics, with simple examples that strip away everything but the polymorphic behavior of the program.

Upcasting Revisited

In the previous chapter you saw how an object can be used as its own type or as an object of its base type. Taking an object reference and treating it as a reference to its base type is called *upcasting* because of the way inheritance trees are drawn with the base class at the top.

You also saw a problem arise, embodied in the following example of musical instruments. Since several of these examples play **Note**s, we first create a separate **Note** enumeration, in a package:

```
// polymorphism/music/Note.java
// Notes to play on musical instruments
package polymorphism.music;
public enum Note {
MIDDLE_C, C_SHARP, B_FLAT; // Etc.
```

}

enums were introduced in the Housekeeping chapter.

Here, **Wind** is a type of **Instrument**; therefore, **Wind** inherits **Instrument**:

```
// polymorphism/music/Instrument.java
package polymorphism.music;
class Instrument {
public void play(Note n) {
System.out.println("Instrument.play()");
}
}
// polymorphism/music/Wind.java
package polymorphism.music;
// Wind objects are instruments
// because they have the same interface:
public class Wind extends Instrument {
// Redefine interface method:
@Override
public void play(Note n) {
System.out.println("Wind.play() " + n);
```

}

}

The method **Music.tune()** accepts an **Instrument** reference,

but also anything derived from **Instrument**:

// polymorphism/music/Music.java

// Inheritance & upcasting

// {java polymorphism.music.Music}

package polymorphism.music;

public class Music {

public static void tune(Instrument i) {

// ...

i.play(Note.MIDDLE_C);

}

public static void main(String[] args) {

Wind flute = **new** Wind();

tune(flute); *// Upcasting*

}

}

/ *Output:*

Wind.play() MIDDLE_C

**/*

In **main()** you see a **Wind** reference passed to **tune()**, with no cast necessary. This is acceptable—the interface in **Instrument** must exist in **Wind**, because **Wind** inherits **Instrument**. Upcasting from **Wind** to **Instrument** can "narrow" that interface, but it cannot make it anything less than the full interface to **Instrument**.

Forgetting the Object Type

Music.java might seem strange to you. Why should anyone intentionally *forget* the type of an object? This "forgetting" is exactly what happens when you upcast, and it seems like it might be much more straightforward if **tune()** takes a **Wind** reference as its argument. This brings up an essential point: If you did that, you'd have to write a new **tune()** for every type of **Instrument** in your system. Suppose you follow this reasoning and add **Stringed** and **Brass** instruments:

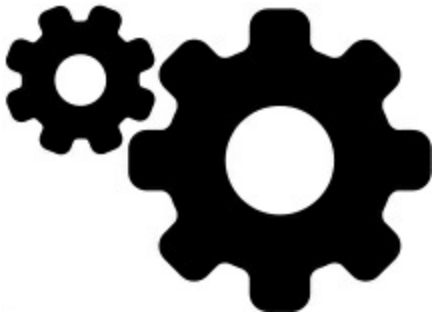
// polymorphism/music/Music2.java

// Overloading instead of upcasting

```
// {java polymorphism.music.Music2}
package polymorphism.music;
class Stringed extends Instrument {
@Override
public void play(Note n) {
System.out.println("Stringed.play() " + n);
}
}
class Brass extends Instrument {
@Override
public void play(Note n) {
System.out.println("Brass.play() " + n);
}
}
public class Music2 {
public static void tune(Wind i) {
i.play(Note.MIDDLE_C);
}
public static void tune(Stringed i) {
i.play(Note.MIDDLE_C);
```

```
}
public static void tune(Brass i) {
i.play(Note.MIDDLE_C);
}
public static void main(String[] args) {
Wind flute = new Wind();
Stringed violin = new Stringed();
Brass frenchHorn = new Brass();
tune(flute); // No upcasting
tune(violin);
tune(frenchHorn);
}
}
/* Output:
Wind.play() MIDDLE_C
Stringed.play() MIDDLE_C
Brass.play() MIDDLE_C
*/
```

This works, but there's a major drawback: You must write type-specific methods for each new **Instrument** class you add. This



means more programming in the first place, but it also means that to add a new method like **tune()** or a new type of **Instrument**, you've got a lot of work to do. Add the fact that the compiler won't tell you if you forget to overload one of your methods, and the whole process of working with types becomes unmanageable.

Wouldn't it be much nicer to write a single method that takes the base class as its argument, and not worry about any of the specific derived classes? That is, wouldn't it be nice to forget there are derived classes, and write your code to talk only to the base class?

That's exactly what polymorphism enables. However, most programmers who come from a procedural programming background have a bit of trouble with the way polymorphism works.

The Twist

The difficulty with **Music.java** can be seen by running the program. The output is **Wind.play()**. This is clearly the desired output, but it doesn't seem to make sense it would work that way. Look at the

tune() method:

```
public static void tune(Instrument i) {
// ...
i.play(Note.MIDDLE_C);
}
```

It receives an **Instrument** reference. So how can the compiler possibly know this **Instrument** reference points to a **Wind** here and not a **Brass** or **Stringed**? The compiler can't. To get a deeper understanding of the issue, it's helpful to examine the subject of *binding*.

Method-Call Binding

Connecting a method call to a method body is called *binding*. When binding is performed before the program runs(by the compiler and linker, if there is one), it's called *early binding*. You might not have heard the term before because it has never been an option with procedural languages. C, for example, has only one kind of method call, and that's early binding.

The confusing part of the preceding program revolves around early binding, because the compiler cannot know the correct method to call when it has only an **Instrument** reference.

The solution is called *late binding*, which means the binding occurs at run time, based on the type of object. Late binding is also called *dynamic binding* or *runtime binding*. When a language implements late binding, there must be some mechanism to determine the type of the object at run time and to call the appropriate method. That is, the compiler still doesn't know the object type, but the method-call mechanism finds out and calls the correct method body. The late-binding mechanism varies from language to language, but you can imagine that some sort of type information must be installed in the objects.

All method binding in Java uses late binding unless the method is **static** or **final** (**private** methods are implicitly **final**). This means that ordinarily you don't make decisions about whether late binding will occur—it happens automatically.

Why would you declare a method **final**? As noted in the last chapter, it prevents anyone from overriding that method. Perhaps more important, it effectively "turns off" dynamic binding, or rather it tells

the compiler that dynamic binding isn't necessary. This allows the compiler to generate slightly more efficient code for **final** method calls. However, in most cases it won't make any overall performance

difference in your program, so it's best to only use **final** as a design decision, and not as an attempt to improve performance.

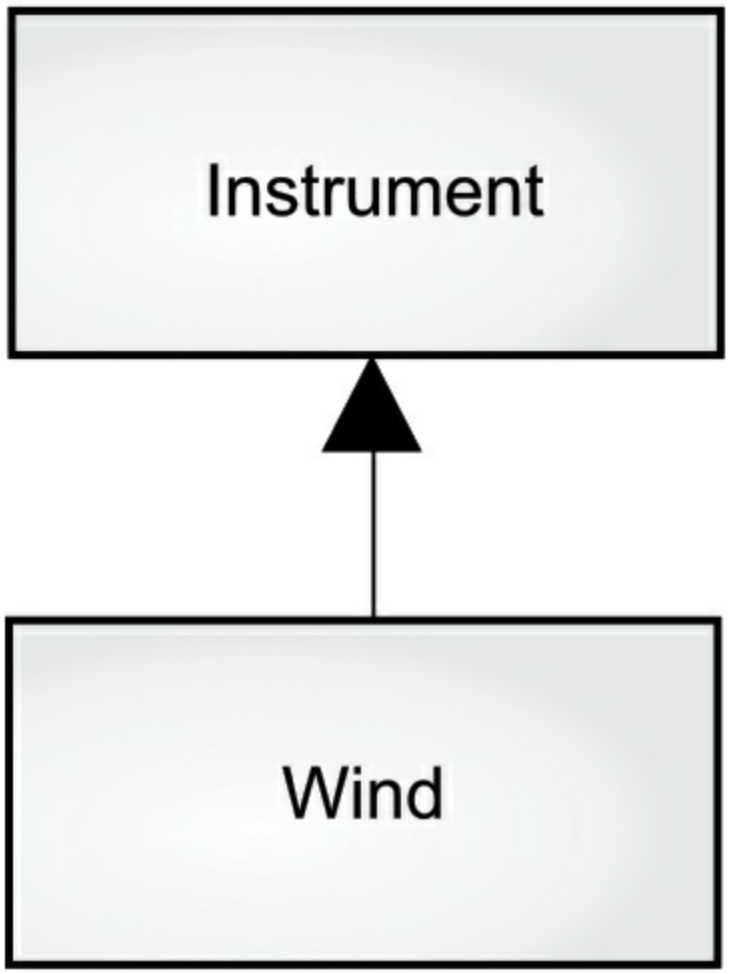
Producing the Right Behavior

Once you know that all method binding in Java happens polymorphically via late binding, you can write your code to talk to the base class and know that all the derived-class cases will work correctly using the same code. Or to put it another way, you "send a message to an object and let the object figure out the right thing to do."

The classic object-oriented example uses shapes. This example is easy to visualize, but unfortunately it can confuse novice programmers into thinking that OOP is just for graphics programming, which is not the case.

The shape example has a base class called **Shape** and various derived types: **Circle**, **Square**, **Triangle**, etc. The reason the example

works so well is it's easy to say, "A circle is a type of shape" and be understood. The inheritance diagram shows the relationships:



The upcast could occur in a statement as simple as:

Shape s = **new** Circle();

This creates a **Circle** object, and the resulting reference is immediately assigned to a **Shape**, which would seem to be an error (assigning one type to another); and yet it's fine because a **Circle** *is*

a **Shape** by inheritance. So the compiler agrees with the statement and doesn't issue an error message.

Suppose you call one of the base-class methods (those overridden in the derived classes):

s.draw();

Again, you might expect that **Shape**s **draw()** is called because this is, after all, a **Shape** reference—how could the compiler know to do anything else? And yet the proper **Circle.draw()** is called because of late binding (polymorphism).

The following example puts it a slightly different way. First, let's create a reusable library of **Shape** types. The base class **Shape** establishes the common interface to anything inherited from **Shape**—all shapes can be drawn and erased:

// polymorphism/shape/Shape.java

package polymorphism.shape;

public class Shape {

public void draw() {}

public void erase() {}

}

The derived classes override these definitions to provide unique

behavior for each specific type of shape:

```
// polymorphism/shape/Circle.java
package polymorphism.shape;
public class Circle extends Shape {
@Override
public void draw() {
System.out.println("Circle.draw()");
}
@Override
public void erase() {
System.out.println("Circle.erase()");
}
}
// polymorphism/shape/Square.java
package polymorphism.shape;
public class Square extends Shape {
@Override
public void draw() {
System.out.println("Square.draw()");
}
```

```
@Override
public void erase() {
System.out.println("Square.erase()");
}
}
// polymorphism/shape/Triangle.java
package polymorphism.shape;
public class Triangle extends Shape {
@Override
public void draw() {
System.out.println("Triangle.draw()");
}
@Override
public void erase() {
System.out.println("Triangle.erase()");
}
}
```

RandomShapes is a kind of “factory” that produces a reference to a randomly created **Shape** object each time you call its **get()** method. Note that the upcasting happens in the **return** statements, each of

which takes a reference to a **Circle**, **Square**, or **Triangle** and sends it out of **get()** as the return type, **Shape**. So whenever you call **get()**, you never get a chance to see what specific type it is, since you always get back a plain **Shape** reference:

```
// polymorphism/shape/RandomShapes.java
// A "factory" that randomly creates shapes
package polymorphism.shape;
import java.util.*;
public class RandomShapes {
private Random rand = new Random(47);
public Shape get() {
switch(rand.nextInt(3)) {
default:
case 0: return new Circle();
case 1: return new Square();
case 2: return new Triangle();
}
}
public Shape[] array(int sz) {
Shape[] shapes = new Shape[sz];
```

```
// Fill up the array with shapes:
for(int i = 0; i < shapes.length; i++)
shapes[i] = get();
return shapes;
}
}
```

The **array()** method allocates and fills an array of **Shape** objects, and is used here in the *for-in* expression:

```
// polymorphism/Shapes.java
// Polymorphism in Java
import polymorphism.shape.*;
public class Shapes {
public static void main(String[] args) {
RandomShapes gen = new RandomShapes();
// Make polymorphic method calls:
for(Shape shape : gen.array(9))
shape.draw();
}
}
/* Output:
```

Triangle.draw()

Triangle.draw()

Square.draw()

Triangle.draw()

Square.draw()

Triangle.draw()

Square.draw()

Triangle.draw()

Circle.draw()

*/

main() steps an array of **Shape** references produced (via the call to **array()**) by calls to **RandomShapes.get()**. Now you know you have **Shape**s, but you don't know anything more specific (and neither does the compiler). However, when you step through this array and call **draw()** for each one, the correct type-specific behavior magically occurs, as you see from the output when you run the program.

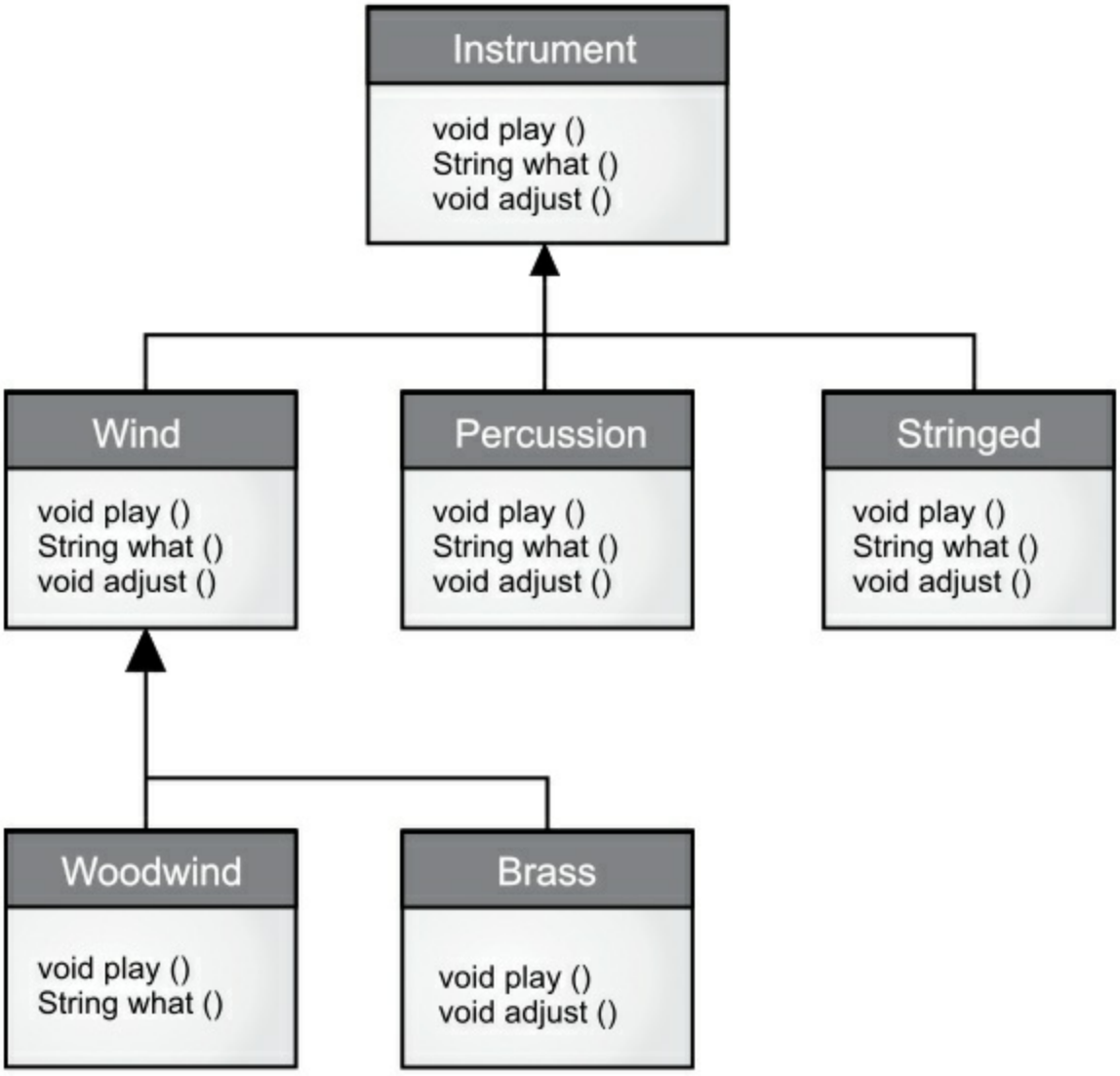
The point of creating the shapes randomly is to drive home the

understanding that the compiler can have no special knowledge that allows it to make the correct calls at compile time. All the calls to **draw()** must be made through dynamic binding.

Extensibility

Now let's return to the musical instrument example. Because of polymorphism, you can add as many new types as you want to the system without changing the **tune()** method. In a well-designed OOP program, many of your methods will follow the model of **tune()** and communicate only with the base-class interface. Such a program is *extensible* because you can add new functionality by inheriting new data types from the common base class. The methods that manipulate the base-class interface will not change to accommodate the new classes.

Consider what happens if you take the instrument example and add



more methods in the base class, along with a number of new classes: All these new classes work correctly with the old, unchanged **tune()** method. Even if **tune()** is in a separate file and new methods are added to the interface of **Instrument**, **tune()** will still work correctly, even without recompiling it. Here is the implementation of the diagram:

```
// polymorphism/music3/Music3.java
// An extensible program
// {java polymorphism.music3.Music3}
package polymorphism.music3;
import polymorphism.music.Note;
class Instrument {
void play(Note n) {
System.out.println("Instrument.play() " + n);
}
String what() { return "Instrument"; }
void adjust() {
System.out.println("Adjusting Instrument");
}
}
class Wind extends Instrument {
@Override
void play(Note n) {
System.out.println("Wind.play() " + n);
}
@Override
```

```
String what() { return "Wind"; }
@Override
void adjust() {
System.out.println("Adjusting Wind");
}
}
class Percussion extends Instrument {
@Override
void play(Note n) {
System.out.println("Percussion.play() " + n);
}
@Override
String what() { return "Percussion"; }
@Override
void adjust() {
System.out.println("Adjusting Percussion");
}
}
class Stringed extends Instrument {
@Override
```

```
void play(Note n) {
System.out.println("Stringed.play() " + n);
}
@Override
String what() { return "Stringed"; }
@Override
void adjust() {
System.out.println("Adjusting Stringed");
}
}
class Brass extends Wind {
@Override
void play(Note n) {
System.out.println("Brass.play() " + n);
}
@Override
void adjust() {
System.out.println("Adjusting Brass");
}
}
```

```
class Woodwind extends Wind {
@Override
void play(Note n) {
System.out.println("Woodwind.play() " + n);
}
@Override
String what() { return "Woodwind"; }
}
public class Music3 {
// Doesn't care about type, so new types
// added to the system still work right:
public static void tune(Instrument i) {
// ...
i.play(Note.MIDDLE_C);
}
public static void tuneAll(Instrument[] e) {
for(Instrument i : e)
tune(i);
}
public static void main(String[] args) {
```

// Upcasting during addition to the array:

Instrument[] orchestra = {

new Wind(),

new Percussion(),

new Stringed(),

new Brass(),

new Woodwind()

};

tuneAll(orchestra);

}

}

/ Output:*

Wind.play() MIDDLE_C

Percussion.play() MIDDLE_C

Stringed.play() MIDDLE_C

Brass.play() MIDDLE_C

Woodwind.play() MIDDLE_C

*/

The new methods are **what()**, which returns a **String** reference with a description of the class, and **adjust()**, which provides some way to adjust each instrument.

In **main()**, when you place something inside the **orchestra** array, you automatically upcast to **Instrument**.

The **tune()** method is blissfully ignorant of all the code changes that happen around it, and yet it works correctly. This is exactly what polymorphism is supposed to provide. Changes in your code don't cause damage to parts of the program that should not be affected. Put another way, polymorphism is an important technique for the programmer to "separate the things that change from the things that stay the same."

Pitfall: "Overriding" private Methods

Here's something you might innocently try to do:

```
// polymorphism/PrivateOverride.java
// Trying to override a private method
// {java polymorphism.PrivateOverride}
package polymorphism;
```

```
public class PrivateOverride {
private void f() {
System.out.println("private f()");
}
public static void main(String[] args) {
PrivateOverride po = new Derived();
po.f();
}
}
class Derived extends PrivateOverride {
public void f() { System.out.println("public f()"); }
}
/* Output:
private f()
*/
```

You might reasonably expect the output to be "**public f()**", but a **private** method is automatically **final**, and is also hidden from the derived class. So **Derived**s **f()** here is a brand new method; it's not even overloaded, since the base-class version of **f()** isn't visible in **Derived**.

The result of this is that only non-**private** methods can be overridden, but watch out for the *appearance* of overriding **private** methods, which generates no compiler warnings, but doesn't do what you might expect. To be clear, use a different name from a **private** base-class method in your derived class.

If you use the **@Override** annotation, the problem is detected:

```
// polymorphism/PrivateOverride2.java
// Detecting a mistaken override using @Override
// {WillNotCompile}
package polymorphism;
```

```
public class PrivateOverride2 {
private void f() {
System.out.println("private f()");
}
public static void main(String[] args) {
PrivateOverride2 po = new Derived2();
po.f();
```

```
}
}
class Derived2 extends PrivateOverride2 {
@Override
public void f() { System.out.println("public f()"); }
}
```

The compiler message is:

error: method does not override or

implement a method from a supertype

Pitfall: Fields and static

Methods

Once you learn about polymorphism, you can begin to think everything happens polymorphically. However, only ordinary method calls can be polymorphic. For example, if you access a field directly, that access is resolved at compile time:

```
// polymorphism/FieldAccess.java
// Direct field access is determined at compile time
class Super {
public int field = 0;
public int getField() { return field; }
```

```
}
class Sub extends Super {
public int field = 1;
@Override
public int getField() { return field; }
public int getSuperField() { return super.field; }
}
public class FieldAccess {
public static void main(String[] args) {
Super sup = new Sub(); // Upcast
System.out.println("sup.field = " + sup.field +
", sup.getField() = " + sup.getField());
Sub sub = new Sub();
System.out.println("sub.field = " +
sub.field + ", sub.getField() = " +
sub.getField() +
", sub.getSuperField() = " +
sub.getSuperField());
}
}
```

/ *Output:*

sup.field = 0, sup.getField() = 1

sub.field = 1, sub.getField() = 1, sub.getSuperField()

= 0

**/*

When a **Sub** object is upcast to a **Super** reference, any field accesses are resolved by the compiler, and are thus not polymorphic. In this example, different storage is allocated for **Super.field** and **Sub.field**. Thus, **Sub** actually contains two fields called **field**: its own and the one it gets from **Super**. However, the **Super** version is not the default that is produced when you refer to **field** in **Sub**. To get the **Super field** you must explicitly say **super.field**.

Although this seems like it could be a confusing issue, in practice it virtually never comes up. For one thing, you'll generally make all fields **private** and so you won't access them directly, but only as side effects of calling methods. In addition, you probably won't give the same name to a base-class field and a derived-class field, because it is confusing.

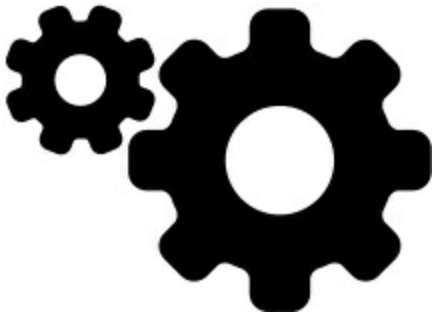
If a method is **static**, it doesn't behave polymorphically:

// polymorphism/StaticPolymorphism.java

```
// Static methods are not polymorphic
class StaticSuper {
public static String staticGet() {
return "Base staticGet()";
}
public String dynamicGet() {
return "Base dynamicGet()";
}
}
class StaticSub extends StaticSuper {
public static String staticGet() {
return "Derived staticGet()";
}
@Override
public String dynamicGet() {
return "Derived dynamicGet()";
}
}
public class StaticPolymorphism {
public static void main(String[] args) {
```

```
StaticSuper sup = new StaticSub(); // Upcast
System.out.println(StaticSuper.staticGet());
System.out.println(sup.dynamicGet());
}
}
/* Output:
Base staticGet()
Derived dynamicGet()
*/
```

static methods are associated with the class, and not the individual objects.



Constructors and Polymorphism

As usual, constructors are different from other kinds of methods. This is also true when polymorphism is involved. Even though constructors are not polymorphic (they're actually **static** methods, but the **static** declaration is implicit), it's important to understand the way constructors work in complex hierarchies and with polymorphism. This understanding will help you avoid unpleasant entanglements.

Order of Constructor Calls

The order of constructor calls was briefly discussed in the Housekeeping chapter and again in the Reuse chapter, but that was before polymorphism was introduced.

A constructor for the base class is always called during the construction process for a derived class. The initialization automatically moves up the inheritance hierarchy so a constructor for every base class is called. This makes sense because the constructor has a special job: to see that the object is built properly. Since fields are usually **private**, you must generally assume that a derived class has access to its own members only, and not to those of the base class. Only the base-class constructor has the proper knowledge and access to initialize its own elements. Therefore, it's essential that all constructors get called; otherwise, the entire object wouldn't be constructed. That's why the compiler enforces a constructor call for

every portion of a derived class. It will silently call the no-arg constructor if you don’t explicitly call a base-class constructor in the derived-class constructor body. If there is no no-arg constructor, the compiler will complain. (In the case where a class has no constructors, the compiler will automatically synthesize a no-arg constructor.)

This example shows the effects of composition, inheritance, and polymorphism on the order of construction:

```
// polymorphism/Sandwich.java
// Order of constructor calls
// {java polymorphism.Sandwich}
package polymorphism;
class Meal {
Meal() { System.out.println("Meal()"); }
}
class Bread {
Bread() { System.out.println("Bread()"); }
}
class Cheese {
Cheese() { System.out.println("Cheese()"); }
}
```

```
class Lettuce {
Lettuce() { System.out.println("Lettuce()"); }
}
class Lunch extends Meal {
Lunch() { System.out.println("Lunch()"); }
}
class PortableLunch extends Lunch {
PortableLunch() {
System.out.println("PortableLunch()");
}
}
public class Sandwich extends PortableLunch {
private Bread b = new Bread();
private Cheese c = new Cheese();
private Lettuce l = new Lettuce();
public Sandwich() {
System.out.println("Sandwich()");
}
public static void main(String[] args) {
new Sandwich();
```

}

}

/ *Output:*

Meal()

Lunch()

PortableLunch()

Bread()

Cheese()

Lettuce()

Sandwich()

**/*

This example creates a complex class out of other classes. Each class has a constructor that announces itself. The important class is **Sandwich**, which reflects three levels of inheritance (four, if you count the implicit inheritance from **Object**) and three member objects.

The output for creating a **Sandwich** object shows that the order of constructor calls for a complex object is as follows:

1. The base-class constructor is called. This step is repeated recursively such that the root of the hierarchy is constructed first,

followed by the next-derived class, etc., until the most-derived class is reached.

2. Member initializers are called in the order of declaration.

3. The body of the derived-class constructor is called.

The order of the constructor calls is important. When you inherit, you know all about the base class and can access any **public** and **protected** members of the base class. This means you can assume that all members of the base class are valid when you're in the derived class. In a normal method, construction has already taken place, so all the members of all parts of the object are also constructed.

Inside the constructor you must be certain all members are already built. The only way to guarantee this is for the base-class constructor to be called first. Then, when you're in the derived-class constructor, all the members you can access in the base class have been initialized. Knowing that all members are valid inside the constructor is also the reason that, whenever possible, you should initialize all member objects (that is, objects placed in the class using composition) at their

point of definition in the class (e.g., **b**, **c**, and **l** in the preceding example). If you follow this practice, you help ensure that all base-class members *and* member objects of the current object have been initialized.

Unfortunately, this doesn't handle every case, as you will see in the next section.

Inheritance and Cleanup

When using composition and inheritance to create a new class, most of the time you won't worry about cleanup. Subobjects can usually be left to the garbage collector. If you do have cleanup issues, you must be diligent and create a **dispose()** method (the name I have chosen to use here; you might come up with something better) for your new class. And with inheritance, you must override **dispose()** in the derived class for any special cleanup that must happen as part of garbage collection. When you override **dispose()** in an inherited class, it's important to remember to call the base-class version of **dispose()**, since otherwise the base-class cleanup will not happen:

```
// polymorphism/Frog.java
// Cleanup and inheritance
// {java polymorphism.Frog}
```

```
package polymorphism;
class Characteristic {
private String s;
Characteristic(String s) {
this.s = s;
System.out.println("Creating Characteristic " + s);
}
protected void dispose() {
System.out.println("disposing Characteristic " + s);
}
}
class Description {
private String s;
Description(String s) {
this.s = s;
System.out.println("Creating Description " + s);
}
protected void dispose() {
System.out.println("disposing Description " + s);
}
```

```
}
class LivingCreature {
private Characteristic p =
new Characteristic("is alive");
private Description t =
new Description("Basic Living Creature");
LivingCreature() {
System.out.println("LivingCreature()");
}
protected void dispose() {
System.out.println("LivingCreature dispose");
t.dispose();
p.dispose();
}
}
class Animal extends LivingCreature {
private Characteristic p =
new Characteristic("has heart");
private Description t =
new Description("Animal not Vegetable");
```

```
Animal() { System.out.println("Animal()"); }
@Override
protected void dispose() {
System.out.println("Animal dispose");
t.dispose();
p.dispose();
super.dispose();
}
}
class Amphibian extends Animal {
private Characteristic p =
new Characteristic("can live in water");
private Description t =
new Description("Both water and land");
Amphibian() {
System.out.println("Amphibian()");
}
@Override
protected void dispose() {
System.out.println("Amphibian dispose");
```

```
t.dispose();
p.dispose();
super.dispose();
}
}
public class Frog extends Amphibian {
private Characteristic p =
new Characteristic("Croaks");
private Description t = new Description("Eats Bugs");
public Frog() { System.out.println("Frog()"); }
@Override
protected void dispose() {
System.out.println("Frog dispose");
t.dispose();
p.dispose();
super.dispose();
}
public static void main(String[] args) {
Frog frog = new Frog();
System.out.println("Bye!");
```

```
frog.dispose();
}
}
/* Output:
Creating Characteristic is alive
Creating Description Basic Living Creature
LivingCreature()
Creating Characteristic has heart
Creating Description Animal not Vegetable
Animal()
Creating Characteristic can live in water
Creating Description Both water and land
Amphibian()
Creating Characteristic Croaks
Creating Description Eats Bugs
Frog()
Bye!
Frog dispose
disposing Description Eats Bugs
disposing Characteristic Croaks
```

Amphibian dispose

disposing Description Both water and land

disposing Characteristic can live in water

Animal dispose

disposing Description Animal not Vegetable

disposing Characteristic has heart

LivingCreature dispose

disposing Description Basic Living Creature

disposing Characteristic is alive

**/*

Each class in the hierarchy contains member objects of types **Characteristic** and **Description**, which must also be

disposed. The order of disposal should be the reverse of the order of initialization, in case one subobject is dependent on another. For fields, this means reverse order of declaration (since fields are initialized in declaration order). For base classes (following the form that's used in C++ for destructors), perform the derived-class cleanup first, then the base-class cleanup. That's because the derived-class cleanup could call some methods in the base class that require the base-class components to be alive, so you cannot destroy them prematurely. The output shows that all parts of the **Frog** object are disposed in reverse order of creation.

Although you don't always perform cleanup, when you do, the process requires care and awareness.

A **Frog** object "owns" its member objects. It creates them, and it knows they should live as long as the **Frog** does, so it knows when to **dispose()** of the member objects. However, if one of these member objects is shared with one or more other objects, the problem becomes more complex and you cannot simply call **dispose()**. Here, *reference counting* might be necessary to keep track of the number of objects still accessing a shared object. Here's what it looks like:

// polymorphism/ReferenceCounting.java

```
// Cleaning up shared member objects
class Shared {
private int refcount = 0;
private static long counter = 0;
private final long id = counter++;
Shared() {
System.out.println("Creating " + this);
}
public void addRef() { refcount++; }
protected void dispose() {
if(--refcount == 0)
System.out.println("Disposing " + this);
}
@Override
public String toString() {
return "Shared " + id;
}
}
class Composing {
private Shared shared;
```

```
private static long counter = 0;
private final long id = counter++;
Composing(Shared shared) {
System.out.println("Creating " + this);
this.shared = shared;
this.shared.addRef();
}
protected void dispose() {
System.out.println("disposing " + this);
shared.dispose();
}
@Override
public String toString() {
return "Composing " + id;
}
}
public class ReferenceCounting {
public static void main(String[] args) {
Shared shared = new Shared();
Composing[] composing = {
```

```
new Composing(shared),
new Composing(shared),
new Composing(shared),
new Composing(shared),
new Composing(shared)
};
for(Composing c : composing)
c.dispose();
}
}
/* Output:
Creating Shared 0
Creating Composing 0
Creating Composing 1
Creating Composing 2
Creating Composing 3
Creating Composing 4
disposing Composing 0
disposing Composing 1
disposing Composing 2
```

disposing Composing 3

disposing Composing 4

Disposing Shared 0

**/*

The **static long counter** keeps track of the number of instances of **Shared** that are created, and it also provides a value for

id. The type of **counter** is **long** rather than **int**, to prevent overflow (this is just good practice; overflowing such a counter is not likely to happen in any of the examples in this book). The **id** is **final** because it should not change its value once initialized.

When you attach a shared object to your class, you must remember to call **addRef()**, but the **dispose()** method will keep track of the reference count and decide when to actually perform the cleanup. This technique requires extra diligence to use, but if you are sharing objects that require cleanup you don’t have much choice.

Behavior of Polymorphic

Methods Inside Constructors

The hierarchy of constructor calls brings up a dilemma. What happens if you're inside a constructor and you call a dynamically bound method of the object that's being constructed?

Inside an ordinary method, the dynamically bound call is resolved at run time, because the object cannot know whether it belongs to the class that the method is in or some class derived from it.

If you call a dynamically bound method inside a constructor, the overridden definition for that method is also used. However, the effect of this call can be rather unexpected because the overridden method is called before the object is fully constructed. This can conceal some difficult-to-find bugs.

Conceptually, the constructor's job is to bring the object into existence (hardly an ordinary feat). Inside any constructor, the entire object might be only partially formed—you can only know that the base-class objects are initialized. If the constructor is only one step in building an object of a class that's been derived from that constructor's class, the derived parts have not yet been initialized at the time the current constructor is called. A dynamically bound method call, however, reaches "outward" into the inheritance hierarchy. It calls a method in a derived class. If you do this inside a constructor, you can call a method

that might manipulate members that haven’t been initialized yet—a sure recipe for disaster.

Here’s the problem:

```
// polymorphism/PolyConstructors.java
// Constructors and polymorphism
// don't produce what you might expect
class Glyph {
void draw() { System.out.println("Glyph.draw()"); }
Glyph() {
System.out.println("Glyph() before draw()");
draw();
System.out.println("Glyph() after draw()");
}
}
class RoundGlyph extends Glyph {
private int radius = 1;
RoundGlyph(int r) {
radius = r;
System.out.println(
"RoundGlyph.RoundGlyph(), radius = " + radius);
```

```
}
@Override
void draw() {
System.out.println(
"RoundGlyph.draw(), radius = " + radius);
}
}
public class PolyConstructors {
public static void main(String[] args) {
new RoundGlyph(5);
}
}
/* Output:
Glyph() before draw()
RoundGlyph.draw(), radius = 0
Glyph() after draw()
RoundGlyph.RoundGlyph(), radius = 5
*/
```

Glyph.draw() is designed for overriding, which happens in **RoundGlyph**. But the **Glyph** constructor calls this method, and the

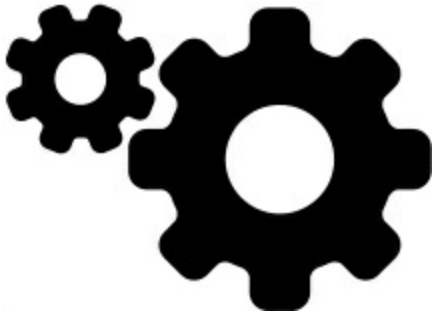
call ends up in **RoundGlyph.draw()**, which would seem to be the intent. The output shows that when **Glyph**s constructor calls **draw()**, the value of **radius** isn't even the default initial value 1. It's 0. This would probably result in either a dot or nothing at all drawn on the screen, and you'd be left staring, trying to figure out why the program won't work.

The order of initialization described in the earlier section isn't quite complete, and that's the key to solving the mystery. The actual process of initialization is:

1. The storage allocated for the object is initialized to binary zero before anything else happens.
2. The base-class constructors are called as described previously. Now the overridden **draw()** method is called (yes, *before* the **RoundGlyph** constructor is called), which discovers a **radius** value of zero, due to Step 1.
3. Member initializers are called in the order of declaration.
4. The body of the derived-class constructor is called.

There's an upside to this: Everything is at least initialized to zero (or whatever zero means for that particular data type) and not just left as garbage. This includes object references embedded inside a class via

composition, which become **null**. So if you forget to initialize that reference, you'll get an exception at run time. Everything else gets zero, usually a telltale value when you are looking at output.



On the other hand, you should be horrified at the outcome of this program. You've done a perfectly logical thing, and yet the behavior is mysteriously wrong, with no complaints from the compiler. (C++ produces more rational behavior in this situation.) Bugs like this can easily be buried and take a long time to discover.

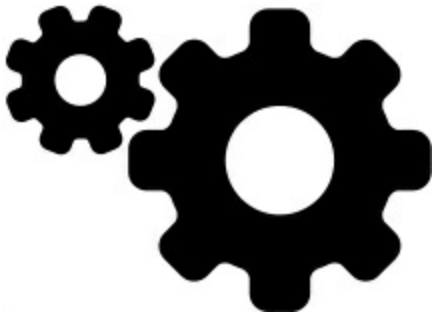
As a result, a good guideline for constructors is "Do as little as possible to set the object into a good state, and if you can possibly avoid it, don't call any other methods in this class." The only safe methods to call inside a constructor are those that are **final** in the base class. (This also applies to **private** methods, which are automatically **final**.) These cannot be overridden and thus cannot produce this kind of surprise. You might not always follow this guideline, but it's something to strive towards.

Covariant Return

Types

Java 5 added *covariant return types*, which means an overridden method in a derived class can return a type *derived from* the type returned by the base-class method:

```
// polymorphism/CovariantReturn.java
class Grain {
@Override
public String toString() { return "Grain"; }
}
class Wheat extends Grain {
@Override
public String toString() { return "Wheat"; }
}
class Mill {
```



```
Grain process() { return new Grain(); }
```

```
}
class WheatMill extends Mill {
@Override
Wheat process() { return new Wheat(); }
}
public class CovariantReturn {
public static void main(String[] args) {
Mill m = new Mill();
Grain g = m.process();
System.out.println(g);
m = new WheatMill();
g = m.process();
System.out.println(g);
}
}
/* Output:
Grain
Wheat
*/
```

The key difference here is that pre-Java-5 versions forced the

overridden version of **process()** to return **Grain**, rather than **Wheat**, even though **Wheat** is derived from **Grain** and thus is still a legitimate return type. Covariant return types allow the more specific **Wheat** return type.

Designing with Inheritance

Once you learn polymorphism, it can seem that everything ought to be inherited, because polymorphism is such a clever tool. This can burden your designs. In fact, if you choose inheritance first when you're using an existing class to make a new class, things can become needlessly complicated.

A better approach is to choose composition first, especially when it's not obvious which approach to use. Composition does not force a design into an inheritance hierarchy. Composition is also more flexible since it's possible to dynamically choose a type (and thus behavior) when using composition, whereas inheritance requires that an exact type be known at compile time. The following example illustrates this:

```
// polymorphism/Transmogrify.java
// Dynamically changing the behavior of an object
// via composition (the "State" design pattern)
```

```
class Actor {
public void act() {}
}
class HappyActor extends Actor {
@Override
public void act() {
System.out.println("HappyActor");
}
}
class SadActor extends Actor {
@Override
public void act() {
System.out.println("SadActor");
}
}
class Stage {
private Actor actor = new HappyActor();
public void change() { actor = new SadActor(); }
public void performPlay() { actor.act(); }
}
```

```
public class Transmogrify {
public static void main(String[] args) {
Stage stage = new Stage();
stage.performPlay();
stage.change();
```

```
stage.performPlay();
}
}
/* Output:
HappyActor
SadActor
*/
```

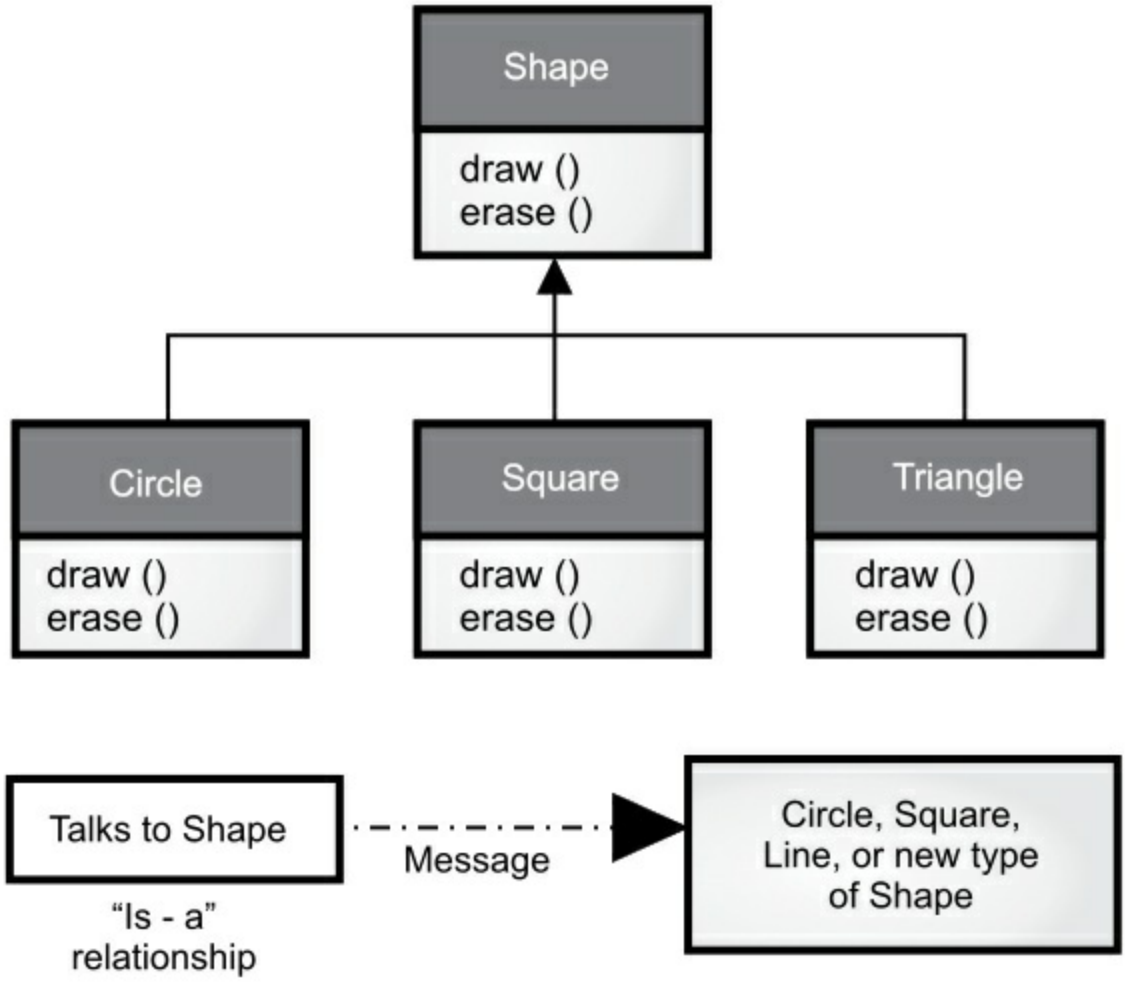
A **Stage** object contains a reference to an **Actor**, which is initialized to a **HappyActor** object. This means **performPlay()** produces a particular behavior. But since a reference can be re-bound to a different object at run time, a reference for a **SadActor** object can be substituted in **actor**, then the behavior produced by

performPlay() changes. Thus you gain dynamic flexibility at run time. (This is also called the *State pattern*). In contrast, you can't decide to inherit differently at run time; that must be completely determined at compile time.

A general guideline is "Use inheritance to express differences in behavior, and fields to express variations in state." In the preceding example, both are used; two different classes are inherited to express the difference in the **act()** method, and **Stage** uses composition to allow its state to be changed. Here, that change in state happens to produce a change in behavior.

Substitution vs. Extension

It would seem that the cleanest way to create an inheritance hierarchy is to take the "pure" approach. That is, only methods from the base class are overridden in the derived class, as seen in this diagram:

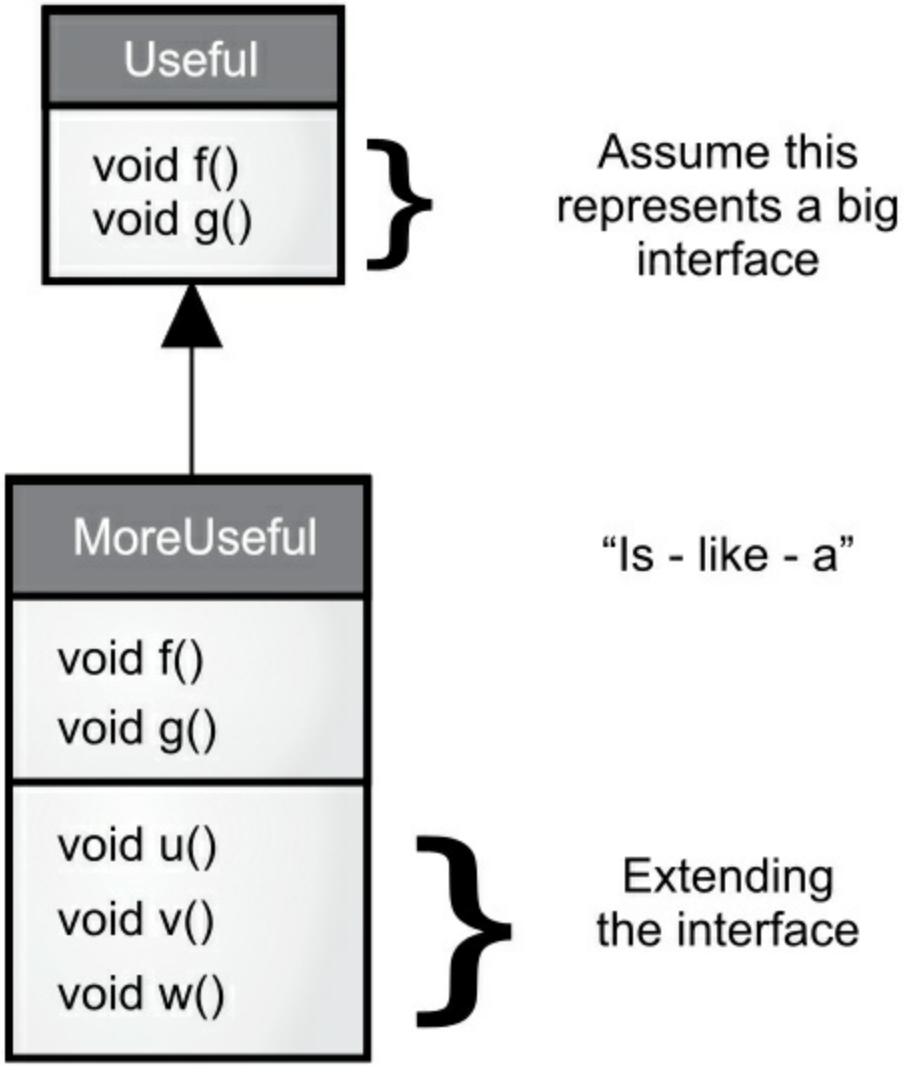


This can be called a pure “is-a” relationship because the interface of a class establishes what it is. Inheritance guarantees that any derived class has the interface of the base class and nothing less. If you follow this diagram, derived classes will also have *no more* than the base-class interface.

This *pure substitution* means derived class objects can be perfectly substituted for the base class, and you don’t know any extra information about the subclasses when you’re using them:

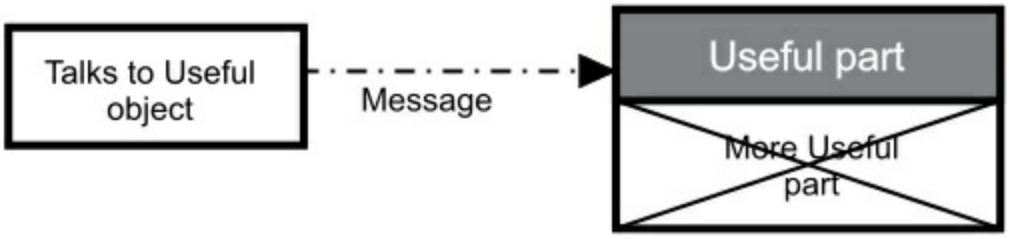
That is, the base class can receive any message you can send to the derived class because the two have exactly the same interface. All you do is upcast from the derived class and never look back to see what exact type of object you're dealing with. Everything is handled through polymorphism.

When you see it this way, it seems like a pure is-a relationship is the only sensible way to do things, and any other design indicates



muddled thinking and is by definition broken. This too is a trap. As soon as you start thinking this way, you'll turn around and discover that extending the interface (which, unfortunately, the keyword **extends** seems to encourage) is the perfect solution to a particular problem. This can be termed an "is-like-a" relationship, because the derived class is *like* the base class—it has the same fundamental interface—but it has other features that require additional methods to implement:

While this is also a useful and sensible approach (depending on the situation), it has a drawback. The extended part of the interface in the



derived class is not available from the base class, so once you upcast, you can't call the new methods:

If you're not upcasting, it won't bother you, but often you'll get into a

situation where you must rediscover the exact type of the object so you can access the extended methods of that type. The following section shows how this is done.

Downcasting and Runtime

Type Information

Since you lose the specific type information via an *upcast* (moving up the inheritance hierarchy), it makes sense that to retrieve the type information—that is, to move back down the inheritance hierarchy—you use a *downcast*.

You know an upcast is always safe because the base class cannot have a bigger interface than the derived class. Therefore, every message you send through the base-class interface is guaranteed to be accepted. With a downcast, however, you don’t really know that a shape (for example) is actually a circle. It could also be a triangle or square or some other type.

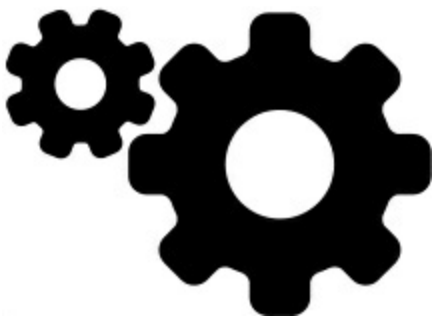
To solve this problem, there must be some way to guarantee that a downcast is correct, so you won’t accidentally cast to the wrong type then send a message that the object can’t accept. That would be unsafe.

In some languages (like C++) you must perform a special operation to

get a type-safe downcast, but in Java, *every* cast is checked! So even though it looks like you're just performing an ordinary parenthesized cast, at run time this cast is checked to ensure it is in fact the type you think it is. If it isn't, you get a **ClassCastException**. This act of checking types at run time is called *runtime type information* (RTTI). The following example demonstrates the behavior of RTTI:

```
// polymorphism/RTTI.java
// Downcasting & Runtime type information (RTTI)
// {ThrowsException}
class Useful {
public void f() {}
public void g() {}
}
class MoreUseful extends Useful {
@Override
public void f() {}
@Override
public void g() {}
public void u() {}
public void v() {}
```

```
public void w() {}
}
public class RTTI {
public static void main(String[] args) {
Useful[] x = {
new Useful(),
new MoreUseful()
};
x[0].f();
x[1].g();
// Compile time: method not found in Useful:
//- x[1].u();
((MoreUseful)x[1]).u(); // Downcast/RTTI
((MoreUseful)x[0]).u(); // Exception thrown
}
}
```



/ *Output:*

___[Error Output]___

Exception in thread "main"

java.lang.ClassCastException: Useful cannot be cast to

MoreUseful

at RTTI.main(RTTI.java:31)

**/*

As in the previous diagram, **MoreUseful** extends the interface of **Useful**. But since it's inherited, it can also be upcast to a **Useful**. You see this happening in the initialization of the array **x** in **main()**. Since both objects in the array are of class **Useful**, you can send the **f()** and **g()** methods to both, and if you try to call **u()** (which exists only in **MoreUseful**), you'll get a compile-time error message.

To access the extended interface of a **MoreUseful** object, you can try downcasting. If it's the correct type, it is successful. Otherwise, you'll get a **ClassCastException**. You don't write any special code for this exception, since it indicates a programmer error that could happen anywhere in a program. The **{ThrowsException}** comment tag tells this book's build system to expect this program to throw an exception when it executes.

There's more to RTTI than a simple cast. For example, there's a way to

see what type you're dealing with *before* you try to downcast it. The Type Information chapter is devoted to the study of different aspects of Java runtime type information.

Summary

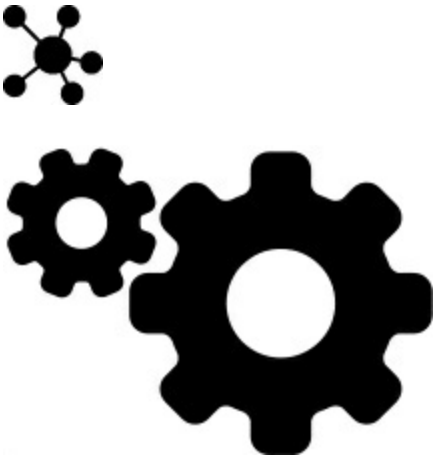
Polymorphism means "different forms." In object-oriented programming, you have the same interface from the base class, and different forms using that interface: the different versions of the dynamically bound methods.

You've seen in this chapter that it's impossible to understand, or even create, an example of polymorphism without using data abstraction and inheritance. Polymorphism is a feature that cannot be viewed in isolation (like a **switch** statement can, for example), but instead works only in concert, as part of the larger picture of class relationships.

To use polymorphism—and thus object-oriented techniques—effectively in your programs, you must expand your view of programming to include not just members and messages of an individual class, but also the commonality among classes and their relationships with each other. Although this requires significant effort, it's a worthy struggle. The results are faster program development, better code organization, extensible programs, and easier code

maintenance.

Keep in mind, however, that polymorphism can be overused. Analyze your code and make sure it’s actually providing a benefit.



Interfaces

Interfaces and abstract classes provide a more structured way to separate interface from implementation.

Such mechanisms are not that common in programming languages. C++, for example, only has indirect support for these concepts. The fact that language keywords exist in Java indicates that these ideas were considered important enough to provide direct support.

First, we’ll look at the *abstract class*, a kind of midway step between an ordinary class and an interface. Although your first impulse is to create an interface, the abstract class is an important and necessary

tool for building classes that have fields and unimplemented methods. You can't always use a pure interface.

Abstract Classes and Methods

In all the "instrument" examples in the previous chapter, the methods in the base class **Instrument** were always "dummy" methods. If these methods are ever called, you've done something wrong. That's because the intent of **Instrument** is to create a common interface for all the classes derived from it.

In those examples, the only reason to create this common interface is so it can be expressed differently for each different subtype. It establishes a basic form, so you can say what's common for all the derived classes. Another way of saying this is to call **Instrument** an *abstract base class*, or simply an *abstract class*.

For an abstract class like **Instrument**, objects of that specific class almost always have no meaning. You create an abstract class when you want to manipulate a set of classes through its common interface. Thus, **Instrument** is meant to express only the interface, and not a particular implementation, so creating an object that is *only* an **Instrument** makes no sense, and you'll probably want to prevent

the user from doing it. This can be accomplished by making all the methods in **Instrument** generate errors, but that delays the information until run time and requires reliable exhaustive testing on the user's part. It's usually better to catch problems at compile time. Java provides a mechanism for doing this called the *abstract method*.1 This is a method that is incomplete; it has only a declaration and no method body. Here is the syntax for an abstract method declaration:

abstract void f();

A class containing abstract methods is called an *abstract class*. If a class contains one or more abstract methods, the class itself must be qualified as **abstract**, otherwise, the compiler produces an error message.

```
// interfaces/Basic.java
abstract class Basic {
abstract void unimplemented();
}
```

If an abstract class is incomplete, what is Java supposed to do when someone tries to make an object of that class? It cannot safely create an object of an abstract class, so you get an error message from the compiler. This ensures the purity of the abstract class, and you don't

worry about misusing it.

```
// interfaces/AttemptToUseBasic.java
// {WillNotCompile}
public class AttemptToUseBasic {
Basic b = new Basic();
// error: Basic is abstract; cannot be instantiated
}
```

If you inherit from an abstract class and you want to make objects of the new type, you must provide method definitions for all the abstract methods in the base class. If you don't (and you might choose not to), then the derived class is also abstract, and the compiler will force you to qualify *that* class with the **abstract** keyword.

```
// interfaces/Basic2.java
abstract class Basic2 extends Basic {
int f() { return 111; }
abstract void g();
// unimplemented() still not implemented
}
```

It's possible to make a class **abstract** without including any **abstract** methods. This is useful when you've got a class where

abstract methods don’t make sense, and yet you want to prevent any instances of that class.

```
// interfaces/AbstractWithoutAbstracts.java
abstract class Basic3 {
int f() { return 111; }
// No abstract methods
}
public class AbstractWithoutAbstracts {
// Basic3 b3 = new Basic3();
// error: Basic3 is abstract; cannot be instantiated
}
```

To create an instantiable class, inherit from your **abstract** class and provide definitions for all the **abstract** methods:

```
// interfaces/Instantiable.java
abstract class Uninstantiable {
abstract void f();
abstract int g();
}
public class Instantiable extends Uninstantiable {
@Override
```

```
void f() { System.out.println("f()"); }
@Override
int g() { return 22; }
public static void main(String[] args) {
Uninstantiable ui = new Instantiable();
}
}
```

Note the use of **@Override**. Without this annotation, if you don't provide the exact method name or signature, the **abstract** mechanism sees you haven't implemented the **abstract** method and produces a compile-time error. Thus, you could effectively argue that **@Override** is redundant here. However, **@Override** also gives the reader a signal that this method is overridden—I consider this useful, and so will use **@Override** even when the compiler would inform me of mistakes without it.

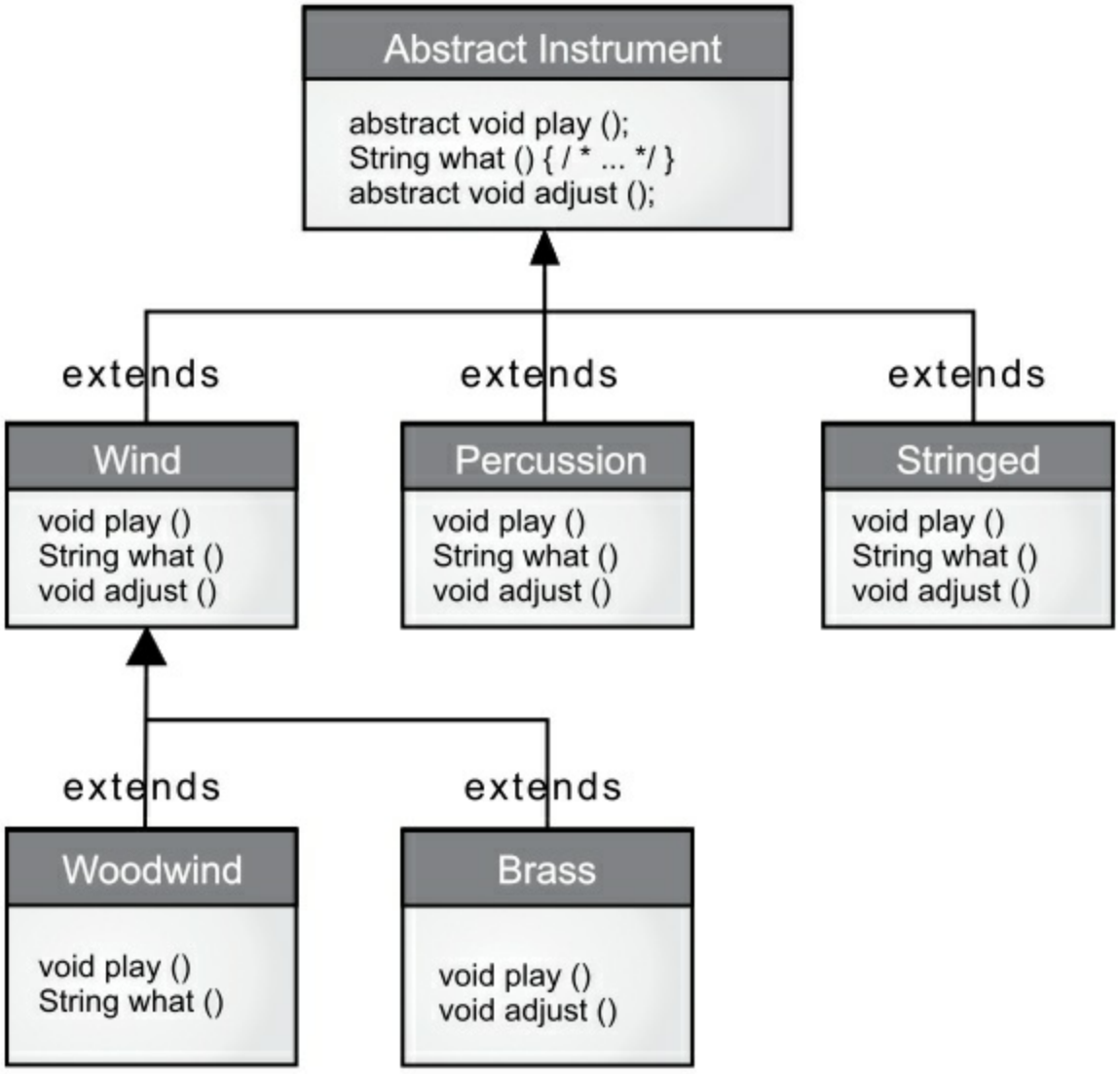
Remember that the defacto access is "friendly." You'll see shortly that an interface automatically makes its methods **public**; in fact, interfaces *only* allow **public** methods and if you don't provide an access specifier, the resulting method is *not* "friendly," but **public**.

Whereas **abstract** classes allow almost everything:

```
// interfaces/AbstractAccess.java
abstract class AbstractAccess {
private void m1() {}
// private abstract void m1a(); // illegal
protected void m2() {}
protected abstract void m2a();
void m3() {}
abstract void m3a();
public void m4() {}
public abstract void m4a();
}
```

It makes sense that **private abstract** is not allowed, because you could never legally provide a definition in any subclass of **AbstractAccess**.

The **Instrument** class from the previous chapter can easily be turned into an **abstract** class. Only some of the methods are **abstract**; making a class **abstract** doesn't force you to make all the methods **abstract**. Here's what it looks like:



Here's the orchestra example modified to use **abstract** classes and methods:

// interfaces/music4/Music4.java

// Abstract classes and methods

// {java interfaces.music4.Music4}

package interfaces.music4;

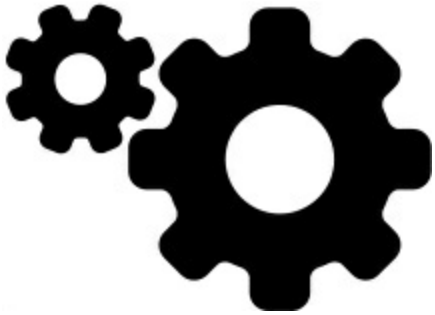
```
import polymorphism.music.Note;
abstract class Instrument {
private int i; // Storage allocated for each
public abstract void play(Note n);
public String what() { return "Instrument"; }
public abstract void adjust();
}
class Wind extends Instrument {
@Override
public void play(Note n) {
System.out.println("Wind.play() " + n);
}
@Override
public String what() { return "Wind"; }
@Override
public void adjust() {
System.out.println("Adjusting Wind");
}
}
class Percussion extends Instrument {
```

```
@Override
public void play(Note n) {
System.out.println("Percussion.play() " + n);
}
@Override
public String what() { return "Percussion"; }
@Override
public void adjust() {
System.out.println("Adjusting Percussion");
}
}
class Stringed extends Instrument {
@Override
public void play(Note n) {
System.out.println("Stringed.play() " + n);
}
@Override
public String what() { return "Stringed"; }
@Override
public void adjust() {
```

```
System.out.println("Adjusting Stringed");
}
}
class Brass extends Wind {
@Override
public void play(Note n) {
System.out.println("Brass.play() " + n);
}
@Override
public void adjust() {
System.out.println("Adjusting Brass");
}
}
class Woodwind extends Wind {
@Override
public void play(Note n) {
System.out.println("Woodwind.play() " + n);
}
@Override
public String what() { return "Woodwind"; }
```

```
}
public class Music4 {
// Doesn't care about type, so new types
// added to the system still work right:
static void tune(Instrument i) {
// ...
i.play(Note.MIDDLE_C);
}
static void tuneAll(Instrument[] e) {
for(Instrument i : e)
tune(i);
}
public static void main(String[] args) {
// Upcasting during addition to the array:
Instrument[] orchestra = {
new Wind(),
new Percussion(),
new Stringed(),
new Brass(),
new Woodwind()
```

```
};
tuneAll(orchestra);
}
}
/* Output:
Wind.play() MIDDLE_C
Percussion.play() MIDDLE_C
Stringed.play() MIDDLE_C
Brass.play() MIDDLE_C
```



```
Woodwind.play() MIDDLE_C
*/
```

There’s really no change except in **Instrument**.

It’s helpful to create **abstract** classes and methods because they make the abstractness of a class explicit, and tell both the user and the compiler its intended use. Abstract classes are also useful refactoring tools, since they allow you to easily move common methods up the

inheritance hierarchy.

Interfaces

To create an interface, use the **interface** keyword. The name "interface" is so commonly used throughout this book that, like "class," I set it in normal body font unless I am specifically referring to the keyword **interface**.

Interfaces were easier to describe before Java 8, because they only allowed **abstract** methods. They looked like this:

```
// interfaces/PureInterface.java
// Interface only looked like this before Java 8
public interface PureInterface {
int m1();
void m2();
double m3();
}
```

You don't even have to use the **abstract** keyword on the methods—because they are in an interface, Java knows they can't have method bodies (you can still add the **abstract** keyword, but then it just looks like you don't understand interfaces and you'll embarrass yourself).

So, before Java 8, we could say things like:

*The **interface** keyword creates a completely abstract class, one that doesn't represent any implementation. With an interface, you describe what a class should look like, and do, but not how it should do it. You determine method names, argument lists, and return types, but no method bodies. An interface provides only a form, but generally no implementation, although in certain restricted cases, it can.*

An interface says, "All classes that implement this particular interface will look like this." Thus, any code that uses a particular interface knows what methods might be called for that interface, and that's all. So the interface is used to establish a "protocol" between classes. (Some object-oriented programming languages have a keyword called protocol to do the same thing.)

With Java 8 the interface waters have been muddied a bit, because Java 8 allows both **default** methods and **static** methods—for important reasons that you'll understand as we progress through the book. The basic concept of the interface still holds, which is that they are more of a *concept* of a type, and less of an implementation. Perhaps the most notable difference between an interface and an

abstract class is the idiomatic ways the two are used. An interface typically suggests a “type of class” or an adjective, like *Runnable*, or *Serializable*, whereas an abstract class is usually part of your class hierarchy and is a “type of thing,” like *String* or *ActionHero*.

To create an interface, use the **interface** keyword instead of the **class** keyword. As with a class, you can add the **public** keyword before the **interface** keyword (but only if that interface is defined in a file of the same name). If you leave off the **public** keyword, you get package access, so the interface is only usable within the same package.

An interface can also contain fields, but these are implicitly **static** and **final**.

To make a class that conforms to a particular interface (or group of interfaces), use the **implements** keyword, which says, “The interface is what it looks like, but now I’m going to say how it *works*.” Other than that, it looks like inheritance.

// interfaces/ImplementingAnInterface.java

interface Concept { *// Package access*

void idea1();

void idea2();

}

class Implementation **implements** Concept {

public void idea1() { System.out.println("idea1"); }

public void idea2() { System.out.println("idea2"); }

}

You can choose to explicitly declare the methods in an interface as **public**, but they are **public** even if you don't say it. So when you **implement** an **interface**, the methods from the interface *must* be defined as **public**. Otherwise, they would default to package access, and you'd be reducing the accessibility of a method during inheritance, which is not allowed by the Java compiler.

Default Methods

Java 8 creates an additional use for the **default** keyword (formerly used only in **switch** statements and annotations). When used within an interface, **default** creates a method body that is substituted whenever the interface is implemented without defining that method. Default methods are a bit more limited than methods on **abstract**

classes, but can be very useful, as we will see in the Streams chapter.

Let’s see how this works by starting with an interface:

```
// interfaces/AnInterface.java
interface AnInterface {
void firstMethod();
void secondMethod();
}
```

We can implement this in the usual way:

```
// interfaces/AnImplementation.java
public class AnImplementation implements AnInterface {
public void firstMethod() {
System.out.println("firstMethod");
}
public void secondMethod() {
System.out.println("secondMethod");
}
public static void main(String[] args) {
AnInterface i = new AnImplementation();
i.firstMethod();
i.secondMethod();
```

}

}

/ *Output:*

firstMethod

secondMethod

**/*

If we add another method **newMethod()** to **AnInterface** without an associated implementation for that method within **AnImplementation**, the compiler will issue an error:

AnImplementation.java:3: error: AnImplementation is not abstract and does not override abstract method newMethod() in AnInterface

public class AnImplementation implements AnInterface {

^

1 error

If we use the **default** keyword and provide a default definition for **newMethod()**, all existing uses of the interface can continue to work, untouched, while new code can call **newMethod()**:

// interfaces/InterfaceWithDefault.java

interface InterfaceWithDefault {

```
void firstMethod();
void secondMethod();
default void newMethod() {
System.out.println("newMethod");
}
}
```

The **default** keyword allows method implementations within interfaces—before Java 8 this was not permitted.

```
// interfaces/Implementation2.java
public class Implementation2
implements InterfaceWithDefault {
public void firstMethod() {
System.out.println("firstMethod");
}
public void secondMethod() {
System.out.println("secondMethod");
}
public static void main(String[] args) {
InterfaceWithDefault i =
new Implementation2();
```

```
i.firstMethod();
i.secondMethod();
```

```
i.newMethod();
}
}
/* Output:
firstMethod
secondMethod
newMethod
*/
```

Although **newMethod()** has no definition within **Implementation2**, it's now available.

The compelling reason to add **default** methods is that they allow you to add methods to an existing interface without breaking all the code that already uses that interface. **default** methods are sometimes also called *defender methods* or *virtual extension methods*.

Multiple Inheritance

Multiple inheritance means a class may inherit characteristics and features from more than one parent type.

When Java was first designed, multiple inheritance in C++ was roundly denigrated. Java was strictly a single-inheritance language: You could only inherit from one class (or **abstract** class). You could also implement as many interfaces as you like, but before Java 8 an interface carried no baggage—it was only a description of what its methods looked like.

Now, many years later, via **default** methods, Java has *some* multiple inheritance. Combining interfaces with **default** methods means you can combine *behaviors* from multiple base types. Because interfaces still don't allow fields (only **static** fields, which don't apply), fields can still only come from the single base class or **abstract** class; that is, you cannot have multiple inheritance of *state*. Here's what it looks like:

```
// interfaces/MultipleInheritance.java
import java.util.*;
interface One {
default void first() { System.out.println("first"); }
}
```

```
interface Two {
default void second() {
System.out.println("second");
}
}
interface Three {
default void third() { System.out.println("third"); }
}
class MI implements One, Two, Three {}
public class MultipleInheritance {
public static void main(String[] args) {
MI mi = new MI();
mi.first();
mi.second();
mi.third();
}
}
/* Output:
first
second
```

third

*/

Now we can do something we never could prior to Java 8: combine implementations from multiple sources. This works fine as long as all the base-class methods have distinct names and argument lists. If not, you get compile-time errors:

```
// interfaces/MICollision.java
import java.util.*;
interface Bob1 {
default void bob() {
System.out.println("Bob1::bob");
}
}
interface Bob2 {
default void bob() {
System.out.println("Bob2::bob");
}
}
// class Bob implements Bob1, Bob2 {}
/* Produces:
```

error: class Bob inherits unrelated defaults

for bob() from types Bob1 and Bob2

class Bob implements Bob1, Bob2 {}

^

1 error

/

interface Sam1 {

default void sam() {

System.out.println("Sam1::sam");

}

}

interface Sam2 {

default void sam(int i) {

System.out.println(i * 2);

}

}

// This works because the argument lists are distinct:

class Sam **implements** Sam1, Sam2 {}

interface Max1 {

default void max() {

```
System.out.println("Max1::max");
}
}
interface Max2 {
default int max() { return 47; }
}
// class Max implements Max1, Max2 {}
/* Produces:
error: types Max2 and Max1 are incompatible;
both define max(), but with unrelated return types
class Max implements Max1, Max2 {}
^
1 error
*/
```

In **Sam**, the two **sam()** methods have the same name but their *signatures* are unique—the signature includes the name and argument types, and it's what the compiler uses to distinguish one method from another. However, as **Max** shows, the return type is not part of the signature and thus cannot be used to differentiate two methods.

To fix the problem, you must override the conflicting method:

```
// interfaces/Jim.java
import java.util.*;
interface Jim1 {
default void jim() {
System.out.println("Jim1::jim");
}
}
interface Jim2 {
default void jim() {
System.out.println("Jim2::jim");
}
}
public class Jim implements Jim1, Jim2 {
@Override
public void jim() { Jim2.super.jim(); }
```

```
public static void main(String[] args) {
new Jim().jim();
```

}

}

/ *Output:*

Jim2::jim

**/*

Of course, you can redefine **jim()** to anything you want, but you'll typically choose one of the base-class implementations using the **super** keyword, as shown.

static Methods in Interfaces

Java 8 also adds the ability to include **static** methods inside interfaces. This allows utilities that rightly belong in the interface, which are typically things that manipulate that interface, or are general-purpose tools:

// onjava/Operations.java

package onjava;

import java.util.*;

public interface Operations {

void execute();

static void runOps(Operations**...** ops) {

for(Operations op : ops)

```
op.execute();
}
static void show(String msg) {
System.out.println(msg);
}
}
```

This is a version of the *Template Method* design pattern (described in the Patterns chapter), where **runOps()** is the template method.

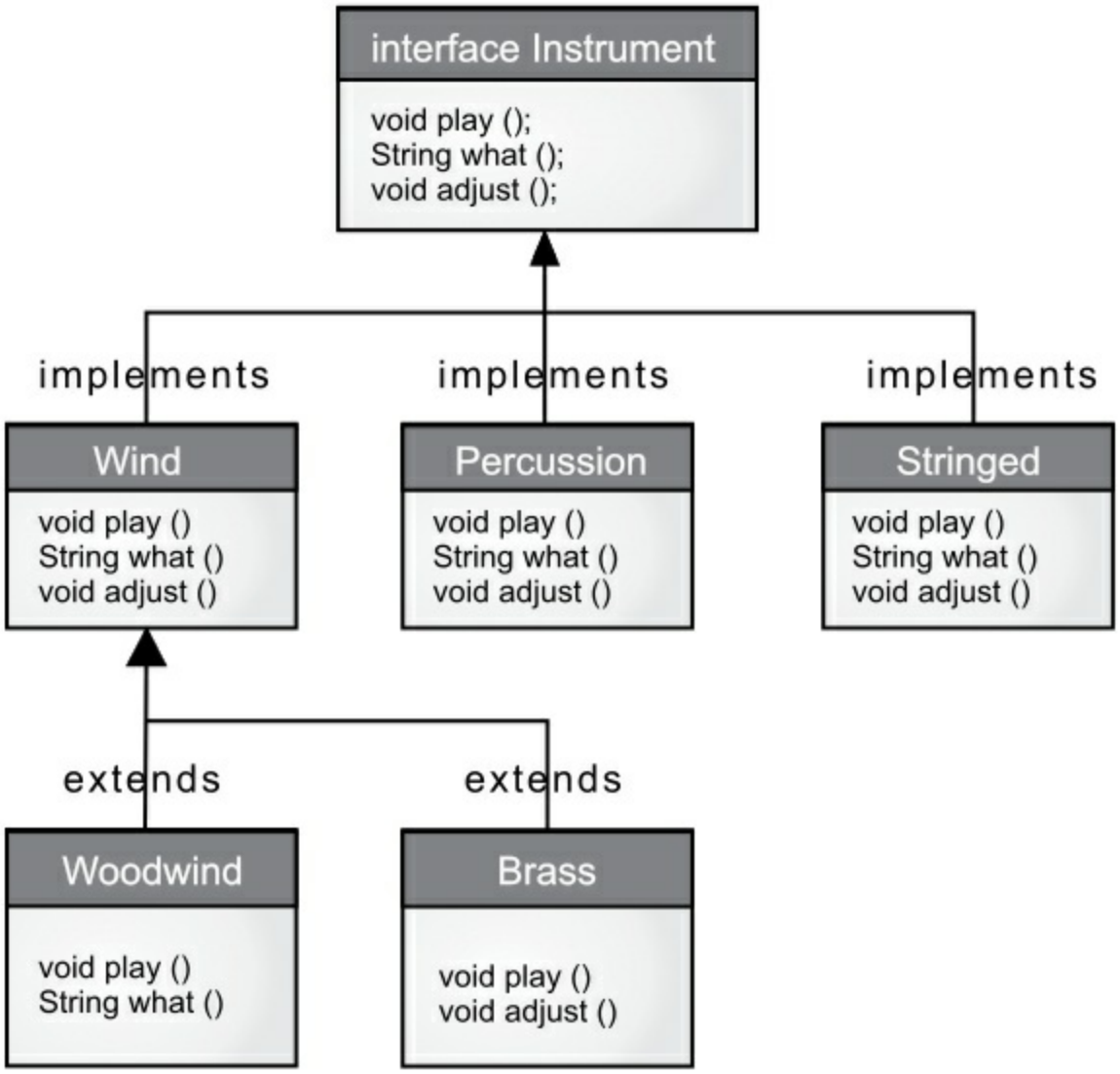
runOps() uses a variable argument list so we can pass as many **Operation** arguments as we want and run them in order:

```
// interfaces/Machine.java
import java.util.*;
import onjava.Operations;
class Bing implements Operations {
public void execute() {
Operations.show("Bing");
}
}
class Crack implements Operations {
public void execute() {
```

```
Operations.show("Crack");
}
}
class Twist implements Operations {
public void execute() {
Operations.show("Twist");
}
}
public class Machine {
public static void main(String[] args) {
Operations.runOps(
new Bing(), new Crack(), new Twist());
}
}
/* Output:
Bing
Crack
Twist
*/
```

Here you see the different ways to create **Operations**: an external

class (**Bing**), an anonymous class, a method reference, and lambda expressions—which certainly appear to be the nicest solution here.



This feature is an improvement, because it allows you to keep **static**

methods in more appropriate places.

Instrument as an Interface

Let’s revisit the instrument example, using interfaces:

The **Woodwind** and **Brass** classes show that once you’ve

implemented an interface, that implementation becomes an ordinary

class that can be extended in the regular way.

Because of the way interfaces work, none of the methods in

Instrument are explicitly **public**, but they’re automatically

public anyway. Both **play()** and **adjust()** have definitions using the **default** keyword. Before Java 8, both definitions had to be

duplicated in each implementation, which was redundant and

annoying:

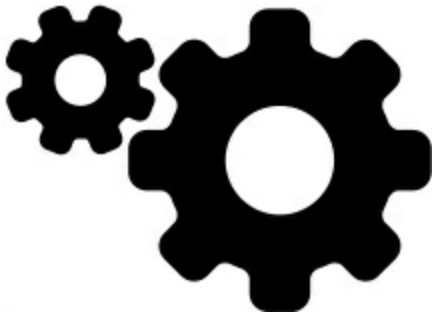
```
// interfaces/music5/Music5.java
// {java interfaces.music5.Music5}
package interfaces.music5;
import polymorphism.music.Note;
interface Instrument {
// Compile-time constant:
int VALUE = 5; // static & final
default void play(Note n) { // Automatically public
System.out.println(this + ".play() " + n);
```

```
}
default void adjust() {
System.out.println("Adjusting " + this);
}
}
class Wind implements Instrument {
@Override
public String toString() { return "Wind"; }
}
class Percussion implements Instrument {
@Override
public String toString() { return "Percussion"; }
}
class Stringed implements Instrument {
@Override
public String toString() { return "Stringed"; }
}
class Brass extends Wind {
@Override
public String toString() { return "Brass"; }
```

```
}
class Woodwind extends Wind {
@Override
public String toString() { return "Woodwind"; }
}
public class Music5 {
// Doesn't care about type, so new types
// added to the system still work right:
static void tune(Instrument i) {
// ...
i.play(Note.MIDDLE_C);
}
static void tuneAll(Instrument[] e) {
for(Instrument i : e)
tune(i);
}
public static void main(String[] args) {
// Upcasting during addition to the array:
Instrument[] orchestra = {
new Wind(),
```

```
new Percussion(),
new Stringed(),
new Brass(),
new Woodwind()
};
tuneAll(orchestra);
}
}
/* Output:
Wind.play() MIDDLE_C
Percussion.play() MIDDLE_C
Stringed.play() MIDDLE_C
Brass.play() MIDDLE_C
Woodwind.play() MIDDLE_C
*/
```

One other change was made to this version of the example: The **what()** method is changed to **toString()**, since that is how the method is used. Since **toString()** is part of the root class **Object**, it doesn't have to appear in the interface.



Notice it doesn’t matter if you are upcasting to a “regular” class called **Instrument**, an **abstract** class called **Instrument**, or to an interface called **Instrument**. The behavior is the same. In fact, the **tune()** method shows that there isn’t any evidence about whether **Instrument** is a “regular” class, an **abstract** class, or an interface.

Abstract Classes

vs. Interfaces

Especially with the addition of **default** methods in Java 8, it can become somewhat confusing to know when an abstract class is the best choice, and when you should instead use an interface. This table should make the distinction clear:

Abstract

Feature

Interfaces

Classes

Can combine

Can only inherit

Combinations

Multiple interfaces

from a single

in a new class.

abstract class.

Cannot contain

Can contain fields.

fields (except

Non-**abstract**

State

static fields,

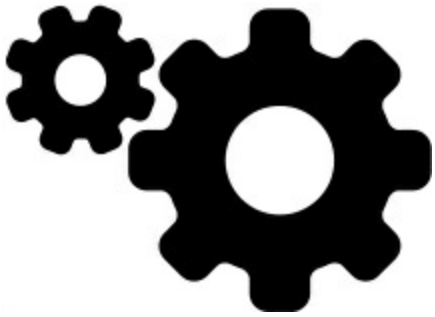
methods may refer

which do not

to these fields.

support object state).

default methods



need not be

abstract methods

default methods

implemented in

must be

& **abstract**

subtypes. **default**

implemented in

methods

methods can only

subtypes.

refer to other

interface methods

(not fields).

Cannot have a

Can have a

Constructor

constructor.

constructor.

Visibility

Can be **protected**

Implicitly **public**.

or “friendly.”

An **abstract** class is still a class, and can thus be the only class inherited when creating a new class. Multiple interfaces can be implemented in the process of creating a new class.

A rule of thumb is to “be as abstract as possible—within reason.” Thus, prefer interfaces over abstract classes. You’ll know when you must use an abstract class. And don’t use either one unless you must. Most of the time, a regular class will do the trick, and when it doesn’t, you can move to an interface or abstract class.

Complete Decoupling

Whenever a method works with a class instead of an interface, you are limited to using that class or its subclasses. If you would like to apply the method to a class that isn’t in that hierarchy, you’re out of luck. An interface relaxes this constraint considerably. As a result, you can

write more reusable code.

For example, suppose you have a **Processor** class with **name()** and **process()** methods. **process()** takes input, modifies it and

produces output. This class is inherited to create different types of

Processor. Here, the **Processor** types modify **String** objects

(note that the return types can be covariant, but not the argument

types):

```
// interfaces/Applicator.java

import java.util.*;

class Processor {

public String name() {

return getClass().getSimpleName();

}

public Object process(Object input) {

return input;

}

}

class Upcase extends Processor {

@Override // Covariant return:

public String process(Object input) {

return ((String)input).toUpperCase();
```

```
}
}
class Downcase extends Processor {
@Override
public String process(Object input) {
return ((String)input).toLowerCase();
}
}
class Splitter extends Processor {
@Override
public String process(Object input) {
// split() divides a String into pieces:
return Arrays.toString(((String)input).split(" "));
}
}
public class Applicator {
public static void apply(Processor p, Object s) {
System.out.println("Using Processor " + p.name());
System.out.println(p.process(s));
}
```

```
public static void main(String[] args) {
String s =
"We are such stuff as dreams are made on";
apply(new Upcase(), s);
apply(new Downcase(), s);
apply(new Splitter(), s);
}
}
/* Output:
Using Processor Upcase
WE ARE SUCH STUFF AS DREAMS ARE MADE ON
Using Processor Downcase
we are such stuff as dreams are made on
Using Processor Splitter
[We, are, such, stuff, as, dreams, are, made, on]
*/
```

The **Applicator.apply()** method takes any kind of **Processor**, applies it to an **Object** and prints the results. Creating a method that behaves differently depending on the argument object you pass it is called the *Strategy* design pattern. The method contains

the fixed part of the algorithm, and the Strategy contains the part that varies. The Strategy is the object you pass in, containing code. Here, the **Processor** object is the Strategy, and **main()** shows three different Strategies applied to the **String s**.

The **split()** method is part of the **String** class. It takes the **String** object and splits it using the argument as a boundary, and returns a **String[]**. It is used here as a shorter way of creating an array of **String**.

Now suppose you discover a set of electronic filters that seem like they might fit into your **Applicator.apply()** method:

```
// interfaces/filters/Waveform.java
package interfaces.filters;
public class Waveform {
private static long counter;
private final long id = counter++;
@Override
public String toString() {
return "Waveform " + id;
}
}
```

```
// interfaces/filters/Filter.java
package interfaces.filters;
public class Filter {
public String name() {
return getClass().getSimpleName();
}
public Waveform process(Waveform input) {
return input;
}
}
// interfaces/filters/LowPass.java
package interfaces.filters;
public class LowPass extends Filter {
double cutoff;
public LowPass(double cutoff) {
this.cutoff = cutoff;
}
@Override
public Waveform process(Waveform input) {
return input; // Dummy processing
```

```
}
}
// interfaces/filters/HighPass.java
package interfaces.filters;
public class HighPass extends Filter {
double cutoff;
public HighPass(double cutoff) {
this.cutoff = cutoff;
}
@Override
public Waveform process(Waveform input) {
return input;
}
}
// interfaces/filters/BandPass.java
package interfaces.filters;
public class BandPass extends Filter {
double lowCutoff, highCutoff;
public BandPass(double lowCut, double highCut) {
lowCutoff = lowCut;
```

```
highCutoff = highCut;
}
@Override
public Waveform process(Waveform input) {
return input;
}
}
```

Filter has the same interface elements as **Processor**, but because it isn't inherited from **Processor**—because the creator of the **Filter** class had no clue you might want to use it as a **Processor**—you can't use a **Filter** with the **Applicator.apply()** method, even though it would work fine. Basically, the coupling between **Applicator.apply()** and **Processor** is stronger than it needs to be, and this prevents the **Applicator.apply()** code from being reused when it ought to be. Also notice that the inputs and outputs are both **Waveform**s.

If **Processor** is an interface, however, the constraints are loosened enough you can reuse an **Applicator.apply()** that takes that interface. Here are the modified versions of **Processor** and **Applicator**:

```
// interfaces/interfaceprocessor/Processor.java
package interfaces.interfaceprocessor;
public interface Processor {
default String name() {
return getClass().getSimpleName();
}
Object process(Object input);
}
// interfaces/interfaceprocessor/Applicator.java
package interfaces.interfaceprocessor;
public class Applicator {
public static void apply(Processor p, Object s) {
System.out.println("Using Processor " + p.name());
System.out.println(p.process(s));
}
}
```

The first way you can reuse code is if client programmers can write their classes to conform to the interface, like this:

```
// interfaces/interfaceprocessor/StringProcessor.java
// {java interfaces.interfaceprocessor.StringProcessor}
```

```
package interfaces.interfaceprocessor;
import java.util.*;
interface StringProcessor extends Processor {
@Override
String process(Object input); // [1]
String S = // [2]
"If she weighs the same as a duck, " +
"she's made of wood";
static void main(String[] args) { // [3]
Applicator.apply(new Upcase(), S);
Applicator.apply(new Downcase(), S);
Applicator.apply(new Splitter(), S);
}
}
class Upcase implements StringProcessor {
@Override // Covariant return:
public String process(Object input) {
return ((String)input).toUpperCase();
}
}
```

```
class Downcase implements StringProcessor {
@Override
public String process(Object input) {
return ((String)input).toLowerCase();
}
}
class Splitter implements StringProcessor {
@Override
public String process(Object input) {
return Arrays.toString(((String)input).split(" "));
}
}
/* Output:
Using Processor Upcase
IF SHE WEIGHS THE SAME AS A DUCK, SHE'S MADE OF WOOD
Using Processor Downcase
if she weighs the same as a duck, she's made of wood
Using Processor Splitter
[If, she, weighs, the, same, as, a, duck,, she's, made,
of, wood]
```

*/

[1] This declaration is unnecessary; the compiler will not complain if you remove it. However it does notate the covariant return change from **Object** to **String**.

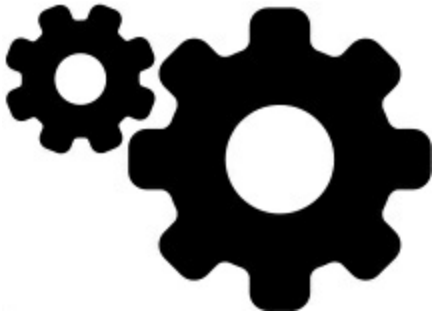
[2] s is automatically **static** and **final** because it's defined inside an interface.

[3] You can even define a **main()** inside an interface.

here, the approach works. However, you are often in the situation of being unable to modify the classes. In the case of the electronic filters, for example, the library was discovered rather than created. In these cases, you can use the *Adapter* design pattern. In Adapter, you write code to take the interface you have and produce the interface you need, like this:

```
// interfaces/interfaceprocessor/FilterProcessor.java
// {java interfaces.interfaceprocessor.FilterProcessor}
package interfaces.interfaceprocessor;
import interfaces.filters.*;
class FilterAdapter implements Processor {
Filter filter;
FilterAdapter(Filter filter) {
```

```
this.filter = filter;
}
@Override
public String name() { return filter.name(); }
@Override
public Waveform process(Object input) {
return filter.process((Waveform)input);
}
}
public class FilterProcessor {
public static void main(String[] args) {
Waveform w = new Waveform();
Applicator.apply(
```



```
new FilterAdapter(new LowPass(1.0)), w);
Applicator.apply(
new FilterAdapter(new HighPass(2.0)), w);
```

```
Applicator.apply(
new FilterAdapter(new BandPass(3.0, 4.0)), w);
}
}
/* Output:
Using Processor LowPass
Waveform 0
Using Processor HighPass
Waveform 0
Using Processor BandPass
Waveform 0
*/
```

In this approach to Adapter, the **FilterAdapter** constructor takes the interface you have—**Filter**—and produces an object that has the **Processor** interface you need. You might also notice delegation in the **FilterAdapter** class.

Covariance allows us to produce a **Waveform** from **process()** rather than just an **Object**.

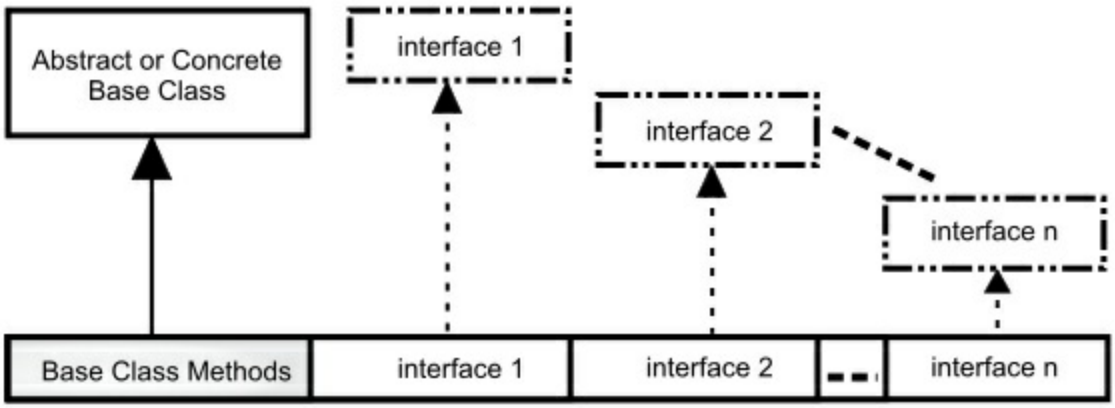
Decoupling interface from implementation allows an interface to be applied to multiple different implementations, and thus your code is

more reusable.

Combining Multiple

Interfaces

Because an interface has no implementation at all—that is, there is no storage associated with an interface—there's nothing to prevent many interfaces from being combined. This is valuable because there are



times when you want to say, "An **x** is an **a** *and* a **b** *and* a **c**."

In a derived class, you aren't forced to have a base class that is either **abstract** or "concrete" (that is, one with no **abstract** methods).

If you *do* inherit from a non-interface, you can inherit from only one. All the rest of the base elements must be interfaces. You place all the interface names after the **implements** keyword and separate them with commas. You can have as many interfaces as you want. You can upcast to each interface, because each interface is an independent type. The following example shows a concrete class combined with

several interfaces to produce a new class:

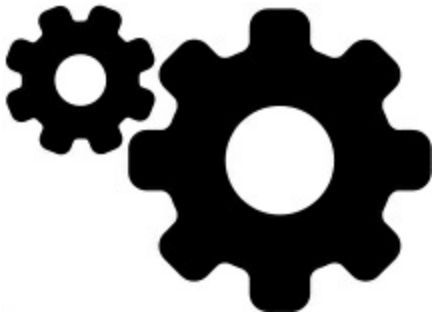
```
// interfaces/Adventure.java
// Multiple interfaces
interface CanFight {
void fight();
}
interface CanSwim {
void swim();
}
interface CanFly {
void fly();
}
class ActionCharacter {
public void fight() {}
}
class Hero extends ActionCharacter
implements CanFight, CanSwim, CanFly {
public void swim() {}
public void fly() {}
}
```

```
public class Adventure {
public static void t(CanFight x) { x.fight(); }
public static void u(CanSwim x) { x.swim(); }
public static void v(CanFly x) { x.fly(); }
public static void w(ActionCharacter x) { x.fight(); }
public static void main(String[] args) {
Hero h = new Hero();
t(h); // Treat it as a CanFight
u(h); // Treat it as a CanSwim
v(h); // Treat it as a CanFly
w(h); // Treat it as an ActionCharacter
}
}
```

Hero combines the concrete class **ActionCharacter** with the interfaces **CanFight**, **CanSwim**, and **CanFly**. When you combine a concrete class with interfaces this way, the concrete class must come first, then the interfaces. (The compiler gives an error otherwise.) The signature for **fight()** is the same in the interface **CanFight** and the class **ActionCharacter**, and **fight()** is *not* provided with a definition in **Hero**. You can extend an interface, but then

you’ve got another interface. When you want to create an object, all the definitions must first exist. Even though **Hero** does not explicitly provide a definition for **fight()**, the definition comes along with **ActionCharacter**; thus, it’s possible to create **Hero** objects.

Adventure shows four methods that take arguments of the various interfaces and of the concrete class. When you create a **Hero** object, it can be passed to any of these methods, which means it is upcast to



each interface in turn. Because of the way interfaces are designed in Java, this works without any particular effort on the part of the programmer.

Keep in mind that one of the core reasons for interfaces is shown in the preceding example: to upcast to more than one base type (and the flexibility this provides). However, a second reason for using interfaces is the same as using an **abstract** base class: to prevent the client programmer from making an object of this class and to establish it is only an interface.

This brings up a question: Should you use an interface or an **abstract** class? If it's possible to create your base class without any method definitions or member variables, prefer interfaces to **abstract** classes. In fact, if you know something is a base class, you can consider making it an interface (this subject is revisited in the chapter summary).

Extending an Interface with Inheritance

You can easily add new method declarations to an interface by using inheritance, and you can also combine several interfaces into a new interface with inheritance. In both cases you get a new interface, as seen in this example:

```
// interfaces/HorrorShow.java
// Extending an interface with inheritance
interface Monster {
void menace();
}
interface DangerousMonster extends Monster {
void destroy();
```

```
}
interface Lethal {
void kill();
}
class DragonZilla implements DangerousMonster {
@Override
public void menace() {}
@Override
public void destroy() {}
}
interface Vampire extends DangerousMonster, Lethal {
void drinkBlood();
}
class VeryBadVampire implements Vampire {
@Override
public void menace() {}
@Override
public void destroy() {}
@Override
public void kill() {}
```

```
@Override
public void drinkBlood() {}
}
public class HorrorShow {
static void u(Monster b) { b.menace(); }
static void v(DangerousMonster d) {
d.menace();
d.destroy();
}
static void w(Lethal l) { l.kill(); }
public static void main(String[] args) {
DangerousMonster barney = new DragonZilla();
u(barney);
v(barney);
Vampire vlad = new VeryBadVampire();
```

```
u(vlad);
v(vlad);
```

w(vlad);

}

}

DangerousMonster is a simple extension to **Monster** that produces a new interface. This is implemented in **DragonZilla**.

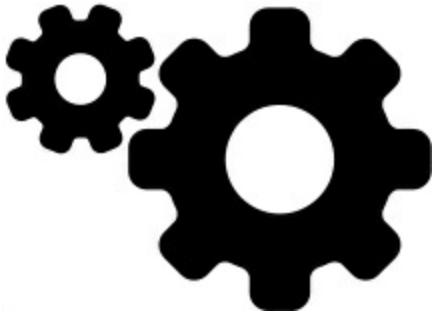
The syntax used in **Vampire** works *only* when inheriting interfaces. Normally, you can use **extends** with only a single class, but **extends** can refer to multiple base interfaces when building a new interface. Notice that interface names are separated with commas.

Name Collisions When Combining Interfaces

There's a small pitfall when implementing multiple interfaces. In the preceding example, both **CanFight** and **ActionCharacter** have identical **void fight()** methods. An identical method is not a problem, but what if the method differs by signature or return type? Here's an example:

```
// interfaces/InterfaceCollision.java
interface I1 { void f(); }
interface I2 { int f(int i); }
interface I3 { int f(); }
```

```
class C { public int f() { return 1; } }

class C2 implements I1, I2 {

@Override

public void f() {}

@Override

public int f(int i) { return 1; } // overloaded
```



```
}

class C3 extends C implements I2 {

@Override

public int f(int i) { return 1; } // overloaded

}

class C4 extends C implements I3 {

// Identical, no problem:

@Override

public int f() { return 1; }

}
```

// Methods differ only by return type:

//- class C5 extends C implements I1 {}

//- interface I4 extends I1, I3 {}

The difficulty occurs because overriding, implementation, and overloading get unpleasantly mixed together. Also, overloaded methods cannot differ only by return type. When the last two lines are uncommented, the error messages say it all:

error: C5 is not abstract and does not override abstract

method f() in I1

class C5 extends C implements I1 {}

error: types I3 and I1 are incompatible; both define f(),

but with unrelated return types

interface I4 extends I1, I3 {}

Using the same method names in different interfaces when you expect those interface to be combined generally causes confusion in the readability of the code. Strive to avoid it.

Adapting to an Interface

One of the most compelling reasons for interfaces is to allow multiple implementations for the same interface. In simple cases this is in the

form of a method that accepts an interface, leaving it up to you to implement that interface and pass your object to the method.

Thus, a common use for interfaces is the aforementioned *Strategy* design pattern. You write a method that performs certain operations, and that method takes an interface you also specify. You're basically saying, "You can use my method with any object you like, as long as your object conforms to my interface." This makes your method more flexible, general and reusable.

For example, the constructor for the **Scanner** class (which you'll learn more about in the Strings chapter) takes a **Readable** interface. You'll find that **Readable** is not an argument for any other method in the Java standard library—it was created solely for **Scanner**, so **Scanner** doesn't constrain its argument to a particular class. This way, **Scanner** can be made to work with more types. If you create a new class and you want it used with **Scanner**, you make it **Readable**, like this:

```
// interfaces/RandomStrings.java
// Implementing an interface to conform to a method
import java.nio.*;
import java.util.*;
```

```
public class RandomStrings implements Readable {
private static Random rand = new Random(47);
private static final char[] CAPITALS =
"ABCDEFGHIJKLMNOPQRSTUVWXYZ".toCharArray();
private static final char[] LOWERS =
"abcdefghijklmnopqrstuvwxyz".toCharArray();
private static final char[] VOWELS =
"aeiou".toCharArray();
private int count;
public RandomStrings(int count) {
this.count = count;
}
@Override
public int read(CharBuffer cb) {
if(count-- == 0)
return -1; // Indicates end of input
cb.append(CAPITALS[rand.nextInt(CAPITALS.length)]);
for(int i = 0; i < 4; i++) {
cb.append(VOWELS[rand.nextInt(VOWELS.length)]);
cb.append(LOWERS[rand.nextInt(LOWERS.length)]);
```

```
}
cb.append(" ");
return 10; // Number of characters appended
}
public static void main(String[] args) {
Scanner s = new Scanner(new RandomStrings(10));
while(s.hasNext())
System.out.println(s.next());
}
}
/* Output:
Yazeruyac
Fowenucor
Goeazimom
Raeuuacio
Nuoadesiw
Hageaikux
Ruqicibui
Numasetih
Kuuuuozog
```

Waqizeyoy

*/

The **Readable** interface only requires the implementation of a **read()** method (notice how the **@Override** points out the salient method). Inside **read()**, you add to the **CharBuffer** argument (there are several ways to do this; see the **CharBuffer** documentation), or return **-1** when you have no more input.

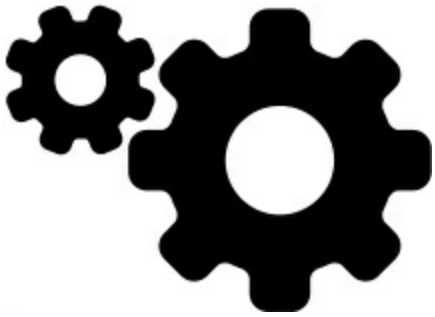
Suppose you have a type that does not already implement **Readable**—how do you make it work with **Scanner**? Here's an example that produces random floating point numbers:

```
// interfaces/RandomDoubles.java
import java.util.*;
public interface RandomDoubles {
Random RAND = new Random(47);
default double next() { return RAND.nextDouble(); }
static void main(String[] args) {
RandomDoubles rd = new RandomDoubles() {};
for(int i = 0; i < 7; i ++)
System.out.print(rd.next() + " ");
}
```

```
}
/* Output:
0.7271157860730044 0.5309454508634242
0.16020656493302599 0.18847866977771732
0.5166020801268457 0.2678662084200585
0.2613610344283964
*/
```

Again, we can use the Adapter pattern, but here the adapted class can be created by implementing both interfaces. So, using the multiple inheritance provided by the **interface** keyword, we produce a new class which is both **RandomDoubles** and **Readable**:

```
// interfaces/AdaptedRandomDoubles.java
// Creating an adapter with inheritance
import java.nio.*;
import java.util.*;
public class AdaptedRandomDoubles
implements RandomDoubles, Readable {
private int count;
public AdaptedRandomDoubles(int count) {
this.count = count;
```



```
}
@Override
public int read(CharBuffer cb) {
if(count-- == 0)
return -1;
String result = Double.toString(next()) + " ";
cb.append(result);
return result.length();
}
public static void main(String[] args) {
Scanner s =
new Scanner(new AdaptedRandomDoubles(7));
while(s.hasNextDouble())
System.out.print(s.nextDouble() + " ");
}
}
```

/ *Output:*

0.7271157860730044 0.5309454508634242

0.16020656493302599 0.18847866977771732

0.5166020801268457 0.2678662084200585

0.2613610344283964

**/*

Because you can add an interface onto any existing class in this way, it means that a method that takes an interface provides a way to adapt any class to work with that method. This is the power of using interfaces instead of classes.

Fields in Interfaces

Because any fields you put into an interface are automatically **static** and **final**, the interface is a convenient tool for creating groups of constant values. Before Java 5, this was the only way to produce the same effect as an **enum** in C or C++. So you will see pre-Java 5 code like this:

// interfaces/Months.java

```
// Using interfaces to create groups of constants
public interface Months {
int
JANUARY = 1, FEBRUARY = 2, MARCH = 3,
APRIL = 4, MAY = 5, JUNE = 6, JULY = 7,
AUGUST = 8, SEPTEMBER = 9, OCTOBER = 10,
NOVEMBER = 11, DECEMBER = 12;
}
```

Notice the Java style of using all uppercase letters (with underscores to separate multiple words in a single identifier) for **static final**s that have constant initializers. The fields in an interface are automatically **public**, so that is not explicitly specified.

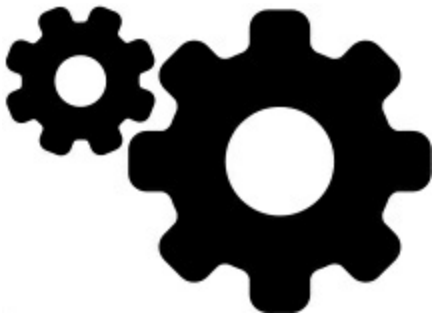
Since Java 5, we have the much more powerful and flexible **enum** keyword and it rarely makes sense to use interfaces to hold groups of constants. However, you will probably run across the old idiom on many occasions when reading legacy code. You can find more details on **enum**s in the Enumerations chapter.

Initializing Fields in Interfaces

Fields defined in interfaces cannot be “blank **final**s,” but they can be

initialized with non-constant expressions. For example:

```
// interfaces/RandVals.java
// Initializing interface fields with
// non-constant initializers
import java.util.*;
public interface RandVals {
Random RAND = new Random(47);
int RANDOM_INT = RAND.nextInt(10);
long RANDOM_LONG = RAND.nextLong() * 10;
```



```
float RANDOM_FLOAT = RAND.nextLong() * 10;
double RANDOM_DOUBLE = RAND.nextDouble() * 10;
}
```

Since the fields are **static**, they are initialized when the class is first loaded, which happens when any of the fields are accessed for the first time. Here's a simple test:

```
// interfaces/TestRandVals.java
```

```
public class TestRandVals {
public static void main(String[] args) {
System.out.println(RandVals.RANDOM_INT);
System.out.println(RandVals.RANDOM_LONG);
System.out.println(RandVals.RANDOM_FLOAT);
System.out.println(RandVals.RANDOM_DOUBLE);
}
}
/* Output:
8
-32032247016559954
-8.5939291E18
5.779976127815049
*/
```

The fields are not part of the interface. The values are stored in the static storage area for that interface.

Nesting Interfaces

Interfaces can be nested within classes and within other interfaces. This reveals a number of interesting features:

```
// interfaces/nesting/NestingInterfaces.java
```

```
// {java interfaces.nesting.NestingInterfaces}
package interfaces.nesting;
class A {
interface B {
void f();
}
public class BImp implements B {
@Override
public void f() {}
}
private class BImp2 implements B {
@Override
public void f() {}
}
public interface C {
void f();
}
class CImp implements C {
@Override
public void f() {}
```

```
}
private class CImp2 implements C {
@Override
public void f() {}
}
private interface D {
void f();
}
private class DImp implements D {
@Override
public void f() {}
}
public class DImp2 implements D {
@Override
public void f() {}
}
public D getD() { return new DImp2(); }
private D dRef;
public void receiveD(D d) {
dRef = d;
```

```
dRef.f();
}
}
interface E {
interface G {
void f();
}
// Redundant "public":
public interface H {
void f();
}
void g();
// Cannot be private within an interface:
//- private interface I {}
}
public class NestingInterfaces {
public class BImp implements A.B {
@Override
public void f() {}
}
```

```
class CImp implements A.C {
@Override
public void f() {}
}
// Cannot implement a private interface except
// within that interface's defining class:
//- class DImp implements A.D {
//- public void f() {}
//- }
class EImp implements E {
@Override
public void g() {}
}
class EGImp implements E.G {
@Override
public void f() {}
}
class EImp2 implements E {
@Override
public void g() {}
```

```
class EG implements E.G {
@Override
public void f() {}
}
}
public static void main(String[] args) {
A a = new A();
// Can't access A.D:
//- A.D ad = a.getD();
// Doesn't return anything but A.D:
//- A.DImp2 di2 = a.getD();
// Cannot access a member of the interface:
//- a.getD().f();
// Only another A can do anything with getD():
A a2 = new A();
a2.receiveD(a.getD());
}
}
```

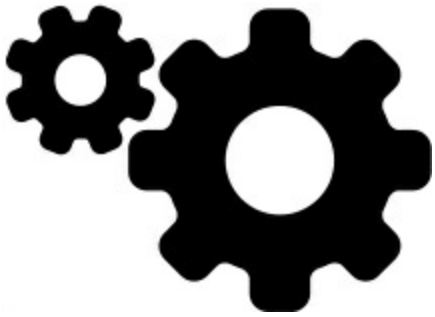
The syntax for nesting an interface within a class is reasonably obvious. Just like non-nested interfaces, these can have **public** or

package-access visibility.

As an added twist, interfaces can also be **private**, as seen in **A.D** (the same qualification syntax is used for nested interfaces as for nested classes). What good is a **private** nested interface? You might guess it can only be implemented as a **private** inner class as in **DImp**, but **A.DImp2** shows it can also be implemented as a **public** class. However, **A.DImp2** can only be used as itself. You are not allowed to mention the fact that it implements the **private** interface **D**, so implementing a **private** interface is a way to force the definition of the methods in that interface without adding any type information (that is, without allowing any upcasting).

The method **getD()** produces a further quandary concerning the **private** interface: It's a **public** method that returns a reference to a **private** interface. What can you do with the return value of this method? **main()** shows several attempts to use the return value, all of which fail. The return value must be handed to an object that has permission to use it—here, another **A**, via the **receiveD()** method.

Interface **E** shows that interfaces can be nested within each other.



However, the rules about interfaces—in particular, that all interface elements must be **public**—are strictly enforced here, so an interface nested within another interface is automatically **public** and cannot be made **private**.

NestingInterfaces shows the various ways that nested interfaces can be implemented. In particular, notice that when you implement an interface, you are not required to implement any interfaces nested within. Also, **private** interfaces cannot be implemented outside of their defining classes.

Initially, these features can seem like they are added strictly for syntactic consistency, but I generally find that once you know about a feature, you often discover places where it is useful.

Interfaces and

Factories

An interface is a gateway to multiple implementations, and a typical way to produce objects that fit the interface is the *Factory Method*

design pattern. Instead of calling a constructor directly, you call a creation method on a factory object which produces an implementation of the interface—this way, in theory, your code is completely isolated from the implementation of the interface, thus making it possible to transparently swap one implementation for another. Here's a demonstration showing the structure of the Factory Method:

```
// interfaces/Factories.java
interface Service {
void method1();
void method2();
}
interface ServiceFactory {
Service getService();
}
class Service1 implements Service {
Service1() {} // Package access
public void method1() {
System.out.println("Service1 method1");
}
```

```
public void method2() {
System.out.println("Service1 method2");
}
}
class Service1Factory implements ServiceFactory {
@Override
public Service getService() {
return new Service1();
}
}
class Service2 implements Service {
Service2() {} // Package access
public void method1() {
System.out.println("Service2 method1");
}
public void method2() {
System.out.println("Service2 method2");
}
}
class Service2Factory implements ServiceFactory {
```

```
@Override
public Service getService() {
return new Service2();
}
}
public class Factories {
public static void
serviceConsumer(ServiceFactory fact) {
Service s = fact.getService();
s.method1();
s.method2();
}
public static void main(String[] args) {
serviceConsumer(new Service1Factory());
// Services are completely interchangeable:
serviceConsumer(new Service2Factory());
}
}
/* Output:
Service1 method1
```

Service1 method2

Service2 method1

Service2 method2

/

Without the Factory Method, your code must somewhere specify the exact type of **Service** created, to call the appropriate constructor. Why would you add this extra level of indirection? One common reason is to create a framework. Suppose you are creating a system to play games; for example, to play both chess and checkers on the same board:

```
// interfaces/Games.java
// A Game framework using Factory Methods
interface Game { boolean move(); }
interface GameFactory { Game getGame(); }
class Checkers implements Game {
private int moves = 0;
private static final int MOVES = 3;
@Override
public boolean move() {
System.out.println("Checkers move " + moves);
```

```
return ++moves != MOVES;
}
}
class CheckersFactory implements GameFactory {
@Override
public Game getGame() { return new Checkers(); }
}
class Chess implements Game {
private int moves = 0;
private static final int MOVES = 4;
@Override
public boolean move() {
System.out.println("Chess move " + moves);
return ++moves != MOVES;
}
```

```
}
class ChessFactory implements GameFactory {
@Override
public Game getGame() { return new Chess(); }
}
public class Games {
public static void playGame(GameFactory factory) {
Game s = factory.getGame();
while(s.move())
;
}
public static void main(String[] args) {
playGame(new CheckersFactory());
playGame(new ChessFactory());
}
}
/* Output:
Checkers move 0
Checkers move 1
Checkers move 2
```

Chess move 0

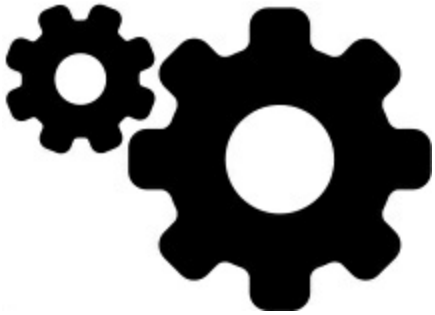
Chess move 1

Chess move 2

Chess move 3

*/

If the **Games** class represents a complex piece of code, this approach



means you can reuse that code with different types of games. You can imagine more elaborate games that can benefit from this pattern.

In the next chapter, you'll see a more elegant way to implement factories using anonymous inner classes.

Summary

It is tempting to decide that interfaces are good, and therefore always choose interfaces over concrete classes. Almost anytime you create a class, you can instead create an interface and a factory.

Many people have fallen to this temptation, creating interfaces and factories whenever it's possible. The logic seems to be that you might

use a different implementation, so always add that abstraction. It has become a kind of premature design optimization.

Any abstraction should be motivated by a real need. Interfaces should be something you refactor to when necessary, rather than installing the extra level of indirection everywhere, along with the extra complexity. That extra complexity is significant, and if you make someone work through that complexity only to realize that you've added interfaces "just in case" and for no compelling reason—well, if I see such a design I begin questioning all the other designs this particular person has done.

An appropriate guideline is to *prefer classes to interfaces*. Start with classes, and if it becomes clear that interfaces are necessary, refactor. Interfaces are a great tool, but they can easily be overused.

1. For C++ programmers, this is the analogue of C++'s *pure virtual function*. ↩

Inner Classes

A class defined within another class is

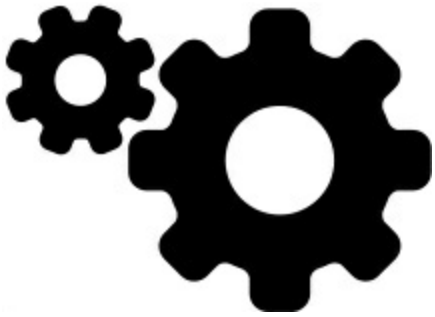
called an *inner class*.

With inner classes you can group classes that logically belong together and control the visibility of one within the other. However, it's important to understand that inner classes are distinctly different from composition.

At first, inner classes look like a simple code-hiding mechanism: You place classes inside other classes. You'll learn, however, that the inner class does more than that—it knows about and can communicate with the surrounding class—and the kind of code you can write with inner classes is more elegant and clear, although there's certainly no guarantee of this (also, Java 8 Lambdas and Method References reduce some of the need for inner classes).

Initially, inner classes can seem odd, and it will take some time to become comfortable using them in your designs. The need for inner classes isn't always obvious, but after the basic syntax and semantics of inner classes are described, the section "Why inner classes?" should begin to make clear their benefits.

The remainder of the chapter contains more detailed explorations of the syntax of inner classes. These features are provided for language



completeness, but you might not use them, at least not at first. So the initial parts of this chapter might be all you need for now, and you can leave the more detailed explorations as reference material.

Creating Inner Classes

You create an inner class just as you'd expect—by placing the class definition inside a surrounding class:

```
// innerclasses/Parcel1.java
// Creating inner classes
public class Parcel1 {
class Contents {
private int i = 11;
public int value() { return i; }
}
class Destination {
private String label;
Destination(String whereTo) {
```

```
label = whereTo;
}
String readLabel() { return label; }
}
// Using inner classes looks just like
// using any other class, within Parcel1:
public void ship(String dest) {
Contents c = new Contents();
Destination d = new Destination(dest);
System.out.println(d.readLabel());
}
public static void main(String[] args) {
Parcel1 p = new Parcel1();
p.ship("Tasmania");
}
}
/* Output:
Tasmania
*/
```

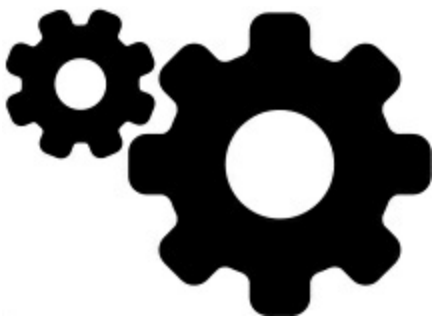
When used inside **ship()**, these inner classes look just like ordinary classes. The only apparent difference is that the names are nested

within **Parcel1**.

More typically, an outer class has a method that returns a reference to an inner class, as seen in the **to()** and **contents()** methods:

```
// innerclasses/Parcel2.java
// Returning a reference to an inner class
public class Parcel2 {
class Contents {
private int i = 11;
public int value() { return i; }
}
class Destination {
private String label;
Destination(String whereTo) {
label = whereTo;
}
String readLabel() { return label; }
}
public Destination to(String s) {
return new Destination(s);
}
```

```
public Contents contents() {
return new Contents();
}
public void ship(String dest) {
Contents c = contents();
Destination d = to(dest);
System.out.println(d.readLabel());
}
public static void main(String[] args) {
Parcel2 p = new Parcel2();
p.ship("Tasmania");
Parcel2 q = new Parcel2();
// Defining references to inner classes:
Parcel2.Contents c = q.contents();
Parcel2.Destination d = q.to("Borneo");
}
```



}

/ *Output:*

Tasmania

**/*

To make an object of the inner class anywhere except from within a non-**static** method of the outer class, you must specify the type of that object as *OuterClassName.InnerClassName*, as seen in **main()**.

The Link to the Outer Class

So far, it appears that inner classes are just a name-hiding and code organization scheme, helpful but not that compelling. However, there's another twist. When you create an inner class, an object of that inner class contains an implicit link to the enclosing object that made it. Through this link, it can access the members of that enclosing object, without any special qualifications. In addition, inner classes have access rights to all the elements in the enclosing class:

// innerclasses/Sequence.java

// Holds a sequence of Objects

interface Selector {

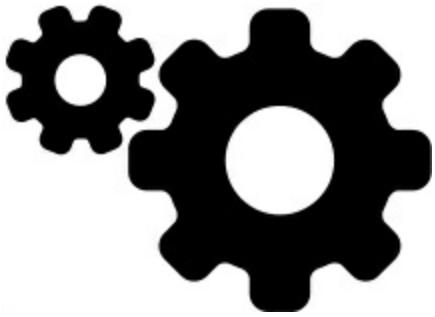
boolean end();

```
Object current();
void next();
}
public class Sequence {
private Object[] items;
private int next = 0;
public Sequence(int size) {
items = new Object[size];
}
public void add(Object x) {
if(next < items.length)
items[next++] = x;
}
private class SequenceSelector implements Selector {
private int i = 0;
@Override
public boolean end() { return i == items.length; }
@Override
public Object current() { return items[i]; }
@Override
```

```
public void next() { if(i < items.length) i++; }
}
public Selector selector() {
return new SequenceSelector();
}
public static void main(String[] args) {
Sequence sequence = new Sequence(10);
for(int i = 0; i < 10; i++)
sequence.add(Integer.toString(i));
Selector selector = sequence.selector();
while(!selector.end()) {
System.out.print(selector.current() + " ");
selector.next();
}
}
}
/* Output:
0 1 2 3 4 5 6 7 8 9
*/
```

The **Sequence** is a fixed-sized array of **Object** with a class wrapped

around it. You call **add()** to add a new **Object** to the end of the sequence (if there's room left). To fetch each of the objects in a **Sequence**, there's an interface called **Selector**. This is an example of the *Iterator* design pattern you shall learn more about in the Collections chapter. A **Selector** tells you whether you're at the **end()**, accesses the **current() Object**, and moves to the **next() Object** in the **Sequence**. Because **Selector** is an interface, other classes can implement the interface in their own ways,



and other methods can take the interface as an argument, to create more general-purpose code.

Here, the **SequenceSelector** is a **private** class that provides **Selector** functionality. In **main()**, you see the creation of a **Sequence**, followed by the addition of a number of **String** objects. Then, a **Selector** is produced with a call to **selector()**, and this is used to move through the **Sequence** and select each item.

At first, the creation of **SequenceSelector** looks like just another

inner class. But examine it closely. Note that each of the methods —**end()**, **current()**, and **next()**—refers to **items**, a reference that isn't part of **SequenceSelector**, but is instead a **private** field in the enclosing class. However, the inner class can access methods and fields from the enclosing class as if it owned them. This turns out to be very convenient, as you see in the preceding example. So an inner class has automatic access to the members of the enclosing class. How can this happen? The inner class secretly captures a reference to the particular object of the enclosing class that was responsible for creating it. Then, when you refer to a member of the enclosing class, that reference is used to select that member. Fortunately, the compiler takes care of all these details for you, but now you see that an object of an inner class can be created only in association with an object of the enclosing class (when, as you shall see, the inner class is non-**static**). Construction of the inner-class object requires the reference to the object of the enclosing class, and the compiler will complain if it cannot access that reference. Most of the time this occurs without any intervention on the part of the programmer.

Using .this and .new

To produce the reference to the outer-class object, you name the outer class followed by a dot and **this**. The resulting reference is automatically the correct type, known and checked at compile time, so there is no runtime overhead. Here's how to use **.this**:

```
// innerclasses/DotThis.java
// Accessing the outer-class object
public class DotThis {
void f() { System.out.println("DotThis.f()"); }
public class Inner {
public DotThis outer() {
return DotThis.this;
// A plain "this" would be Inner's "this"
}
}
public Inner inner() { return new Inner(); }
public static void main(String[] args) {
DotThis dt = new DotThis();
DotThis.Inner dti = dt.inner();
dti.outer().f();
}
```

}

/ *Output:*

DotThis.f()

**/*

Sometimes you want to tell some other object to create an object of one of its inner classes. To do this, provide a reference to the other outer-class object in the **new** expression, using the **.new** syntax, like this:

// innerclasses/DotNew.java

// Creating an inner class directly using .new syntax

public class DotNew {

public class Inner {}

public static void main(String[] args) {

DotNew dn = **new** DotNew();

DotNew.Inner dni = dn.new Inner();

}

}

To create an object of the inner class directly, you don’t follow the same form and refer to the outer class name **DotNew** as you might expect. Instead, use an *object* of the outer class to make an object of

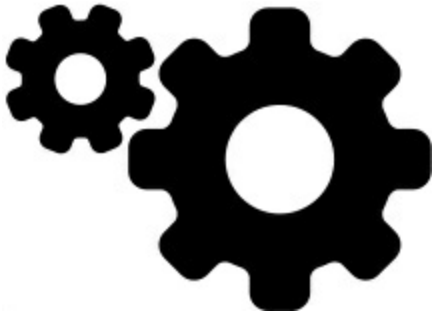
the inner class, as you see above. This also resolves the name scoping issues for the inner class, so you don't say (indeed, you *cannot* say) **dn.new DotNew.Inner()**.

Here, you see **.new** applied to the "Parcel" example:

```
// innerclasses/Parcel3.java
// Using .new to create instances of inner classes
public class Parcel3 {
class Contents {
private int i = 11;
public int value() { return i; }
}
class Destination {
private String label;
Destination(String whereTo) { label = whereTo; }
String readLabel() { return label; }
}
public static void main(String[] args) {
Parcel3 p = new Parcel3();
// Must use instance of outer class
// to create an instance of the inner class:
```

```
Parcel3.Contents c = p.new Contents();
Parcel3.Destination d =
p.new Destination("Tasmania");
}
}
```

It’s not possible to create an object of the inner class unless you already have an object of the outer class. This is because the object of the inner class is quietly connected to the object of the outer class it was made from. However, if you make a *nested class* (a **static** inner



class), it doesn’t need a reference to the outer-class object.

Inner Classes and

Upcasting

Inner classes become more interesting when you upcast to a base class, and in particular to an interface. (The effect of producing an interface reference from an object that implements it is essentially the same as upcasting to a base class.) That’s because the inner class—the

implementation of the interface—can then be unseen and unavailable, which is convenient for hiding the implementation. All you get back is a reference to the base class or the interface.

We can create interfaces for the previous examples:

```
// innerclasses/Destination.java
public interface Destination {
String readLabel();
}
// innerclasses/Contents.java
public interface Contents {
int value();
}
```

Now **Contents** and **Destination** represent interfaces available to the client programmer. Remember that an interface automatically makes all of its members **public**.

When you get a reference to the base class or the interface, it's possible you can't even find out the exact type, as shown here:

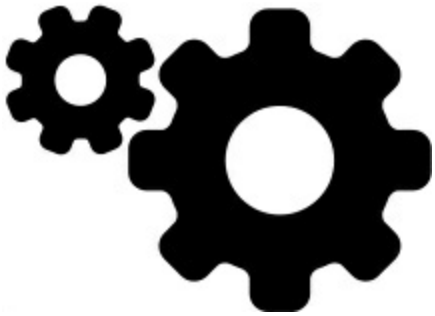
```
// innerclasses/TestParcel.java
class Parcel4 {
private class PContents implements Contents {
```

```
private int i = 11;
@Override
public int value() { return i; }
}
protected final class
PDestination implements Destination {
private String label;
private PDestination(String whereTo) {
label = whereTo;
}
@Override
public String readLabel() { return label; }
}
public Destination destination(String s) {
return new PDestination(s);
}
public Contents contents() {
return new PContents();
}
}
```

```
public class TestParcel {
public static void main(String[] args) {
Parcel4 p = new Parcel4();
Contents c = p.contents();
Destination d = p.destination("Tasmania");
// Illegal -- can't access private class:
//- Parcel4.PContents pc = p.new PContents();
}
}
```

In **Parcel4**, the inner class **PContents** is **private**, so nothing but **Parcel4** can access it. Normal (non-inner) classes cannot be made **private** or **protected**; they can only be given **public** or package access.

PDestination is **protected**, so it can only be accessed by **Parcel4**, classes in the same package (since **protected** also gives



package access), and the inheritors of **Parcel4**. This means the client

programmer has restricted knowledge and access to these members. In fact, you can't even downcast to a **private** inner class (or a **protected** inner class unless you're an inheritor), because you can't access the name, as you see in **class TestParcel**.

private inner classes provide a way for the class designer to completely prevent any type-coding dependencies and to completely hide details about implementation. In addition, extension of an interface is useless from the client programmer's perspective since the client programmer cannot access any additional methods that aren't part of the **public** interface. This also provides an opportunity for the Java compiler to generate more efficient code.

Inner Classes in

Methods and Scopes

What you've seen so far encompasses the typical use for inner classes. In general, the inner classes you'll write and read are "plain", and simple to understand. However, the syntax for inner classes covers a number of other, more obscure techniques.

Inner classes can be created within a method or even an arbitrary scope. There are two reasons for doing this:

1. As shown previously, you're implementing an interface of some

kind so you can create and return a reference.

2. You're solving a complicated problem and you create a class to aid in your solution, but you don't want it publicly available.

In the following examples, the previous code is modified to use:

1. A class defined within a method.

2. A class defined within a scope inside a method.

3. An *anonymous* class implementing an interface.

4. An anonymous class extending a class that has a non-default constructor.

5. An anonymous class that performs field initialization.

6. An anonymous class that performs construction using instance initialization (anonymous inner classes cannot have constructors).

The first example shows the creation of an entire class within the scope of a method (instead of the scope of another class). This is called a *local inner class*:

```
// innerclasses/Parcel5.java
// Nesting a class within a method
public class Parcel5 {
public Destination destination(String s) {
```

```
final class PDestination implements Destination {
private String label;
private PDestination(String whereTo) {
label = whereTo;
}
@Override
public String readLabel() { return label; }
}
return new PDestination(s);
}
public static void main(String[] args) {
Parcel5 p = new Parcel5();
Destination d = p.destination("Tasmania");
}
}
```

The class **PDestination** is part of **destination()** rather than being part of **Parcel5**. Therefore, **PDestination** cannot be accessed outside of **destination()**. The upcasting in the **return** statement means nothing comes out of **destination()** except a reference to a **Destination** interface. The fact that the name of the

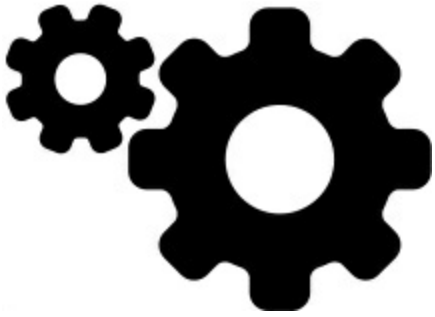
class **PDestination** is placed inside **destination()** doesn’t mean **PDestination** is not a valid object once **destination()** returns.

You can use the class identifier **PDestination** for an inner class inside each class in the same subdirectory without a name clash.

Next, see how you can nest an inner class within any arbitrary scope:

```
// innerclasses/Parcel6.java
// Nesting a class within a scope
public class Parcel6 {
private void internalTracking(boolean b) {
if(b) {
class TrackingSlip {
private String id;
TrackingSlip(String s) {
id = s;
}
String getSlip() { return id; }
}
TrackingSlip ts = new TrackingSlip("slip");
String s = ts.getSlip();
```

```
}
// Can't use it here! Out of scope:
//- TrackingSlip ts = new TrackingSlip("x");
}
public void track() { internalTracking(true); }
public static void main(String[] args) {
Parcel6 p = new Parcel6();
p.track();
}
```



```
}
```

The class **TrackingSlip** is nested inside the scope of an **if** statement. This does not mean that the *class* is conditionally created—it gets compiled along with everything else. However, it’s not available outside the scope where it is defined. Other than that, it looks just like an ordinary class.

Anonymous Inner

Classes

The next example looks a little odd:

```
// innerclasses/Parcel7.java
// Returning an instance of an anonymous inner class
public class Parcel7 {
public Contents contents() {
return new Contents() { // Insert class definition
private int i = 11;
@Override
public int value() { return i; }
}; // Semicolon required
}
public static void main(String[] args) {
Parcel7 p = new Parcel7();
Contents c = p.contents();
}
}
```

The **contents()** method combines the creation of the return value with the definition of the class that represents that return value. In addition, the class has no name—it’s anonymous. It looks as if you’re

creating a **Contents** object, But then, before you get to the semicolon, you say, “But wait, I think I’ll slip in a class definition.” What this strange syntax means is “Create an object of an anonymous class that’s inherited from **Contents**.” The reference returned by the **new** expression is automatically upcast to a **Contents** reference. The anonymous inner-class syntax is shorthand for:

```
// innerclasses/Parcel7b.java
// Expanded version of Parcel7.java
public class Parcel7b {
class MyContents implements Contents {
private int i = 11;
@Override
public int value() { return i; }
}
public Contents contents() {
return new MyContents();
}
public static void main(String[] args) {
Parcel7b p = new Parcel7b();
Contents c = p.contents();
```

```
}
}
```

In the anonymous inner class, **Contents** is created with a no-arg constructor. Here's what to do if your base class needs a constructor with an argument:

```
// innerclasses/Parcel8.java
// Calling the base-class constructor
public class Parcel8 {
public Wrapping wrapping(int x) {
// Base constructor call:
return new Wrapping(x) { // [1]
@Override
public int value() {
return super.value() * 47;
}
}; // [2]
}
public static void main(String[] args) {
Parcel8 p = new Parcel8();
Wrapping w = p.wrapping(10);
```

}

}

[1] You pass the appropriate argument to the base-class constructor.

[2] The semicolon at the end of an anonymous inner class doesn't mark the end of the class body. Instead, it marks the end of the expression that happens to contain the anonymous class. Thus, it's identical to the way the semicolon is used everywhere else.

Although it's an ordinary class with an implementation, **Wrapping** is also used as a common "interface" to its derived classes:

```
// innerclasses/Wrapping.java
public class Wrapping {
private int i;
public Wrapping(int x) { i = x; }
public int value() { return i; }
}
```

For variety, **Wrapping**'s constructor requires an argument.

You can also perform initialization when you define fields in an anonymous class:

```
// innerclasses/Parcel9.java
```

```
public class Parcel9 {
// Argument must be final or "effectively final"
// to use within the anonymous inner class:
public Destination destination(final String dest) {
return new Destination() {
private String label = dest;
@Override
public String readLabel() { return label; }
};
}
public static void main(String[] args) {
Parcel9 p = new Parcel9();
Destination d = p.destination("Tasmania");
}
}
```

If you’re defining an anonymous inner class and must use an object that’s defined outside the anonymous inner class, the compiler requires that the argument reference be **final** or “effectively final” (that is, it’s never changed after initialization, so it can be treated as if it is **final**), as you see in the argument to **destination()**. Here

you can leave off the **final** without a problem, but it’s usually better to include it as a reminder.

As long as you’re assigning a field, the approach in this example is fine. But what if you must perform some constructor-like activity? You can’t have a named constructor in an anonymous class (since there’s no name). With *instance initialization*, you can, in effect, create a constructor for an anonymous inner class, like this:

```
// innerclasses/AnonymousConstructor.java
// Creating a constructor for an anonymous inner class
abstract class Base {
Base(int i) {
System.out.println("Base constructor, i = " + i);
}
public abstract void f();
}
public class AnonymousConstructor {
public static Base getBase(int i) {
return new Base(i) {
{ System.out.println(
"Inside instance initializer"); }
```

```
@Override
public void f() {
System.out.println("In anonymous f()");
}
};
}
public static void main(String[] args) {
Base base = getBase(47);
base.f();
}
}
/* Output:
Base constructor, i = 47
Inside instance initializer
In anonymous f()
*/
```

Here, the variable **i** did *not* have to be **final**. While **i** is passed to the base constructor of the anonymous class, it is never directly used

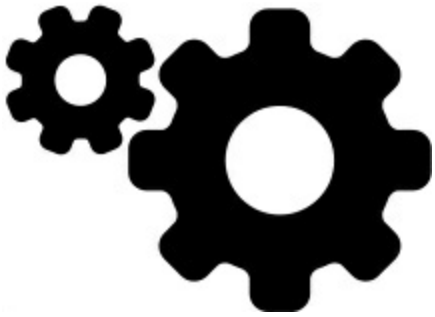
inside the anonymous class.

Here's the "parcel" theme with instance initialization. Note that the

arguments to **destination()** must be **final** or "effectively final"

since they are used within the anonymous class:

```
// innerclasses/Parcel10.java
// Using "instance initialization" to perform
// construction on an anonymous inner class
public class Parcel10 {
public Destination
destination(final String dest, final float price) {
return new Destination() {
private int cost;
// Instance initialization for each object:
{
cost = Math.round(price);
if(cost > 100)
System.out.println("Over budget!");
}
private String label = dest;
@Override
public String readLabel() { return label; }
};
}
```



```
public static void main(String[] args) {
Parcel10 p = new Parcel10();
Destination d = p.destination("Tasmania", 101.395F);
}
}
/* Output:
Over budget!
*/
```

Inside the instance initializer you see code that couldn’t be executed as part of a field initializer (that is, the **if** statement). So in effect, an instance initializer is the constructor for an anonymous inner class. However, it’s limited; you can’t overload instance initializers, so you can have only one of these constructors.

Anonymous inner classes are somewhat limited compared to regular inheritance, because they can either extend a class or implement an interface, but not both. And if you do implement an interface, you can

only implement one.

Nested Classes

If you don’t need a connection between the inner-class object and the outer-class object, you can make the inner class **static**. This is commonly called a *nested class*. To understand the meaning of **static** when applied to inner classes, remember that the object of an ordinary inner class implicitly keeps a reference to the object of the enclosing class that created it. This is not true for a **static** inner class. A nested class means:

1. You don’t need an outer-class object to create an object of a nested class.
2. You can’t access a non-**static** outer-class object from an object of a nested class.

Nested classes are different from ordinary inner classes in another way. Fields and methods in ordinary inner classes can only be at the outer level of a class, so ordinary inner classes cannot have **static** data, **static** fields, or nested classes. However, nested classes can have all these:

// innerclasses/Parcel11.java

// Nested classes (static inner classes)

```
public class Parcel11 {
private static class
ParcelContents implements Contents {
private int i = 11;
@Override
public int value() { return i; }
}
protected static final class ParcelDestination
implements Destination {
private String label;
private ParcelDestination(String whereTo) {
label = whereTo;
}
@Override
public String readLabel() { return label; }
// Nested classes can contain other static elements:
public static void f() {}
static int x = 10;
static class AnotherLevel {
public static void f() {}
```

```
static int x = 10;
}
}
public static Destination destination(String s) {
return new ParcelDestination(s);
}
public static Contents contents() {
return new ParcelContents();
}
public static void main(String[] args) {
Contents c = contents();
Destination d = destination("Tasmania");
```

```
}
}
```

In **main()**, no object of **Parcel11** is necessary; instead, you use the normal syntax for selecting a **static** member to call the methods that return references to **Contents** and **Destination**.

An ordinary (non-**static**) inner class can create a link to the outer-class object using a special **this** reference. A nested class does not have a special **this** reference, which makes it analogous to a **static** method.

Classes Inside Interfaces

A nested class can be part of an interface. Any class you put inside an interface is automatically **public** and **static**. Since the class is **static**, the nested class is only placed inside the namespace of the interface. You can even implement the surrounding interface in the inner class, like this:

```
// innerclasses/ClassInInterface.java
// {java ClassInInterface$Test}
public interface ClassInInterface {
void howdy();
class Test implements ClassInInterface {
@Override
public void howdy() {
System.out.println("Howdy!");
}
public static void main(String[] args) {
```

new Test().howdy();

}

}

}

/ Output:*

Howdy!

**/*

It’s convenient to nest a class inside an interface when you create common code to use with all different implementations of that interface.

Earlier I suggested putting a **main()** in every class to act as a test bed for that class. A potential drawback is that your test fixtures are exposed in your shipping product. If this is a problem, you can use a nested class to hold your test code:

// innerclasses/TestBed.java

// Putting test code in a nested class

// {java TestBed$Tester}

```
public class TestBed {
public void f() { System.out.println("f()"); }
public static class Tester {
public static void main(String[] args) {
TestBed t = new TestBed();
t.f();
}
}
}
/* Output:
f()
*/
```

This generates a separate class called **TestBed$Tester** (to run the program, you say **java TestBed$Tester**, but you must escape the **$** under Unix/Linux systems). You can use this class for testing, but you don't have to include it in your shipping product; you can delete **TestBed$Tester.class** before packaging things up.

Reaching Outward from a Multiply Nested Class

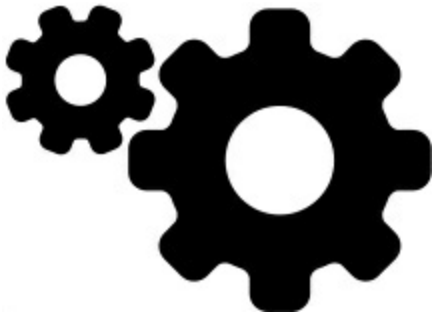
It doesn't matter how deeply an inner class is nested—it can

transparently access all members of all classes it is nested within, as seen here:

```
// innerclasses/MultiNestingAccess.java
// Nested classes can access all members of all
// levels of the classes they are nested within
class MNA {
private void f() {}
class A {
private void g() {}
public class B {
void h() {
g();
f();
}
}
}
}
public class MultiNestingAccess {
public static void main(String[] args) {
MNA mna = new MNA();
```

```
MNA.A mnaa = mna.new A();
MNA.A.B mnaab = mnaa.new B();
mnaab.h();
}
}
```

Notice how the **private** methods **g()** and **f()** are callable without any qualification. This example also demonstrates the syntax necessary to create objects of multiply nested inner classes when you create the objects in a different class. The "**.new**" syntax produces the correct scope, so you do not have to qualify the class name in the constructor call.



Why Inner Classes?

You've seen a lot of syntax and semantics describing the way inner classes work, but this doesn't answer the question of why they exist. Why did the Java designers go to so much trouble to add this fundamental language feature?

Typically, the inner class inherits from a class or implements an interface, and the code in the inner class manipulates the outer-class object it was created within. An inner class provides a kind of window into the outer class.

A question that cuts to the heart of inner classes is this: If I just need a reference to an interface, why don't I just make the outer class implement that interface? The answer is "If that's all you need, that's how to do it." So what is it that distinguishes an inner class implementing an interface from an outer class implementing the same interface? The answer is that you can't always have the convenience of interfaces—sometimes you're working with implementations. So the most compelling reason for inner classes is:

Each inner class can independently inherit from an implementation. Thus, the inner class is not limited by whether the outer class is already inheriting from an implementation.

Without the ability that inner classes provide to inherit—in effect—from more than one concrete or **abstract** class, some design and programming problems are intractable. So one way to look at the inner

class is as the rest of the solution of the multiple-inheritance problem. Interfaces solve part of the problem, but inner classes effectively allow "multiple implementation inheritance." That is, inner classes effectively allow you to inherit from more than one non-interface.

To see this in more detail, consider a situation where you have two interfaces that must somehow be implemented within a class. Because of the flexibility of interfaces, you have two choices: a single class or an inner class.

```
// innerclasses/mui/MultiInterfaces.java
// Two ways a class can implement multiple interfaces
// {java innerclasses.mui.MultiInterfaces}
package innerclasses.mui;
interface A {}
interface B {}
class X implements A, B {}
class Y implements A {
B makeB() {
// Anonymous inner class:
return new B() {};
}
```

```
}
public class MultiInterfaces {
static void takesA(A a) {}
static void takesB(B b) {}
public static void main(String[] args) {
X x = new X();
Y y = new Y();
takesA(x);
takesA(y);
takesB(x);
takesB(y.makeB());
}
}
```

This assumes the structure of your code makes logical sense either way. You'll ordinarily have some kind of guidance from the nature of the problem about whether to use a single class or an inner class. But without any other constraints, the approach in the preceding example doesn't really make much difference from an implementation standpoint. Both of them work.

Using **abstract** or concrete classes instead of interfaces suddenly

limits you to inner classes if your class must somehow implement both of the others:

```
// innerclasses/MultiImplementation.java
// For concrete or abstract classes, inner classes
// produce "multiple implementation inheritance"
// {java innerclasses.MultiImplementation}
package innerclasses;
class D {}
abstract class E {}
class Z extends D {
E makeE() { return new E() {}; }
}
public class MultiImplementation {
static void takesD(D d) {}
static void takesE(E e) {}
public static void main(String[] args) {
Z z = new Z();
takesD(z);
takesE(z.makeE());
}
```

}

If you didn’t have to solve the “multiple implementation inheritance” problem, you could conceivably code around everything else without the need for inner classes. But with inner classes you have these additional features:

1. The inner class can have multiple instances, each with its own state information, independent of the information in the outer-class object.
2. In a single outer class you can have several inner classes, each of which implements the same interface or inherits from the same class in a different way. An example of this is shown shortly.

3. The point of creation of the inner-class object is not tied to the creation of the outer-class object.
4. There is no potentially confusing “is-a” relationship with the inner class; it’s a separate entity.

As an example, if **Sequence.java** did not use inner classes, you’d say, “A **Sequence** is a **Selector**,” and you’d only be allowed one

Selector for a particular **Sequence**. You can easily have a second method, **reverseSelector()**, that produces a **Selector** that moves backward through the sequence. This kind of flexibility is only available with inner classes.

Closures & Callbacks

A *closure* is a callable object that retains information from the scope where it was created. From this definition, you see that an inner class is an object-oriented closure, because it doesn't just contain each piece of information from the outer-class object ("the scope where it was created"), but it automatically holds a reference back to the whole outer-class object, where it has permission to manipulate all the members, even **private** ones.

Before Java 8, the only way to produce closure-like behavior was through inner classes. With Java 8, we now have lambda expressions which also have closure behavior, but with much nicer and more concise syntax; you'll learn all about these in the Functional Programming chapter. Although you should prefer lambdas to innerclass closures, you will see pre-Java-8 code that uses the inner class approach, so it's still necessary to understand it.

One of the most compelling arguments for including some kind of pointer mechanism in Java was to allow *callbacks*. With a callback,

some other object is given a piece of information that allows it to call back into the originating object at some later point. This is a powerful concept, as you will see later in the book. If a callback is implemented using a pointer, however, you must rely on the programmer to behave properly and not misuse the pointer. As you've seen by now, Java tends to be more careful than that, so pointers were not included in the language.

The closure provided by the inner class is a good solution—more flexible and far safer than a pointer. Here's an example:

```
// innerclasses/Callbacks.java
// Using inner classes for callbacks
// {java innerclasses.Callbacks}
package innerclasses;
interface Incrementable {
void increment();
}
// Very simple to just implement the interface:
class Callee1 implements Incrementable {
private int i = 0;
@Override
```

```
public void increment() {
i++;
System.out.println(i);
}
}
class MyIncrement {
public void increment() {
System.out.println("Other operation");
}
static void f(MyIncrement mi) { mi.increment(); }
}
// If your class must implement increment() in
// some other way, you must use an inner class:
class Callee2 extends MyIncrement {
private int i = 0;
@Override
public void increment() {
super.increment();
i++;
System.out.println(i);
```

```
}
private class Closure implements Incrementable {
@Override
public void increment() {
// Specify outer-class method, otherwise
// you'll get an infinite recursion:
Callee2.this.increment();
}
}
Incrementable getCallbackReference() {
return new Closure();
}
}
class Caller {
private Incrementable callbackReference;
Caller(Incrementable cbh) {
callbackReference = cbh;
}
void go() { callbackReference.increment(); }
}
```

```
public class Callbacks {
public static void main(String[] args) {
Callee1 c1 = new Callee1();
Callee2 c2 = new Callee2();
MyIncrement.f(c2);
Caller caller1 = new Caller(c1);
Caller caller2 =
new Caller(c2.getCallbackReference());
caller1.go();
caller1.go();
caller2.go();
caller2.go();
}
}
/* Output:
Other operation
1
1
2
Other operation
```

2

Other operation

3

**/*

This shows a further distinction between implementing an interface in an outer class versus doing so in an inner class. **Callee1** is clearly the simpler solution in terms of the code. **Callee2** inherits from **MyIncrement**, which already has a different **increment()** method that does something unrelated to the one expected by the **Incrementable** interface. When **MyIncrement** is inherited into **Callee2**, **increment()** can't be overridden for use by **Incrementable**, so you're forced to provide a separate implementation using an inner class. Also note that when you create an inner class, you do not add to or modify the interface of the outer class.

Everything except **getCallbackReference()** in **Callee2** is **private**. To allow *any* connection to the outside world, the interface **Incrementable** is essential. Here you see how interfaces allow for a complete separation of interface from implementation.

The inner class **Closure** implements **Incrementable** to provide a

hook back into **Callee2**—but a safe hook. Whoever gets the **Incrementable** reference can only call **increment()** and has no other abilities (unlike a pointer, which would allow you to run wild). **Caller** takes an **Incrementable** reference in its constructor (although capturing the callback reference can happen at any time) and then, sometime later, uses the reference to "call back" into the **Callee** class.

The value of the callback is in its flexibility; you can dynamically decide what methods are called at run time. In user interfaces, for example, callbacks are often used everywhere to implement GUI functionality.

Inner Classes & Control Frameworks

A more concrete example of inner classes is found in something I refer to here as a *control framework*.

An *application framework* is a class or a set of classes designed to solve a particular type of problem. To apply an application framework,

you typically inherit from one or more classes and override some of the methods. The code you write in the overridden methods customizes the general solution provided by that application framework to solve your specific problem. This is an example of the *Template Method* design pattern. The Template Method contains the basic structure of the algorithm, and it calls one or more overrideable methods to complete the action of that algorithm. A design pattern separates things that change from things that stay the same, and here the Template Method is the part that stays the same, and the overrideable methods are the things that change.

A control framework is a particular type of application framework dominated by the need to respond to events. A system that primarily responds to events is called an *event-driven system*. A common problem in application programming is the graphical user interface (GUI), which is almost entirely event-driven.

To see how inner classes allow the simple creation and use of control frameworks, consider a framework that executes events whenever those events are “ready.” Although “ready” could mean anything, here it is based on clock time. What follows is a control framework that contains no specific information about what it’s controlling. That

information is supplied during inheritance, when the **action()** portion of the algorithm is implemented.

Here is the interface that describes any control event. It's an **abstract** class instead of an actual interface because the default behavior is to perform the control based on time. Thus, some of the implementation is included:

```
// innerclasses/controller/Event.java
// The common methods for any control event
package innerclasses.controller;
import java.time.*; // Java 8 time classes
public abstract class Event {
private Instant eventTime;
protected final Duration delayTime;
public Event(long millisecondDelay) {
delayTime = Duration.ofMillis(millisecondDelay);
start();
}
public void start() { // Allows restarting
eventTime = Instant.now().plus(delayTime);
}
```

```
public boolean ready() {
return Instant.now().isAfter(eventTime);
}
public abstract void action();
}
```

The constructor captures the time in milliseconds (measured from the time of creation of the object) when you want the **Event** to run, then calls **start()**, which takes the current time and adds the delay time to produce the time when the event will occur. Rather than including it in the constructor, **start()** is a separate method. This way, you can restart the timer after the event has run out, so the **Event** object can be reused. For example, if you want a repeating event, you can call **start()** inside your **action()** method.

ready() tells you when it's time to run the **action()** method. However, **ready()** can be overridden in a derived class to base the **Event** on something other than time.

Next we write the actual control framework to manage and fire events. The **Event** objects are held inside a collection object of type **List<Event>** (pronounced "List of Event"), which you'll learn more about in the Collections chapter. For now, all you must know is that **add()** will append an **Event** to the end of the **List**, **size()**

produces the number of entries in the **List**, the *for-in* syntax fetches successive **Event**s from the **List**, and **remove()** removes the specified **Event** from the **List**.

```
// innerclasses/controller/Controller.java
// The reusable framework for control systems
package innerclasses.controller;
import java.util.*;
public class Controller {
// A class from java.util to hold Event objects:
private List<Event> eventList = new ArrayList<>();
public void addEvent(Event c) { eventList.add(c); }
public void run() {
while(eventList.size() > 0)
// Make a copy so you're not modifying the list
// while you're selecting the elements in it:
for(Event e : new ArrayList<>(eventList))
if(e.ready()) {
System.out.println(e);
e.action();
eventList.remove(e);
```

}

}

}

The **run()** method loops through a copy of the **eventList**, hunting for an **Event** object that's **ready()** to run. For each one it finds **ready()**, it prints information using the object's **toString()** method, calls the **action()** method, then removes the **Event** from the list.

So far, you know nothing about exactly *what* an **Event** does. And this is the crux of the design—how it "separates the things that change from the things that stay the same." Or, to use my term, the "vector of change" is the different actions of the various kinds of **Event** objects, and you express different actions by creating different **Event** subclasses.

This is where inner classes come into play. They allow two things:

1. The entire implementation of a control framework is created in a single class, thereby encapsulating everything that's unique about that implementation. Inner classes are used to express the many different kinds of **action()** necessary to solve the problem.

2. Inner classes keep this implementation from becoming awkward, because you easily access any of the members in the outer class.

Without this, the code might become unpleasant enough that you'd seek an alternative.

Consider a particular implementation of the control framework designed to control greenhouse functions. Each action is entirely different: turning lights, water, and thermostats on and off, ringing bells, and restarting the system. The control framework is designed to easily isolate this different code. Inner classes allow multiple derived versions of the same base class, **Event**, within a single class. For each type of action, you inherit a new **Event** inner class, and write the control code in the **action()** implementation.

As is typical with an application framework, the class **GreenhouseControls** inherits **Controller**:

```
// innerclasses/GreenhouseControls.java
// This produces a specific application of the
// control system, all in a single class. Inner
// classes allow you to encapsulate different
// functionality for each type of event.
import innerclasses.controller.*;
public class GreenhouseControls extends Controller {
private boolean light = false;
```

```
public class LightOn extends Event {
public LightOn(long delayTime) {
super(delayTime);
}
@Override
public void action() {
// Put hardware control code here to
// physically turn on the light.
light = true;
}
@Override
public String toString() {
return "Light is on";
}
}
public class LightOff extends Event {
public LightOff(long delayTime) {
super(delayTime);
}
@Override
```

```
public void action() {
// Put hardware control code here to
// physically turn off the light.
light = false;
}
@Override
public String toString() {
return "Light is off";
}
}
private boolean water = false;
public class WaterOn extends Event {
public WaterOn(long delayTime) {
super(delayTime);
}
@Override
public void action() {
// Put hardware control code here.
water = true;
}
```

```
@Override
public String toString() {
return "Greenhouse water is on";
}
}
public class WaterOff extends Event {
public WaterOff(long delayTime) {
super(delayTime);
}
@Override
public void action() {
// Put hardware control code here.
water = false;
}
@Override
public String toString() {
return "Greenhouse water is off";
}
}
private String thermostat = "Day";
```

```
public class ThermostatNight extends Event {
public ThermostatNight(long delayTime) {
super(delayTime);
}
@Override
public void action() {
// Put hardware control code here.
thermostat = "Night";
}
@Override
public String toString() {
return "Thermostat on night setting";
}
}
public class ThermostatDay extends Event {
public ThermostatDay(long delayTime) {
super(delayTime);
}
@Override
public void action() {
```

```
// Put hardware control code here.
thermostat = "Day";
}
@Override
public String toString() {
return "Thermostat on day setting";
}
}
// An example of an action() that inserts a
// new one of itself into the event list:
public class Bell extends Event {
public Bell(long delayTime) {
super(delayTime);
}
@Override
public void action() {
addEvent(new Bell(delayTime.toMillis()));
}
@Override
public String toString() {
```

```
return "Bing!";
}
}
public class Restart extends Event {
private Event[] eventList;
public
Restart(long delayTime, Event[] eventList) {
super(delayTime);
this.eventList = eventList;
for(Event e : eventList)
addEvent(e);
}
@Override
public void action() {
for(Event e : eventList) {
e.start(); // Rerun each event
addEvent(e);
}
start(); // Rerun this Event
addEvent(this);
```

```
}
@Override
public String toString() {
return "Restarting system";
}
}
public static class Terminate extends Event {
public Terminate(long delayTime) {
super(delayTime);
}
@Override
public void action() { System.exit(0); }
@Override
public String toString() {
return "Terminating";
}
}
}
```

Note that **light**, **water**, and **thermostat** belong to the outer class **GreenhouseControls**, and yet the inner classes can access

those fields without qualification or special permission. Also, the **action()** methods usually involve some sort of hardware control. Most of the **Event** classes look similar, but **Bell** and **Restart** are special. **Bell** rings, then adds a new **Bell** object to the event list, so it will ring again later. Notice how inner classes *almost* look like multiple inheritance: **Bell** and **Restart** have all the methods of **Event** and also appear to have all the methods of the outer class **GreenhouseControls**.

Restart is given an array of **Event** objects it adds to the controller. Since **Restart** is just another **Event** object, you can also add a **Restart** object within **Restart.action()** so the system regularly restarts itself.

The following class configures the system by creating a **GreenhouseControls** object and adding various kinds of **Event** objects. This is an example of the *Command* design pattern—each object in **eventList** is a request encapsulated as an object:

```
// innerclasses/GreenhouseController.java
// Configure and execute the greenhouse system
import innerclasses.controller.*;
public class GreenhouseController {
```

```
public static void main(String[] args) {
GreenhouseControls gc = new GreenhouseControls();
// Instead of using code, you could parse
// configuration information from a text file:
gc.addEvent(gc.new Bell(900));
Event[] eventList = {
gc.new ThermostatNight(0),
gc.new LightOn(200),
gc.new LightOff(400),
gc.new WaterOn(600),
gc.new WaterOff(800),
gc.new ThermostatDay(1400)
};
gc.addEvent(gc.new Restart(2000, eventList));
gc.addEvent(
new GreenhouseControls.Terminate(5000));
gc.run();
}
}
/* Output:
```

Thermostat on night setting

Light is on

Light is off

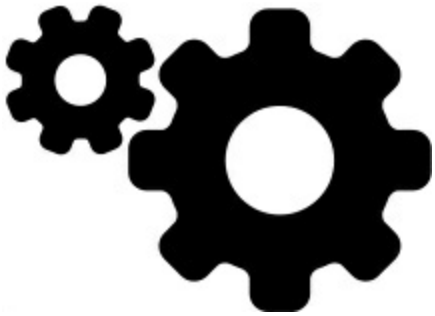
Greenhouse water is on

Greenhouse water is off

Bing!

Thermostat on day setting

Bing!



Restarting system

Thermostat on night setting

Light is on

Light is off

Greenhouse water is on

Bing!

Greenhouse water is off

Thermostat on day setting

Bing!

Restarting system

Thermostat on night setting

Light is on

Light is off

Bing!

Greenhouse water is on

Greenhouse water is off

Terminating

*/

This class initializes the system and adds all the appropriate events.

The **Restart** event is repeatedly run, and it loads the **eventList** into the **GreenhouseControls** object each time. If you provide a command-line argument indicating milliseconds, it will terminate the program after that many milliseconds (this is used for testing).

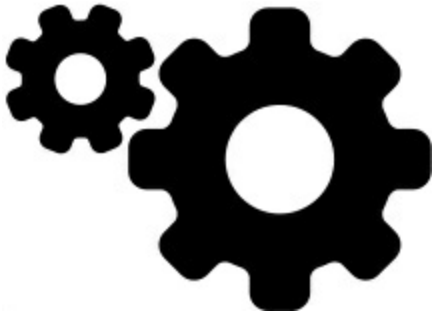
It’s more flexible to read the events from a file instead of hard-coding them.

This example moves you toward an appreciation of the value of inner classes, especially when used within a control framework.

Inheriting from Inner

Classes

Because the inner-class constructor must attach to a reference of the enclosing class object, things are slightly complicated when you inherit



from an inner class. The problem is that the “secret” reference to the enclosing class object *must* be initialized, and yet in the derived class there’s no longer a default object to attach to. You must use a special syntax to make the association explicit:

```
// innerclasses/InheritInner.java
// Inheriting an inner class
class WithInner {
class Inner {}
}
public class InheritInner extends WithInner.Inner {
//- InheritInner() {} // Won't compile
InheritInner(WithInner wi) {
wi.super();
```

```
}
public static void main(String[] args) {
WithInner wi = new WithInner();
InheritInner ii = new InheritInner(wi);
}
}
```

InheritInner is extending only the inner class, not the outer one. But when it comes time to create a constructor, the default one is no good, and you can't just pass a reference to an enclosing object. In addition, you must use the syntax

```
enclosingClassReference.super();
```

inside the constructor. This provides the necessary reference, and the program will then compile.

Can Inner Classes Be Overridden?

What happens when you create an inner class, then inherit from the enclosing class and redefine the inner class? That is, is it possible to "override" the entire inner class? This seems like a powerful concept, but "overriding" an inner class as if it were another method of the outer class doesn't really do anything:

```
// innerclasses/BigEgg.java
// An inner class cannot be overridden like a method
class Egg {
private Yolk y;
protected class Yolk {
public Yolk() {
System.out.println("Egg.Yolk()");
}
}
Egg() {
System.out.println("New Egg()");
y = new Yolk();
}
}
public class BigEgg extends Egg {
public class Yolk {
public Yolk() {
System.out.println("BigEgg.Yolk()");
}
}
```

```
public static void main(String[] args) {
new BigEgg();
}
}
/* Output:
New Egg()
Egg.Yolk()
*/
```

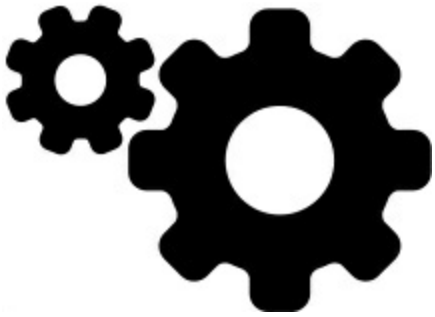
The no-arg constructor is synthesized automatically by the compiler, and this calls the base-class no-arg constructor. You might think, since a **BigEgg** is created, the “overridden” version of **Yolk** is used, but this is not the case, as you see from the output.

There’s no extra inner-class magic when you inherit from the outer class. The two inner classes are completely separate entities, each in its own namespace. However, it’s still possible to explicitly inherit from the inner class:

```
// innerclasses/BigEgg2.java
// Proper inheritance of an inner class
class Egg2 {
protected class Yolk {
```

```
public Yolk() {
System.out.println("Egg2.Yolk()");
}
public void f() {
System.out.println("Egg2.Yolk.f()");
}
}
private Yolk y = new Yolk();
Egg2() { System.out.println("New Egg2()"); }
public void insertYolk(Yolk yy) { y = yy; }
public void g() { y.f(); }
}
public class BigEgg2 extends Egg2 {
public class Yolk extends Egg2.Yolk {
public Yolk() {
System.out.println("BigEgg2.Yolk()");
}
@Override
public void f() {
System.out.println("BigEgg2.Yolk.f()");
```

```
}
}
public BigEgg2() { insertYolk(new Yolk()); }
public static void main(String[] args) {
Egg2 e2 = new BigEgg2();
e2.g();
}
}
/* Output:
Egg2.Yolk()
New Egg2()
```



```
Egg2.Yolk()
BigEgg2.Yolk()
BigEgg2.Yolk.f()
*/
```

Now **BigEgg2.Yolk** explicitly **extends Egg2.Yolk** and

overrides its methods. The method **insertYolk()** allows **BigEgg2**

to upcast one of its own **Yolk** objects into the **y** reference in **Egg2**, so when **g()** calls **y.f()**, the overridden version of **f()** is used. The

second call to **Egg2.Yolk()** is the base-class constructor call of the

BigEgg2.Yolk constructor. The overridden version of **f()** is used

when **g()** is called.

Local Inner Classes

As noted earlier, inner classes can also be created inside code blocks,

typically inside the body of a method. A local inner class cannot have

an access specifier because it isn't part of the outer class, but it does

have access to the final variables in the current code block and all the

members of the enclosing class. Here's an example comparing the

creation of a local inner class with an anonymous inner class:

```
// innerclasses/LocalInnerClass.java
// Holds a sequence of Objects
interface Counter {
int next();
}
public class LocalInnerClass {
private int count = 0;
Counter getCounter(final String name) {
```

```
// A local inner class:
class LocalCounter implements Counter {
LocalCounter() {
// Local inner class can have a constructor
System.out.println("LocalCounter()");
}
@Override
public int next() {
System.out.print(name); // Access local final
return count++;
}
}
return new LocalCounter();
}
// Repeat, but with an anonymous inner class:
Counter getCounter2(final String name) {
return new Counter() {
// Anonymous inner class cannot have a named
// constructor, only an instance initializer:
{
```

```
System.out.println("Counter()");
}
@Override
public int next() {
System.out.print(name); // Access local final
return count++;
}
};
}
public static void main(String[] args) {
LocalInnerClass lic = new LocalInnerClass();
Counter
c1 = lic.getCounter("Local inner "),
c2 = lic.getCounter2("Anonymous inner ");
for(int i = 0; i < 5; i++)
System.out.println(c1.next());
for(int i = 0; i < 5; i++)
System.out.println(c2.next());
}
}
```

/ *Output:*

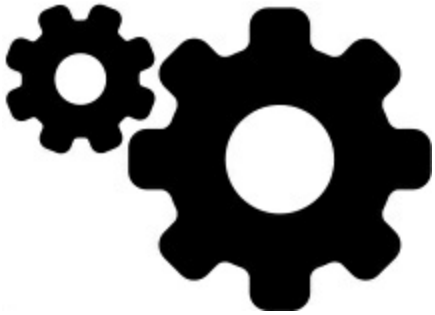
LocalCounter()

Counter()

Local inner 0

Local inner 1

Local inner 2



Local inner 3

Local inner 4

Anonymous inner 5

Anonymous inner 6

Anonymous inner 7

Anonymous inner 8

Anonymous inner 9

**/*

Counter returns the next value in a sequence. It is implemented here as both a local class and an anonymous inner class, each with the same

behaviors and capabilities. Since the name of the local inner class is not accessible outside the method, the only justification for using a local inner class instead of an anonymous inner class is if you need a named constructor and/or an overloaded constructor, since an anonymous inner class can only use instance initialization.

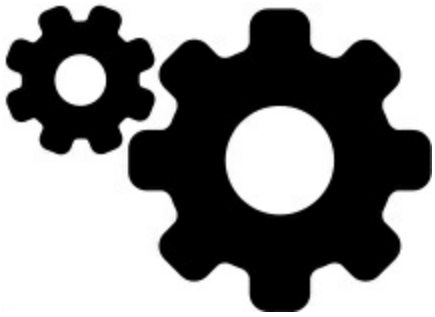
Another reason to make a local inner class rather than an anonymous inner class is if you make more than one object of that class.

Inner-Class Identifiers

After compilation, every class produces a **.class** file that holds all the information about how to create objects of that type. Upon loading, each class file produces a "meta-class" called the **Class** object.

You might guess that inner classes also produce **.class** files to contain the information for *their* **Class** objects. The names of these files/classes have a formula: the name of the enclosing class, followed by a **$**, followed by the name of the inner class. For example, the **.class** files created by **LocalInnerClass.java** include:

Counter.class



LocalInnerClass$1.class

LocalInnerClass$1LocalCounter.class

LocalInnerClass.class

If inner classes are anonymous, the compiler generates numbers as inner-class identifiers. If inner classes are nested within inner classes, their names are appended after a **$** and the outer-class identifier(s). This scheme of generating internal names is simple and straightforward. It's also robust and handles most situations.1 Since it is the standard naming scheme for Java, the generated files are automatically platform-independent. (Note that the Java compiler is changing your inner classes in all sorts of other ways to make them work.)

Summary

Interfaces and inner classes are more sophisticated concepts than what you'll find in many OOP languages; for example, there's nothing like them in C++. Together, they solve the same problem that C++

attempts to solve with its multiple inheritance (MI) feature. However, MI in C++ turns out to be rather difficult to use, whereas Java interfaces and inner classes are, by comparison, much more accessible. Although the features themselves are reasonably straightforward, using these features is a design issue, much the same as polymorphism. Over time, you'll become better at recognizing situations where you should use an interface, or an inner class, or both. But at this point in the book, you should at least be comfortable with the syntax and semantics. As you see these language features in use, you'll eventually internalize them.

1. On the other hand, **$** is a meta-character to the Unix shell and so you'll sometimes have trouble when listing the **.class** files. This is a bit strange coming from Sun, a Unix-based company. My guess is they weren't considering this issue, but instead thought you'd naturally focus on the source-code files.↩

Collections

It's a fairly simple program that only has a fixed quantity of objects with known

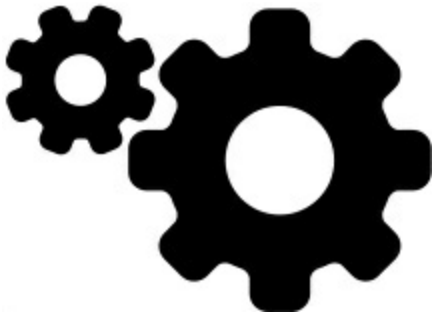
lifetimes.

In general, your programs will always be creating new objects based on some criteria known only at run time. You won't know the quantity or even the exact type of the objects you need. To solve the general programming problem, you must create any number of objects, anytime, anywhere. So you can't rely on creating a named reference to hold each one of your objects:

MyType aReference;

since you'll never know how many of these you'll actually need.

Most languages provide some way to solve this essential problem. Java has several ways to hold objects (or rather, references to objects). The compiler-supported type is the array, previously discussed. An array is the most efficient way to hold a group of objects, and you're pointed towards this choice to hold a group of primitives. But an array has a fixed size, and in the more general case, you won't know at the time you're writing the program how many objects you're going to need, or whether you need a more sophisticated way to store your objects—so the fixed-sized constraint of an array is too limiting.



The **java.util** library has a reasonably complete set of *collection*

classes to solve this problem, the basic types of which are **List**, **Set**, **Queue**, and **Map**. These types are also known as *container classes*, but I shall use the term that the Java library uses. Collections provide

sophisticated ways to hold objects, and solve a surprising number of

problems.

Among their other characteristics—**Set**, for example, holds only one

object of each value, and **Map** is an *associative array* that lets you

associate objects with other objects—the Java collection classes will

automatically resize themselves. So, unlike arrays, you can put in any

number of objects without worrying about how big the collection

should be.

Even though they don't have direct keyword support in Java, 1

collection classes are fundamental tools that significantly increase

your programming muscle. In this chapter you'll get a basic working

knowledge of the Java collection library, with an emphasis on typical

usage. Here, we'll focus on the collections that you'll use in day-to-day

programming. Later, in the Appendix: Collection Topics, you'll learn about the rest of the collections and more details about their

functionality and how to use them.

Generics and Type-

Safe Collections

One of the problems of using pre-Java 5 collections was that the

compiler allowed you to insert an incorrect type into a collection. For

example, consider a collection of **Apple** objects, using the basic

workhorse collection, **ArrayList**. For now, you can think of

ArrayList as "an array that automatically expands itself." Using an

ArrayList is straightforward: Create one, insert objects using

add(), and access them with **get()**, using an index—just as you do

with an array, but without the square brackets.2 **ArrayList** also has a method **size()** that tells how many elements were added, so you

don't inadvertently index off the end and cause an error (by throwing a

runtime exception; exceptions are introduced in the chapter

Exceptions).

In this example, **Apples** and **Orange**s are placed into the collection,

then pulled out. Normally, the Java compiler will give you a warning

because the example does *not* use generics. Here, a special *annotation*

is used to suppress the warning. Annotations start with an **@** sign, and

can take an argument; this one is **@SuppressWarnings** and the argument indicates that “unchecked” warnings only should be suppressed (You’ll learn more about Java annotations in the Annotations chapter):

```
// collections/ApplesAndOrangesWithoutGenerics.java
// Simple collection use (suppressing compiler warnings)
// {ThrowsException}
import java.util.*;
class Apple {
private static long counter;
private final long id = counter++;
public long id() { return id; }
}
class Orange {}
public class ApplesAndOrangesWithoutGenerics {
@SuppressWarnings("unchecked")
public static void main(String[] args) {
ArrayList apples = new ArrayList();
for(int i = 0; i < 3; i++)
apples.add(new Apple());
```

```
// No problem adding an Orange to apples:
apples.add(new Orange());
for(Object apple : apples) {
((Apple) apple).id();
// Orange is detected only at run time
}
}
}
/* Output:
___[ Error Output ]___
Exception in thread "main"
java.lang.ClassCastException: Orange cannot be cast to
Apple
at ApplesAndOrangesWithoutGenerics.main(ApplesA
ndOrangesWithoutGenerics.java:23)
*/
```

The classes **Apple** and **Orange** are distinct; they have nothing in common except they are both **Object**s. (Remember that if you don't explicitly say what class you're inheriting from, you automatically inherit from **Object**.) Since **ArrayList** holds **Object**s, you can

not only add **Apple** objects into this collection using the **ArrayList** method **add()**, but you can also add **Orange** objects without complaint at either compile time or run time. When you go to fetch out what you think are **Apple** objects using the **ArrayList** method **get()**, you get back a reference to an **Object** you must cast to an **Apple**. Then you must surround the entire expression with parentheses to force the evaluation of the cast before calling the **id()** method for **Apple**; otherwise, you'll get a syntax error.

At run time, when you try to cast the **Orange** object to an **Apple**, you get the error as shown in the output.

In the Generics chapter, you'll learn that *creating* classes using Java generics can be complex. However, *applying* predefined generic classes is reasonably straightforward. For example, to define an **ArrayList** intended to hold **Apple** objects, you say **ArrayList<Apple>** instead of just **ArrayList**. The angle brackets surround the *type parameter(s)* (there might be more than one), which specify the type(s) that can be held by that instance of the collection.

With generics, you're prevented, *at compile time*, from putting the wrong type of object into a collection.[3] Here's the example again, using generics:

```
// collections/ApplesAndOrangesWithGenerics.java
import java.util.*;
public class ApplesAndOrangesWithGenerics {
public static void main(String[] args) {
ArrayList<Apple> apples = new ArrayList<>();
for(int i = 0; i < 3; i++)
apples.add(new Apple());
// Compile-time error:
// apples.add(new Orange());
for(Apple apple : apples) {
System.out.println(apple.id());
}
}
}
/* Output:
0
1
2
*/
```

On the right-hand side of the definition for **apples**, you see **new**

ArrayList<>(). This is sometimes called the “diamond syntax” because of the <> . Before Java 7, you had to, in effect, duplicate the type declaration on both sides, like this:

ArrayList<Apple> apples = **new** ArrayList<Apple>();

As types got more complex, this duplication produced code that was quite messy and hard to read. Programmers began observing that all the information is available on the left-hand side, so there was no reason for the compiler to force us to repeat ourselves on the right-hand side. This request for *type inference*, even on such a small scale, was heard by the Java language team.

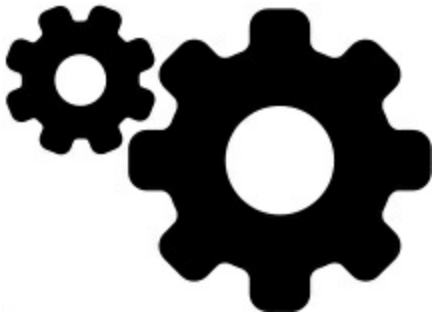
With the type specified in the **ArrayList** definition, the compiler prevents you from putting an **Orange** into **apples**, so it becomes a compile-time error rather than a runtime error.

With generics, the cast is not necessary when fetching items from the **List**. Since the **List** knows what type it holds, it does the cast for you when you call **get()**. Thus, with generics you not only know that the compiler will check the type of object you put into a collection, but you also get cleaner syntax when using the objects in the collection.

You are not limited to putting the exact type of object into a collection when you specify that type as a generic parameter. Upcasting works

the same with generics as it does with other types:

```
// collections/GenericsAndUpcasting.java
import java.util.*;
class GrannySmith extends Apple {}
class Gala extends Apple {}
class Fuji extends Apple {}
class Braeburn extends Apple {}
public class GenericsAndUpcasting {
public static void main(String[] args) {
ArrayList<Apple> apples = new ArrayList<>();
apples.add(new GrannySmith());
apples.add(new Gala());
apples.add(new Fuji());
apples.add(new Braeburn());
for(Apple apple : apples)
System.out.println(apple);
}
}
/* Output:
```



GrannySmith@15db9742

Gala@6d06d69c

Fuji@7852e922

Braeburn@4e25154f

*/

Thus, you can add a subtype of **Apple** to a collection specified to hold **Apple** objects.

The output is produced from the default **toString()** method of **Object**, which prints the class name followed by the unsigned hexadecimal representation of the *hash code* of the object (generated by the **hashCode()** method). You'll learn about hash codes in detail in the Appendix: Understanding **equals()** and **hashCode()**.

Basic Concepts

The Java collection library takes the idea of "holding objects" and divides it into two distinct concepts, expressed as the basic interfaces of the library:

1. **Collection**: a sequence of individual elements with one or more rules applied to them. A **List** must hold the elements in the way they were inserted, a **Set** cannot have duplicate elements, and a **Queue** *produces* the elements in the order determined by a *queuing discipline* (usually the same order in which they are inserted).

2. **Map**: a group of key-value object pairs that looks up a value using a key. An **ArrayList** looks up an object using a number, so in a sense it associates numbers to objects. A *map* looks up an object using *another object*. It's also called an *associative array*, because it associates objects with other objects, or a *dictionary*, because you look up a value object using a key object just like you look up a definition using a word. **Map**s are powerful programming tools.

Although it's not always possible, ideally you'll write most of your code to talk to these interfaces, and the only place you'll specify the precise type you're using is at the point of creation. Thus, you can create a **List** like this:

```
List<Apple> apples = new ArrayList<>();
```

Notice that the **ArrayList** is upcast to a **List**, in contrast to the way it was handled in the previous examples. The intent of using the interface is that if you decide to change your implementation, you just

change it at the point of creation, like this:

List<Apple> apples = **new** LinkedList<>();

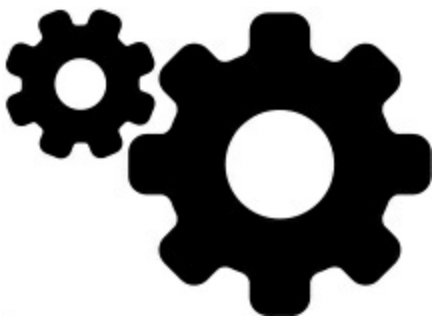
Thus, you'll typically make an object of a concrete class, upcast it to the corresponding interface, then use the interface throughout the rest of your code.

This approach won't always work, because some classes have additional functionality. For example, **LinkedList** has additional methods not in the **List** interface, and a **TreeMap** has methods not in the **Map** interface. If you use those methods, you can't upcast to the more general interface.

The **Collection** interface generalizes the idea of a *sequence*—a way of holding a group of objects. Here's a simple example that fills a **Collection** (represented here with an **ArrayList**) with **Integer** objects, then prints each element in the resulting collection:

// collections/SimpleCollection.java

import java.util.*;



```
public class SimpleCollection {
public static void main(String[] args) {
Collection<Integer> c = new ArrayList<>();
for(int i = 0; i < 10; i++)
c.add(i); // Autoboxing
for(Integer i : c)
System.out.print(i + ", ");
}
}
/* Output:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
*/
```

This example only uses **Collection** methods, so any object of a class inherited from **Collection** would work. However, **ArrayList** is the most basic type of sequence.

The **add()** method name suggests that it puts a new element in the **Collection**. However, the documentation carefully states that **add()** "ensures this **Collection** contains the specified element." This is to allow for the meaning of **Set**, which adds the element only if it isn't already there. With an **ArrayList**, or any sort of **List**,

add() always means “put it in,” because **List**s don’t care if there are duplicates.

All **Collection**s can be traversed using the *for-in* syntax, as shown here. Later in this chapter you’ll learn about a more flexible concept called an *Iterator*.

Adding Groups of Elements

The **Arrays** and **Collections** classes in **java.util** contain utility methods to add groups of elements to a **Collection**.

Arrays.asList() takes either an array or a comma-separated list of elements (using varargs) and turns it into a **List** object.

Collections.addAll() takes a **Collection** object and either an array or a comma-separated list and adds the elements to the **Collection**. Here you see both methods, as well as the more conventional **addAll()** method that’s part of all **Collection** types:

```
// collections/AddingGroups.java
// Adding groups of elements to Collection objects
import java.util.*;
public class AddingGroups {
public static void main(String[] args) {
```

```
Collection<Integer> collection =
new ArrayList<>(Arrays.asList(1, 2, 3, 4, 5));
Integer[] moreInts = { 6, 7, 8, 9, 10 };
collection.addAll(Arrays.asList(moreInts));
// Runs significantly faster, but you can't
// construct a Collection this way:
Collections.addAll(collection, 11, 12, 13, 14, 15);
Collections.addAll(collection, moreInts);
// Produces a list "backed by" an array:
List<Integer> list = Arrays.asList(16,17,18,19,20);
list.set(1, 99); // OK -- modify an element
// list.add(21); // Runtime error; the underlying
// array cannot be resized.
}
}
```

The constructor for a **Collection** can accept another **Collection** which it uses for initializing itself, so you can use **Arrays.asList()** to produce input for the constructor. However, **Collections.addAll()** runs much faster, and it’s just as easy to construct the **Collection** with no elements, then call

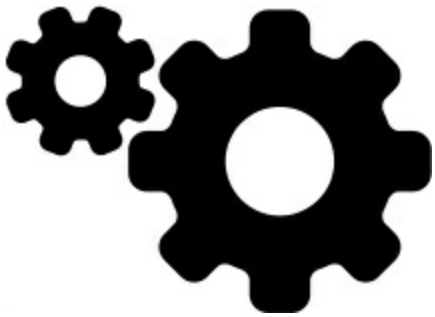
Collections.addAll(), so this is the preferred approach.

The **Collection.addAll()** method can only take an argument of another **Collection** object, so it is not as flexible as **Arrays.asList()** or **Collections.addAll()**, which use variable argument lists.

It's also possible to use the output of **Arrays.asList()** directly, as a **List**, but the underlying representation here is the array, which cannot be resized. If you try to **add()** or **delete()** elements in such a list, that would attempt to change the size of an array, so you'll get an "Unsupported Operation" error at run time:

```
// collections/AsListInference.java
import java.util.*;
class Snow {}
class Powder extends Snow {}
class Light extends Powder {}
class Heavy extends Powder {}
class Crusty extends Snow {}
class Slush extends Snow {}
public class AsListInference {
public static void main(String[] args) {
```

```
List<Snow> snow1 = Arrays.asList(
new Crusty(), new Slush(), new Powder());
//- snow1.add(new Heavy()); // Exception
List<Snow> snow2 = Arrays.asList(
new Light(), new Heavy());
//- snow2.add(new Slush()); // Exception
List<Snow> snow3 = new ArrayList<>();
Collections.addAll(snow3,
new Light(), new Heavy(), new Powder());
snow3.add(new Crusty());
```



```
// Hint with explicit type argument specification:
List<Snow> snow4 = Arrays.<Snow>asList(
new Light(), new Heavy(), new Slush());
//- snow4.add(new Powder()); // Exception
}
}
```

In **snow4**, notice the “hint” in the middle of **Arrays.asList()**, to tell the compiler what the actual target type should be for the resulting **List** type produced by **Arrays.asList()**. This is called an *explicit type argument specification*.

Printing Collections

You must use **Arrays.toString()** to produce a printable representation of an array, but the collections print nicely without any help. Here’s an example that also introduces you to the basic Java collections:

```
// collections/PrintingCollections.java
// Collections print themselves automatically
import java.util.*;
public class PrintingCollections {
static Collection
fill(Collection<String> collection) {
collection.add("rat");
collection.add("cat");
collection.add("dog");
collection.add("dog");
return collection;
```

```
}
static Map fill(Map<String, String> map) {
map.put("rat", "Fuzzy");
map.put("cat", "Rags");
map.put("dog", "Bosco");
map.put("dog", "Spot");
return map;
}
public static void main(String[] args) {
System.out.println(fill(new ArrayList<>()));
System.out.println(fill(new LinkedList<>()));
System.out.println(fill(new HashSet<>()));
System.out.println(fill(new TreeSet<>()));
System.out.println(fill(new LinkedHashSet<>()));
System.out.println(fill(new HashMap<>()));
System.out.println(fill(new TreeMap<>()));
System.out.println(fill(new LinkedHashMap<>()));
}
}
/* Output:
```

[rat, cat, dog, dog]

[rat, cat, dog, dog]

[rat, cat, dog]

[cat, dog, rat]

[rat, cat, dog]

{rat=Fuzzy, cat=Rags, dog=Spot}

{cat=Rags, dog=Spot, rat=Fuzzy}

{rat=Fuzzy, cat=Rags, dog=Spot}

*/

This shows the two primary categories in the Java collection library. The distinction is based on the number of items held in each "slot" in the collection. The **Collection** category only holds one item in each slot. It includes **List**, which holds a group of items in a specified sequence, **Set**, which only allows the addition of one identical item, and **Queue**, which only inserts objects at one "end" of the collection and removes objects from the other "end" (for the purposes of this example, this is just another way of looking at a sequence and so is not shown). A **Map** holds two objects, a *key* and an associated *value*, in each slot.

The default printing behavior, provided via each collection's

toString() method, produces reasonably readable results. A **Collection** is printed surrounded by square brackets, with each element separated by a comma. A **Map** is surrounded by curly braces, with each key and value associated with an equal sign (keys on the left, values on the right).

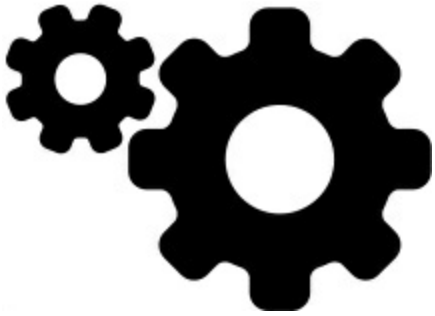
The first **fill()** method works with all types of **Collection**, each of which implements the **add()** method to include new elements. **ArrayList** and **LinkedList** are both types of **List**, and the output shows that they both hold elements in insertion order. The difference between the two is not only performance for certain types of operations, but also that a **LinkedList** contains more operations than an **ArrayList**. These are explored more fully later in this chapter.

HashSet, **TreeSet** and **LinkedHashSet** are types of **Set**. The output shows that a **Set** only holds one of each identical item, and that the different **Set** implementations store the elements differently. The **HashSet** stores elements using a rather complex approach, explored in the Appendix: Collection Topics—all you must know now is that this technique is the fastest way to retrieve elements, and as a result the storage order can seem nonsensical (you often care only that something is a member of the **Set**, and order is unimportant). If

storage order is important, you can use a **TreeSet**, which keeps the objects in ascending comparison order, or a **LinkedHashSet**, which keeps the objects in the order in which they were added.

A **Map** (also called an *associative array*) looks up an object using a *key*, like a simple database. The associated object is called a *value*. If you have a **Map** that associates states with their capitals and you want

the capital of Ohio, you look it up using “Ohio” as the key—almost as if you were indexing into an array. Because of this behavior, a **Map** only accepts one of each key.



Map.put(key, value) adds a value (what you want) and associates it with a key (how you look it up). **Map.get(key)** produces the value associated with that key. The above example only adds key-value pairs, and does not perform lookups. That is shown later.

Notice you don’t specify (or think about) the size of the **Map** because it resizes itself automatically. Also, **Map**s know how to print themselves, showing the association with keys and values.

The example uses the three basic flavors of **Map**: **HashMap**, **TreeMap** and **LinkedHashMap**.

The order that the keys and values are held inside a **HashMap** is not the insertion order because the **HashMap** implementation uses a very fast algorithm that controls the order. A **TreeMap** keeps the keys

sorted by ascending comparison order, and a **LinkedHashMap** keeps the keys in insertion order while retaining the lookup speed of the **HashMap**.

List

Lists promise to maintain elements in a particular sequence. The **List** interface adds a number of methods to **Collection** that allow insertion and removal of elements in the middle of a **List**.

There are two types of **List**:

The basic **ArrayList**, which excels at randomly accessing elements, but is slower when inserting and removing elements in the middle of a **List**.

The **LinkedList**, which provides optimal sequential access, with inexpensive insertions and deletions in the middle of the **List**. A **LinkedList** is relatively slow for random access, but it has a larger feature set than the **ArrayList**.

The following example reaches forward in the book to use a library from the Type Information chapter by importing **typeinfo.pets**. This is a library that contains a hierarchy of **Pet** classes along with some tools to randomly generate **Pet** objects. You don’t need the full details, just that:

1. There’s a **Pet** class and various subtypes of **Pet**.

2. The **static Pets.list()** method returns an **ArrayList**

filled with randomly selected **Pet** objects.

```
// collections/ListFeatures.java
import typeinfo.pets.*;
import java.util.*;
public class ListFeatures {
public static void main(String[] args) {
Random rand = new Random(47);
List<Pet> pets = Pets.list(7);
System.out.println("1: " + pets);
Hamster h = new Hamster();
pets.add(h); // Automatically resizes
System.out.println("2: " + pets);
System.out.println("3: " + pets.contains(h));
pets.remove(h); // Remove by object
Pet p = pets.get(2);
System.out.println(
"4: " + p + " " + pets.indexOf(p));
Pet cymric = new Cymric();
```

```
System.out.println("5: " + pets.indexOf(cymric));
System.out.println("6: " + pets.remove(cymric));
// Must be the exact object:
System.out.println("7: " + pets.remove(p));
System.out.println("8: " + pets);
pets.add(3, new Mouse()); // Insert at an index
System.out.println("9: " + pets);
List<Pet> sub = pets.subList(1, 4);
System.out.println("subList: " + sub);
System.out.println("10: " + pets.containsAll(sub));
Collections.sort(sub); // In-place sort
System.out.println("sorted subList: " + sub);
// Order is not important in containsAll():
System.out.println("11: " + pets.containsAll(sub));
Collections.shuffle(sub, rand); // Mix it up
System.out.println("shuffled subList: " + sub);
System.out.println("12: " + pets.containsAll(sub));
List<Pet> copy = new ArrayList<>(pets);
sub = Arrays.asList(pets.get(1), pets.get(4));
System.out.println("sub: " + sub);
```

```
copy.retainAll(sub);
System.out.println("13: " + copy);
copy = new ArrayList<>(pets); // Get a fresh copy
copy.remove(2); // Remove by index
System.out.println("14: " + copy);
copy.removeAll(sub); // Only removes exact objects
System.out.println("15: " + copy);
copy.set(1, new Mouse()); // Replace an element
System.out.println("16: " + copy);
copy.addAll(2, sub); // Insert a list in the middle
System.out.println("17: " + copy);
System.out.println("18: " + pets.isEmpty());
pets.clear(); // Remove all elements
System.out.println("19: " + pets);
System.out.println("20: " + pets.isEmpty());
pets.addAll(Pets.list(4));
System.out.println("21: " + pets);
Object[] o = pets.toArray();
System.out.println("22: " + o[3]);
Pet[] pa = pets.toArray(new Pet[0]);
```

```
System.out.println("23: " + pa[3].id());
}
}
/* Output:
1: [Rat, Manx, Cymric, Mutt, Pug, Cymric, Pug]
2: [Rat, Manx, Cymric, Mutt, Pug, Cymric, Pug, Hamster]
3: true
4: Cymric 2
5: -1
6: false
7: true
8: [Rat, Manx, Mutt, Pug, Cymric, Pug]
9: [Rat, Manx, Mutt, Mouse, Pug, Cymric, Pug]
subList: [Manx, Mutt, Mouse]
10: true
sorted subList: [Manx, Mouse, Mutt]
11: true
shuffled subList: [Mouse, Manx, Mutt]
12: true
sub: [Mouse, Pug]
```

13: [Mouse, Pug]

14: [Rat, Mouse, Mutt, Pug, Cymric, Pug]

15: [Rat, Mutt, Cymric, Pug]

16: [Rat, Mouse, Cymric, Pug]

17: [Rat, Mouse, Mouse, Pug, Cymric, Pug]

18: false

19: []

20: true

21: [Manx, Cymric, Rat, EgyptianMau]

22: EgyptianMau

23: 14

**/*

The print lines are numbered so the output can be related to the source code. The first output line shows the original **List** of **Pet**s. Unlike an array, a **List** can add or remove elements after creation, and it resizes itself. That's its fundamental value: a modifiable sequence. You see the result of adding a **Hamster** in output line 2—the object is appended to the end of the list.

You can find out whether an object is in the list using the **contains()** method. To remove an object, you can pass that

object's reference to the **remove()** method. Also, with a reference to an object, you can discover the index number where that object is located in the **List** using **indexOf()**, as you see in output line 4.

When deciding whether an element is part of a **List**, discovering the index of an element, and removing an element from a **List** by reference, the **equals()** method (part of the root class **Object**) is used. Each **Pet** is defined as a unique object, so even though there are two **Cymric**s in the list, if I create a new **Cymric** object and pass it to **indexOf()**, the result is **-1** (indicating it wasn't found), and attempts to **remove()** the object will return **false**. For other classes, **equals()** can be defined differently—**String**s, for example, are equal if the contents of two **String**s are identical. So to prevent surprises, it's important to be aware that **List** behavior changes depending on **equals()** behavior.

Output lines 7 and 8 show the success of removing an object that exactly matches an object in the **List**.

It's possible to insert an element in the middle of the **List**, as in output line 9 and the code that precedes it, but this brings up an issue: for a **LinkedList**, insertion and removal in the middle of a list is a cheap operation (except for, in this case, the actual random access into

the middle of the list), but for an **ArrayList** it is an expensive operation. Does this mean you should never insert elements in the middle of an **ArrayList**, and switch to a **LinkedList** if you do? No, it just means you should be aware of the issue, and if you start doing many insertions in the middle of an **ArrayList** *and* your program starts slowing down, you might look at your **List** implementation as the possible culprit (the best way to discover such a bottleneck is to use a profiler). Optimization is a tricky issue, and the best policy is to leave it alone until you discover you must worry about it (although understanding the issues is always a good idea).

The **subList()** method easily creates a slice out of a larger list, and this naturally produces a **true** result when passed to **containsAll()** for that larger list. Notice that order is unimportant—you see in output lines 11 and 12 that calling the intuitively named **Collections.sort()** and **Collections.shuffle()** on **sub** doesn't affect the outcome of **containsAll()**. **subList()** produces a list backed by the original list. Therefore, changes in the returned list are reflected in the original list, and vice versa.

The **retainAll()** method is effectively a "set intersection"

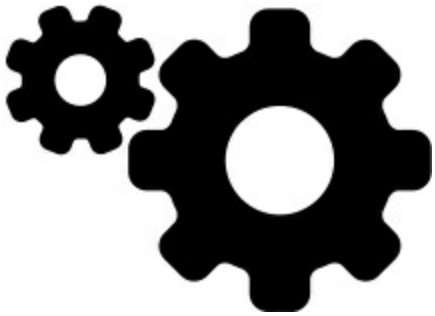
operation, in this case keeping all the elements in **copy** that are also in **sub**. Again, the resulting behavior depends on the **equals()** method.

Output line 14 shows the result of removing an element using its index number, which is more straightforward than removing it by object reference since you don't worry about **equals()** behavior when using indexes.

The **removeAll()** method also operates based on the **equals()** method. As the name implies, it removes all the objects from the **List** that are in the argument **List**.

The **set()** method is rather unfortunately named because of the potential confusion with the **Set** class—"replace" might be a better name here, because it replaces the element at the index (the first argument) with the second argument.

Output line 17 shows that for **List**s, there's an overloaded



addAll() method that inserts the new list in the middle of the

original list, instead of just appending it to the end with the **addAll()** that comes from **Collection**.

Output lines 18-20 show the effect of the **isEmpty()** and **clear()** methods.

Output lines 22 and 23 show how you can convert any **Collection** to an array using **toArray()**. This is an overloaded method; the no-argument version returns an array of **Object**, but if you pass an array of the target type to the overloaded version, it produces an array of the type specified (assuming it passes type checking). If the argument array is too small to hold all the objects in the **List** (as is the case here), **toArray()** creates a new array of the appropriate size. **Pet** objects have an **id()** method, which you see is called on one of the objects in the resulting array.

Iterators

In any collection, you must have a way to insert elements and fetch them out again. After all, that's the primary job of a collection—to hold things. In a **List**, **add()** is one way to insert elements, and **get()** is one way to fetch elements.

When you start thinking at a higher level, there's a drawback: You must program to the exact type of the collection to use it. This might

not seem bad at first, but what if you write code for a **List**, and later on you discover it would be convenient to apply that same code to a **Set**? Or suppose you'd like to write, from the beginning, a piece of general-purpose code that doesn't know or care what type of collection it's working with, so it can be used on different types of collections without rewriting that code?

The concept of an *Iterator* (another design pattern) achieves this abstraction. An iterator is an object that moves through a sequence and selects each object in that sequence without the client programmer knowing or caring about the underlying structure of that sequence. In addition, an iterator is usually what's called a *lightweight object*: one that's cheap to create. For that reason, you'll often find seemingly strange constraints for iterators; for example, the Java **Iterator** can move in only one direction. There's not much you can do with an **Iterator** except:

1. Ask a **Collection** to hand you an **Iterator** using a method called **iterator()**. That **Iterator** is ready to return the first element in the sequence.
2. Get the next object in the sequence with **next()**.
3. See if there are any more objects in the sequence with

hasNext().

4. Remove the last element returned by the iterator with

remove().

To see how it works, we again use the **Pet** tools from the Type Information chapter:

```
// collections/SimpleIteration.java
import typeinfo.pets.*;
import java.util.*;
public class SimpleIteration {
public static void main(String[] args) {
List<Pet> pets = Pets.list(12);
Iterator<Pet> it = pets.iterator();
while(it.hasNext()) {
Pet p = it.next();
System.out.print(p.id() + ":" + p + " ");
}
System.out.println();
// A simpler approach, when possible:
for(Pet p : pets)
System.out.print(p.id() + ":" + p + " ");
```

```
System.out.println();
// An Iterator can also remove elements:
it = pets.iterator();
for(int i = 0; i < 6; i++) {
it.next();
it.remove();
}
System.out.println(pets);
}
}
/* Output:
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx 8:Cymric 9:Rat 10:EgyptianMau 11:Hamster
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx 8:Cymric 9:Rat 10:EgyptianMau 11:Hamster
[Pug, Manx, Cymric, Rat, EgyptianMau, Hamster]
*/
```

With an **Iterator**, you don't worry about the number of elements in the collection. That's taken care of for you by **hasNext()** and **next()**.

If you’re moving forward through the **List** and not trying to modify the **List** object itself, you see that the *for-in* syntax is more succinct.

An **Iterator** can also remove the last element produced by **next()**, which means you must call **next()** before you call **remove()**.4

This idea performing an operation on each object in a collection is powerful and is seen throughout this book.

Now consider the creation of a **display()** method that is collection-agnostic:

```
// collections/CrossCollectionIteration.java
import typeinfo.pets.*;
import java.util.*;
public class CrossCollectionIteration {
public static void display(Iterator<Pet> it) {
while(it.hasNext()) {
Pet p = it.next();
System.out.print(p.id() + ":" + p + " ");
}
System.out.println();
}
```

```
public static void main(String[] args) {
List<Pet> pets = Pets.list(8);
LinkedList<Pet> petsLL = new LinkedList<>(pets);
HashSet<Pet> petsHS = new HashSet<>(pets);
TreeSet<Pet> petsTS = new TreeSet<>(pets);
display(pets.iterator());
display(petsLL.iterator());
display(petsHS.iterator());
display(petsTS.iterator());
}
}
/* Output:
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
5:Cymric 2:Cymric 7:Manx 1:Manx 3:Mutt 6:Pug 4:Pug
0:Rat
```

*/

display() contains no information about the type of sequence it is traversing. This shows the true power of the **Iterator**: the ability to separate the operation of traversing a sequence from the underlying structure of that sequence. For this reason, we sometimes say that iterators *unify access to collections*.

We can produce a cleaner version of the previous example by using the **Iterable** interface, which describes “anything that can produce an **Iterator**”:

```
// collections/CrossCollectionIteration2.java
import typeinfo.pets.*;
import java.util.*;
public class CrossCollectionIteration2 {
public static void display(Iterable<Pet> ip) {
Iterator<Pet> it = ip.iterator();
while(it.hasNext()) {
Pet p = it.next();
System.out.print(p.id() + ":" + p + " ");
}
System.out.println();
```

```
}
public static void main(String[] args) {
List<Pet> pets = Pets.list(8);
LinkedList<Pet> petsLL = new LinkedList<>(pets);
HashSet<Pet> petsHS = new HashSet<>(pets);
TreeSet<Pet> petsTS = new TreeSet<>(pets);
display(pets);
display(petsLL);
display(petsHS);
display(petsTS);
}
}
/* Output:
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
5:Cymric 2:Cymric 7:Manx 1:Manx 3:Mutt 6:Pug 4:Pug
```

0:Rat

**/*

All of the classes are **Iterable**, so now the calls to **display()** are notably simpler.

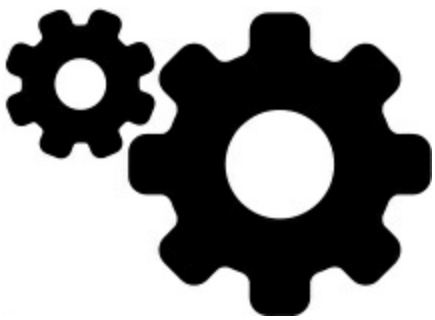
ListIterator

ListIterator is a more powerful subtype of **Iterator** that is produced only by **List** classes. While **Iterator** can only move forward, **ListIterator** is bidirectional. It can produce indices of the next and previous elements relative to where the iterator is pointing in the list, and it can replace the last element it visited using the **set()** method. You can produce a **ListIterator** that points to the beginning of the **List** by calling **listIterator()**, and you can also create a **ListIterator** that starts out pointing to an index **n** in the list by calling **listIterator(n)**. Here's demonstration of these abilities:

// collections/ListIteration.java

import typeinfo.pets.*;

```
import java.util.*;
public class ListIteration {
public static void main(String[] args) {
List<Pet> pets = Pets.list(8);
ListIterator<Pet> it = pets.listIterator();
while(it.hasNext())
System.out.print(it.next() +
", " + it.nextIndex() +
", " + it.previousIndex() + "; ");
System.out.println();
// Backwards:
while(it.hasPrevious())
System.out.print(it.previous().id() + " ");
System.out.println();
System.out.println(pets);
it = pets.listIterator(3);
```



```
while(it.hasNext()) {
it.next();
it.set(Pets.get());
}
System.out.println(pets);
}
}
/* Output:
Rat, 1, 0; Manx, 2, 1; Cymric, 3, 2; Mutt, 4, 3; Pug,
5, 4; Cymric, 6, 5; Pug, 7, 6; Manx, 8, 7;
7 6 5 4 3 2 1 0
[Rat, Manx, Cymric, Mutt, Pug, Cymric, Pug, Manx]
[Rat, Manx, Cymric, Cymric, Rat, EgyptianMau, Hamster,
EgyptianMau]
*/
```

The **Pets.get()** method is used to replace all the **Pet** objects in the **List** from location 3 onward.

LinkedList

LinkedList implements the basic **List** interface like **ArrayList** does, but it performs insertion and removal in the middle of the **List**

more efficiently than **ArrayList**. However, it is less efficient for random-access operations.

LinkedList adds methods to use it as a stack, a Queue or a double-ended queue(deque). Some of these methods are aliases or slight variations of each other, producing names familiar for a particular use (**Queue**, in particular).

getFirst() and **element()** are identical—they return the head (first element) of the list without removing it, and throw **NoSuchElementException** if the **List** is empty. **peek()** is a slight variation of those two that returns **null** if the list is empty.

removeFirst() and **remove()** are also identical—they remove and return the head of the list, and throw **NoSuchElementException** for an empty list. **poll()** is a slight variation that returns **null** if this list is empty.

addFirst() inserts an element at the beginning of the list.

offer() is the same as **add()** and **addLast()**. They all add an element to the tail (end) of a list.

removeLast() removes and returns the last element of the list.

Here’s an example that shows the basic similarity and differences

between these features. It doesn’t repeat the behavior that was shown in **ListFeatures.java**:

```
// collections/LinkedListFeatures.java
import typeinfo.pets.*;
import java.util.*;
public class LinkedListFeatures {
public static void main(String[] args) {
LinkedList<Pet> pets =
new LinkedList<>(Pets.list(5));
System.out.println(pets);
// Identical:
System.out.println(
"pets.getFirst(): " + pets.getFirst());
System.out.println(
"pets.element(): " + pets.element());
// Only differs in empty-list behavior:
System.out.println("pets.peek(): " + pets.peek());
// Identical; remove and return the first element:
System.out.println(
"pets.remove(): " + pets.remove());
```

```
System.out.println(
"pets.removeFirst(): " + pets.removeFirst());
// Only differs in empty-list behavior:
System.out.println("pets.poll(): " + pets.poll());
System.out.println(pets);
pets.addFirst(new Rat());
System.out.println("After addFirst(): " + pets);
pets.offer(Pets.get());
System.out.println("After offer(): " + pets);
pets.add(Pets.get());
System.out.println("After add(): " + pets);
pets.addLast(new Hamster());
System.out.println("After addLast(): " + pets);
System.out.println(
"pets.removeLast(): " + pets.removeLast());
}
}
/* Output:
[Rat, Manx, Cymric, Mutt, Pug]
pets.getFirst(): Rat
```

pets.element(): Rat

pets.peek(): Rat

pets.remove(): Rat

pets.removeFirst(): Manx

pets.poll(): Cymric

[Mutt, Pug]

After addFirst(): [Rat, Mutt, Pug]

After offer(): [Rat, Mutt, Pug, Cymric]

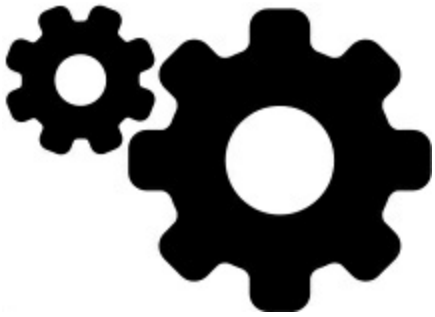
After add(): [Rat, Mutt, Pug, Cymric, Pug]

After addLast(): [Rat, Mutt, Pug, Cymric, Pug, Hamster]

pets.removeLast(): Hamster

**/*

The result of **Pets.list()** is handed to the **LinkedList** constructor to populate it. If you look at the **Queue** interface, you'll see the **element()**, **offer()**, **peek()**, **poll()** and **remove()** methods that were added to **LinkedList** so it could be a **Queue** implementation. Full examples of **Queue**s are given later in this chapter.



Stack

A stack is a “last-in, first-out” (LIFO) collection. It’s sometimes called a *pushdown stack*, because whatever you “push” on the stack last is the first item you can “pop” off of the stack. An often-used analogy is cafeteria trays in a spring-loaded holder—the last ones that go in are the first ones that come out.

Java 1.0 came with a **Stack** class that turned out to be badly designed (for backward compatibility, we are forever stuck with old design mistakes in Java). Java 6 added **ArrayDeque**, with methods that directly implement stack functionality:

```
// collections/StackTest.java
import java.util.*;
public class StackTest {
public static void main(String[] args) {
Deque<String> stack = new ArrayDeque<>();
for(String s : "My dog has fleas".split(" "))
```

```
stack.push(s);
while(!stack.isEmpty())
System.out.print(stack.pop() + " ");
}
}
/* Output:
fleas has dog My
*/
```

Even though it acts in all ways as a stack, we must still declare it as a **Deque**. Suppose that a class named **Stack** tells the story better:

```
// onjava/Stack.java
// A Stack class built with an ArrayDeque
package onjava;
import java.util.Deque;
import java.util.ArrayDeque;
public class Stack<T> {
private Deque<T> storage = new ArrayDeque<>();
public void push(T v) { storage.push(v); }
public T peek() { return storage.peek(); }
public T pop() { return storage.pop(); }
```

```
public boolean isEmpty() { return storage.isEmpty(); }
@Override
public String toString() {
return storage.toString();
}
}
```

This introduces the simplest possible example of a class definition using generics. The **<T>** after the class name tells the compiler this is a *parameterized type*, and that the type parameter—which is substituted with a real type when the class is used—is **T**. Basically, this says, "We're defining a **Stack** that holds objects of type **T**." The **Stack** is implemented using an **ArrayDeque**, which also holds type **T**. Notice that **push()** takes an object of type **T**, while **peek()** and **pop()** return an object of type **T**. The **peek()** method provides you with the top element without removing it from the top of the stack, while **pop()** removes and returns the top element.

If you want only stack behavior, inheritance is inappropriate here because that would produce a class with all the rest of the **ArrayDeque** methods (you'll see in the Appendix: Collection Topics that this very mistake was made by the Java 1.0 designers when they created **java.util.Stack**). Using composition, we choose which

methods to expose and how to name them.

We'll use the same code from **StackTest.java** to demonstrate this new **Stack** class:

```
// collections/StackTest2.java
import onjava.*;
public class StackTest2 {
public static void main(String[] args) {
Stack<String> stack = new Stack<>();
for(String s : "My dog has fleas".split(" "))
stack.push(s);
while(!stack.isEmpty())
System.out.print(stack.pop() + " ");
}
}
/* Output:
fleas has dog My
*/
```

To use this **Stack** in your own code, you fully specify the package—or change the name of the class—when you create one; otherwise, you'll probably collide with the **Stack** in **java.util**. For example, if we

import java.util.* into the above example, we must use

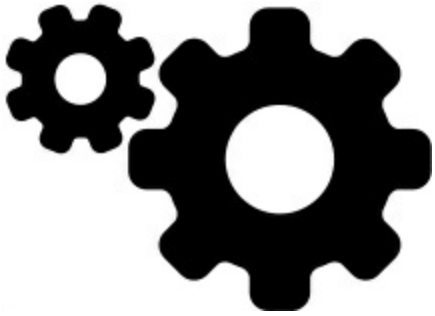
package names to prevent collisions:

```
// collections/StackCollision.java
public class StackCollision {
public static void main(String[] args) {
onjava.Stack<String> stack = new onjava.Stack<>();
for(String s : "My dog has fleas".split(" "))
stack.push(s);
while(!stack.isEmpty())
System.out.print(stack.pop() + " ");
System.out.println();
java.util.Stack<String> stack2 =
new java.util.Stack<>();
for(String s : "My dog has fleas".split(" "))
stack2.push(s);
while(!stack2.empty())
System.out.print(stack2.pop() + " ");
}
}
/* Output:
```

fleas has dog My

fleas has dog My

*/



Even though **java.util.Stack** exists, **ArrayDeque** produces a much better **Stack** and so is preferable.

You can also control the selection of the “preferred” **Stack** implementation using an explicit import:

import onjava.Stack;

Now any reference to **Stack** will select the **onjava** version, and to select **java.util.Stack** you must use full qualification.

Set

A **Set** refuses to hold more than one instance of each object value. If you try to add more than one instance of an equivalent object, the **Set** prevents duplication. The most common use for a **Set** is to test for membership, so you can easily ask whether an object is in a **Set**. Because of this, lookup is typically the most important operation for a

Set, so you'll usually choose a **HashSet** implementation, which is optimized for rapid lookup.

Set has the same interface as **Collection**, so there isn't any extra functionality like there is in the two different types of **List**. Instead, the **Set** is exactly a **Collection**—it just has different behavior. (This is the ideal use of inheritance and polymorphism: to express different behavior.) A **Set** determines membership based on the "value" of an object, a more complex topic covered in the Appendix: Collection Topics.

This uses a **HashSet** with **Integer** objects:

```
// collections/SetOfInteger.java
import java.util.*;
public class SetOfInteger {
public static void main(String[] args) {
Random rand = new Random(47);
Set<Integer> intset = new HashSet<>();
for(int i = 0; i < 10000; i++)
intset.add(rand.nextInt(30));
System.out.println(intset);
}
```

}

/ *Output:*

[0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15,

16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29]

**/*

Ten thousand random numbers from 0 up to 29 are added to the **Set**, so you can imagine that each value has many duplications. And yet you see that only one instance of each appears in the result.

The **HashSet** in earlier versions of Java produced output no discernible order. A **HashSet** uses *hashing* for speed—hashing is covered in the Appendix: Collection Topics chapter. The order maintained by a **HashSet** is different from a **TreeSet** or a **LinkedHashSet**, since each implementation has a different way of storing elements. **TreeSet** keeps elements sorted into a red-black tree data structure, whereas **HashSet** uses the hashing function. **LinkedHashSet** also uses hashing for lookup speed, but *appears* to maintain elements in insertion order using a linked list. Apparently, the hashing algorithm was changed and now **Integer**s end up in sorted order. However, you should not depend on this behavior:

// collections/SetOfString.java

import java.util.*;

```
public class SetOfString {
public static void main(String[] args) {
Set<String> colors = new HashSet<>();
for(int i = 0; i < 100; i++) {
colors.add("Yellow");
colors.add("Blue");
colors.add("Red");
colors.add("Red");
colors.add("Orange");
colors.add("Yellow");
colors.add("Blue");
colors.add("Purple");
}
System.out.println(colors);
}
}
/* Output:
[Red, Yellow, Blue, Purple, Orange]
*/
```

String objects don’t seem to produce an order. To sort the results,

one approach is to use a **TreeSet** instead of a **HashSet**:

```
// collections/SortedSetOfString.java
import java.util.*;
public class SortedSetOfString {
public static void main(String[] args) {
Set<String> colors = new TreeSet<>();
for(int i = 0; i < 100; i++) {
colors.add("Yellow");
colors.add("Blue");
colors.add("Red");
colors.add("Red");
colors.add("Orange");
colors.add("Yellow");
colors.add("Blue");
colors.add("Purple");
}
System.out.println(colors);
}
}
/* Output:
```

[Blue, Orange, Purple, Red, Yellow]

*/

One of the most common operations is a test for set membership using **contains()**, but there are also operations like the Venn diagrams you might have been taught in elementary school:

```
// collections/SetOperations.java
import java.util.*;
public class SetOperations {
public static void main(String[] args) {
Set<String> set1 = new HashSet<>();
Collections.addAll(set1,
"A B C D E F G H I J K L".split(" "));
set1.add("M");
System.out.println("H: " + set1.contains("H"));
System.out.println("N: " + set1.contains("N"));
Set<String> set2 = new HashSet<>();
Collections.addAll(set2, "H I J K L".split(" "));
System.out.println(
"set2 in set1: " + set1.containsAll(set2));
set1.remove("H");
```

```
System.out.println("set1: " + set1);
System.out.println(
"set2 in set1: " + set1.containsAll(set2));
set1.removeAll(set2);
System.out.println(
"set2 removed from set1: " + set1);
Collections.addAll(set1, "X Y Z".split(" "));
System.out.println(
"'X Y Z' added to set1: " + set1);
}
}
/* Output:
H: true
N: false
set2 in set1: true
set1: [A, B, C, D, E, F, G, I, J, K, L, M]
set2 in set1: false
set2 removed from set1: [A, B, C, D, E, F, G, M]
'X Y Z' added to set1: [A, B, C, D, E, F, G, M, X, Y,
Z]
```

*/

The method names are self-explanatory, and there are a few more in the JDK documentation.

Producing a list of unique elements can be useful. For example, suppose you'd like to list all the words in the file **SetOperations.java**, above. Using the **java.nio.file.Files.readAllLines()** method introduced later in the book, you can open a file and read it as a **List<String>** , with each **String** a line from the input file:

```
// collections/UniqueWords.java
import java.util.*;
import java.nio.file.*;
public class UniqueWords {
public static void
main(String[] args) throws Exception {
List<String> lines = Files.readAllLines(
Paths.get("SetOperations.java"));
Set<String> words = new TreeSet<>();
for(String line : lines)
for(String word : line.split("\\W+"))
```

```
if(word.trim().length() > 0)
words.add(word);
System.out.println(words);
}
}
/* Output:
[A, B, C, Collections, D, E, F, G, H, HashSet, I, J, K,
L, M, N, Output, Set, SetOperations, String, System, X,
Y, Z, add, addAll, added, args, class, collections,
contains, containsAll, false, from, import, in, java,
main, new, out, println, public, remove, removeAll,
removed, set1, set2, split, static, to, true, util,
void]
*/
```

We step through each line in the file and break it into words using **String.split()**, using the *regular expression* **\\W+**, which means it splits on one or more (that's the **+**) *non*-word letters (regular expressions are introduced in the Strings chapter). Each resulting word is added to the **words Set**. Since it is a **TreeSet**, the result is sorted. Here, the sorting is done *lexicographically* so the uppercase and lowercase letters are in separate groups. If you'd like to sort it

alphabetically, you can pass the

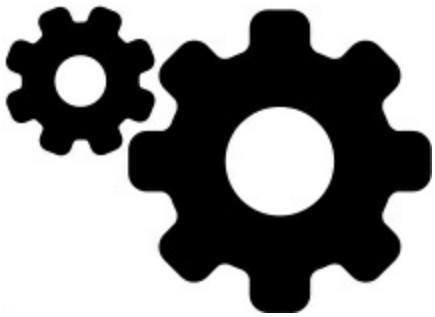
String.CASE_INSENSITIVE_ORDER Comparator (a

comparator is an object that establishes order) to the **TreeSet**

constructor:

```
// collections/UniqueWordsAlphabetic.java
// Producing an alphabetic listing
import java.util.*;
import java.nio.file.*;
public class UniqueWordsAlphabetic {
public static void
main(String[] args) throws Exception {
List<String> lines = Files.readAllLines(
Paths.get("SetOperations.java"));
Set<String> words =
new TreeSet<>(String.CASE_INSENSITIVE_ORDER);
for(String line : lines)
for(String word : line.split("\\W+"))
if(word.trim().length() > 0)
words.add(word);
System.out.println(words);
```

```
}
}
/* Output:
[A, add, addAll, added, args, B, C, class, collections,
contains, containsAll, D, E, F, false, from, G, H,
HashSet, I, import, in, J, java, K, L, M, main, N, new,
out, Output, println, public, remove, removeAll,
removed, Set, set1, set2, SetOperations, split, static,
String, System, to, true, util, void, X, Y, Z]
*/
```



Comparators are explored in detail in the Arrays chapter.

Map

The ability to map objects to other objects is a powerful way to solve programming problems. For example, consider a program to examine the randomness of Java's **Random** class. Ideally, **Random** would produce a perfect distribution of numbers, but to test this you must

generate many random numbers and count the ones that fall in the various ranges. A **Map** easily solves the problem. Here, the key is the number produced by **Random**, and the value is the number of times that number appears:

```
// collections/Statistics.java
// Simple demonstration of HashMap
import java.util.*;
public class Statistics {
public static void main(String[] args) {
Random rand = new Random(47);
Map<Integer, Integer> m = new HashMap<>();
for(int i = 0; i < 10000; i++) {
// Produce a number between 0 and 20:
int r = rand.nextInt(20);
Integer freq = m.get(r); // [1]
m.put(r, freq == null ? 1 : freq + 1);
}
System.out.println(m);
}
}
```

/ *Output:*

{0=481, 1=502, 2=489, 3=508, 4=481, 5=503, 6=519,

7=471, 8=468, 9=549, 10=513, 11=531, 12=521, 13=506,

14=477, 15=497, 16=533, 17=509, 18=478, 19=464}

**/*

[1] Autoboxing converts the randomly generated **int** into an **Integer** reference that can be used with the **HashMap** (you can't use primitives with collections). **get()** returns **null** if the key is not already in the collection (which means this is the first time the number was found). Otherwise, **get()** produces the associated **Integer** value for the key, which is incremented (again, autoboxing simplifies the expression but there are actually conversions to and from **Integer** taking place).

Next, we'll use a **String** description to look up **Pet** objects. This also shows how you can test a **Map** to see if it contains a key or a value with **containsKey()** and **containsValue()**:

```
// collections/PetMap.java
import typeinfo.pets.*;
import java.util.*;
public class PetMap {
```

```
public static void main(String[] args) {
Map<String, Pet> petMap = new HashMap<>();
petMap.put("My Cat", new Cat("Molly"));
petMap.put("My Dog", new Dog("Ginger"));
petMap.put("My Hamster", new Hamster("Bosco"));
System.out.println(petMap);
Pet dog = petMap.get("My Dog");
System.out.println(dog);
System.out.println(petMap.containsKey("My Dog"));
System.out.println(petMap.containsValue(dog));
}
}
/* Output:
{My Dog=Dog Ginger, My Cat=Cat Molly, My
Hamster=Hamster Bosco}
Dog Ginger
true
true
*/
```

Maps, like arrays and **Collection**s, can easily be expanded to multiple dimensions; you make a **Map** whose values are **Map**s (and the

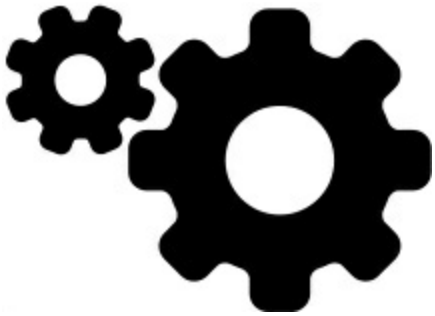
values of *those* **Map**s can be other collections, even other **Map**s). Thus, it's easy to combine collections to quickly produce powerful data

structures. For example, suppose you are keeping track of people who

have multiple pets—all you need is a **Map<Person, List<Pet>>** :

```
// collections/MapOfList.java
// {java collections.MapOfList}
package collections;
import typeinfo.pets.*;
import java.util.*;
public class MapOfList {
public static final Map<Person, List< ? extends Pet>>
petPeople = new HashMap<>();
static {
petPeople.put(new Person("Dawn"),
Arrays.asList(
new Cymric("Molly"),
new Mutt("Spot")));
petPeople.put(new Person("Kate"),
Arrays.asList(new Cat("Shackleton"),
new Cat("Elsie May"), new Dog("Margrett")));
petPeople.put(new Person("Marilyn"),
```

```
Arrays.asList(
new Pug("Louie aka Louis Snorkelstein Dupree"),
new Cat("Stanford"),
new Cat("Pinkola")));
petPeople.put(new Person("Luke"),
Arrays.asList(
new Rat("Fuzzy"), new Rat("Fizzy")));
petPeople.put(new Person("Isaac"),
Arrays.asList(new Rat("Freckly")));
}
public static void main(String[] args) {
System.out.println("People: " + petPeople.keySet());
System.out.println("Pets: " + petPeople.values());
for(Person person : petPeople.keySet()) {
System.out.println(person + " has:");
```



```
for(Pet pet : petPeople.get(person))
```

```
System.out.println(" " + pet);
}
}
}
/* Output:
People: [Person Dawn, Person Kate, Person Isaac, Person
Marilyn, Person Luke]
Pets: [[Cymric Molly, Mutt Spot], [Cat Shackleton, Cat
Elsie May, Dog Margrett], [Rat Freckly], [Pug Louie aka
Louis Snorkelstein Dupree, Cat Stanford, Cat Pinkola],
[Rat Fuzzy, Rat Fizzy]]
Person Dawn has:
Cymric Molly
Mutt Spot
Person Kate has:
Cat Shackleton
Cat Elsie May
Dog Margrett
Person Isaac has:
Rat Freckly
```

Person Marilyn has:

Pug Louie aka Louis Snorkelstein Dupree

Cat Stanford

Cat Pinkola

Person Luke has:

Rat Fuzzy

Rat Fizzy

*/

A **Map** can return a **Set** of its keys, a **Collection** of its values, or a **Set** of its pairs. The **keySet()** method produces a **Set** of all the keys in **petPeople**, used in the *for-in* statement to iterate through the **Map**.

Queue

A *queue* is typically a *first-in-first-out* (FIFO) collection. That is, you put things in at one end and pull them out at the other, and the order you put them in is the same order they come out. Queues are commonly used as a way to reliably transfer objects from one area of a program to another. Queues are especially important in Concurrent Programming, because they safely transfer objects from one task to another.

LinkedList implements the **Queue** interface with methods to support queue behavior, so a **LinkedList** can be used as a **Queue** implementation. By upcasting a **LinkedList** to a **Queue**, this example uses the **Queue**-specific methods in the **Queue** interface:

```
// collections/QueueDemo.java
// Upcasting to a Queue from a LinkedList
import java.util.*;
public class QueueDemo {
public static void printQ(Queue queue) {
while(queue.peek() != null)
System.out.print(queue.remove() + " ");
System.out.println();
}
public static void main(String[] args) {
Queue<Integer> queue = new LinkedList<>();
Random rand = new Random(47);
for(int i = 0; i < 10; i++)
queue.offer(rand.nextInt(i + 10));
printQ(queue);
Queue<Character> qc = new LinkedList<>();
```

```
for(char c : "Brontosaurus".toCharArray())
qc.offer(c);
printQ(qc);
}
}
/* Output:
8 1 1 1 5 14 3 1 0 1
B r o n t o s a u r u s
*/
```

offer() is a **Queue**-specific method that inserts an element at the tail of the queue if it can, or returns **false**. Both **peek()** and **element()** return the head of the queue *without removing it*, but **peek()** returns **null** if the queue is empty and **element()** throws **NoSuchElementException**. Both **poll()** and **remove()** remove and return the head of the queue, but **poll()** returns **null** if the queue is empty, while **remove()** throws **NoSuchElementException**.

Autoboxing automatically converts the **int** result of **nextInt()** into the **Integer** object required by **queue**, and the **char c** into the **Character** object required by **qc**. The **Queue** interface narrows access to the methods of **LinkedList** so only the appropriate methods are available, and you are thus less tempted to use **LinkedList** methods (here, you can actually cast **queue** back to a **LinkedList**, but you are at least discouraged from doing so).

The **Queue**-specific methods provide complete and standalone functionality. That is, you can have a usable **Queue** without any of the methods in **Collection**, from which it is inherited.

PriorityQueue

First-in, first-out (FIFO) describes the most typical *queuing discipline*. A queuing discipline decides, given a group of elements in the queue, which one goes next. First-in, first-out says that the next element should be the one that was waiting the longest.

A *priority queue* says that the element that goes next is the one with the greatest need (the highest priority). For example, in an airport, a customer might be pulled out of a queue if their plane is about to leave. If you build a messaging system, some messages are more important than others, and should be dealt with sooner, regardless of

when they arrive. The **PriorityQueue** was added in Java 5 to provide an automatic implementation for this behavior.

When you **offer()** an object onto a **PriorityQueue**, that object is sorted into the queue.5 The default sorting uses the *natural order* of the objects in the queue, but you can modify the order by providing your own **Comparator**. The **PriorityQueue** ensures that when you call **peek()**, **poll()** or **remove()**, the element you get is the one with the highest priority.

It's trivial to make a **PriorityQueue** that works with built-in types like **Integer**, **String** or **Character**. In the following example, the first set of values are the identical random values from the previous example, showing that they emerge differently from the **PriorityQueue**:

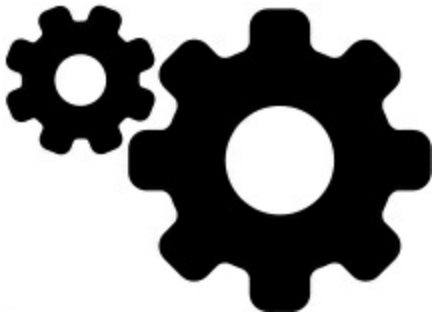
```
// collections/PriorityQueueDemo.java
import java.util.*;
public class PriorityQueueDemo {
public static void main(String[] args) {
PriorityQueue<Integer> priorityQueue =
new PriorityQueue<>();
Random rand = new Random(47);
for(int i = 0; i < 10; i++)
```

```
priorityQueue.offer(rand.nextInt(i + 10));
QueueDemo.printQ(priorityQueue);
List<Integer> ints = Arrays.asList(25, 22, 20,
18, 14, 9, 3, 1, 1, 2, 3, 9, 14, 18, 21, 23, 25);
priorityQueue = new PriorityQueue<>(ints);
QueueDemo.printQ(priorityQueue);
priorityQueue = new PriorityQueue<>(
ints.size(), Collections.reverseOrder());
priorityQueue.addAll(ints);
QueueDemo.printQ(priorityQueue);
String fact = "EDUCATION SHOULD ESCHEW OBFUSCATION";
List<String> strings =
Arrays.asList(fact.split(""));
PriorityQueue<String> stringPQ =
new PriorityQueue<>(strings);
QueueDemo.printQ(stringPQ);
stringPQ = new PriorityQueue<>(
strings.size(), Collections.reverseOrder());
stringPQ.addAll(strings);
QueueDemo.printQ(stringPQ);
```

```
Set<Character> charSet = new HashSet<>();
for(char c : fact.toCharArray())
charSet.add(c); // Autoboxing
PriorityQueue<Character> characterPQ =
new PriorityQueue<>(charSet);
QueueDemo.printQ(characterPQ);
}
}
/* Output:
0 1 1 1 1 1 3 5 8 14
1 1 2 3 3 9 9 14 14 18 18 20 21 22 23 25 25
25 25 23 22 21 20 18 18 14 14 9 9 3 3 2 1 1
A A B C C C D D E E E F H H I I L N N O O O O S S
S T T U U U W
W U U U T T S S S O O O O N N L I I H H F E E E D D C C
C B A A
A B C D E F H I L N O S T U W
*/
```

Duplicates are allowed, and the lowest values have the highest priority (in the case of **String**, spaces also count as values and are higher in

priority than letters). To change the ordering using a **Comparator** object, the third constructor call to **PriorityQueue<Integer>** and the second call to **PriorityQueue<String>** use the reverse-order **Comparator** produced by



Collections.reverseOrder().

The last section adds a **HashSet** to eliminate duplicate **Character**s.

Integer, **String** and **Character** work with **PriorityQueue** because these classes already have natural ordering built in. If you want you use your own class in a **PriorityQueue**, you must include additional functionality to produce natural ordering, or provide your own **Comparator**. There's a more sophisticated example that demonstrates this in the Appendix: Collection Topics.

Collection vs. Iterator

Collection is the root interface common to all sequence collections. It might be thought of as an "incidental interface," one that

appeared because of commonality between other interfaces. In addition, the **java.util.AbstractCollection** class provides a default implementation for a **Collection**, so you can create a new subtype of **AbstractCollection** without unnecessary code duplication.

One argument for having an interface is it creates more generic code. By writing to an interface rather than an implementation, your code can be applied to more types of objects. [6] So if I write a method that takes a **Collection**, that method can be applied to any type that implements **Collection**—and this allows a new class to implement **Collection** for use with my method. The Standard C++ Library has no common base class for its collections—all commonality between collections is achieved through iterators. In Java, it might seem sensible to follow the C++ approach, and to express commonality between collections using an iterator rather than a **Collection**. However, the two approaches are bound together, since implementing **Collection** also means providing an **iterator()** method:

```
// collections/InterfaceVsIterator.java
import typeinfo.pets.*;
import java.util.*;
public class InterfaceVsIterator {
```

```
public static void display(Iterator<Pet> it) {
while(it.hasNext()) {
Pet p = it.next();
System.out.print(p.id() + ":" + p + " ");
}
System.out.println();
}
public static void display(Collection<Pet> pets) {
for(Pet p : pets)
System.out.print(p.id() + ":" + p + " ");
System.out.println();
}
public static void main(String[] args) {
List<Pet> petList = Pets.list(8);
Set<Pet> petSet = new HashSet<>(petList);
Map<String, Pet> petMap = new LinkedHashMap<>();
String[] names = ("Ralph, Eric, Robin, Lacey, " +
"Britney, Sam, Spot, Fluffy").split(", ");
for(int i = 0; i < names.length; i++)
petMap.put(names[i], petList.get(i));
```

```
display(petList);
display(petSet);
display(petList.iterator());
display(petSet.iterator());
System.out.println(petMap);
System.out.println(petMap.keySet());
display(petMap.values());
display(petMap.values().iterator());
}
}
/* Output:
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
{Ralph=Rat, Eric=Manx, Robin=Cymric, Lacey=Mutt,
```

Britney=Pug, Sam=Cymric, Spot=Pug, Fluffy=Manx}

[Ralph, Eric, Robin, Lacey, Britney, Sam, Spot, Fluffy]

0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug

7:Manx

0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug

7:Manx

**/*

Both versions of **display()** work with **Map** objects as well as subtypes of **Collection**. Both **Collection** and **Iterator** decouple the **display()** methods from knowing the particular implementation of the underlying collection.

here the two approaches come up even. In fact, **Collection** pulls ahead a bit because it is **Iterable**, and so in the implementation of **display(Collection)** the *for-in* construct can be used, which makes the code a little cleaner.

An **Iterator** becomes compelling when you implement a foreign class, one that is not a **Collection**, when it would be difficult or annoying to make it implement the **Collection** interface. For example, if we create a **Collection** implementation by inheriting from a class that holds **Pet** objects, we must implement all the

Collection methods, even if we don't use them within the

display() method. Although this can easily be accomplished by

inheriting from **AbstractCollection**, you're forced to implement

iterator() anyway, along with **size()**, to provide the methods not implemented by **AbstractCollection**, but used by the other

methods in **AbstractCollection**:

```
// collections/CollectionSequence.java

import typeinfo.pets.*;

import java.util.*;

public class CollectionSequence

extends AbstractCollection<Pet> {

private Pet[] pets = Pets.array(8);

@Override

public int size() { return pets.length; }

@Override

public Iterator<Pet> iterator() {

return new Iterator<Pet>() { // [1]

private int index = 0;

@Override

public boolean hasNext() {

return index < pets.length;
```

```
}
@Override
public Pet next() { return pets[index++]; }
@Override
public void remove() { // Not implemented
throw new UnsupportedOperationException();
}
};
}
public static void main(String[] args) {
CollectionSequence c = new CollectionSequence();
InterfaceVsIterator.display(c);
InterfaceVsIterator.display(c.iterator());
}
}
/* Output:
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
```

*/

The **remove()** method is an “optional operation,” covered in the

Appendix: Collection Topics. Here, it’s not necessary to implement it, and if you call it, it will throw an exception.

[1] You might think, since **iterator()** returns

Iterator<Pet> , that the anonymous inner class definition

could use the diamond syntax and Java could infer the type. But

that doesn’t work; the type inference is still quite limited.

This example shows that if you implement **Collection**, you also

implement **iterator()**, and just implementing **iterator()**

alone requires only slightly less effort than inheriting from

AbstractCollection. However, if your class already inherits

from another class, you cannot also inherit from

AbstractCollection. In that case, to implement **Collection**

you’d have to implement all the methods in the interface. Here it’s

much easier to inherit and add the ability to create an iterator:

// collections/NonCollectionSequence.java

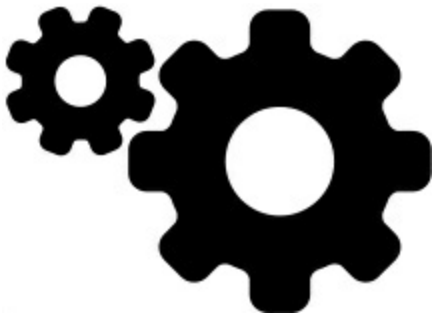
import typeinfo.pets.*;

import java.util.*;

class PetSequence {

protected Pet[] pets = Pets.array(8);

```
}
public class NonCollectionSequence extends PetSequence {
public Iterator<Pet> iterator() {
return new Iterator<Pet>() {
private int index = 0;
@Override
public boolean hasNext() {
return index < pets.length;
}
@Override
public Pet next() { return pets[index++]; }
@Override
public void remove() { // Not implemented
```



```
throw new UnsupportedOperationException();
}
};
```

```
}
public static void main(String[] args) {
NonCollectionSequence nc =
new NonCollectionSequence();
InterfaceVsIterator.display(nc.iterator());
}
}
/* Output:
0:Rat 1:Manx 2:Cymric 3:Mutt 4:Pug 5:Cymric 6:Pug
7:Manx
*/
```

Producing an **Iterator** is the least-coupled way of connecting a sequence to a method that consumes that sequence, and puts far fewer constraints on the sequence class than does implementing **Collection**.

for-in and Iterators

So far, the *for-in* syntax is primarily used with arrays, but it also works with any **Collection** object. You've actually seen a few examples of this using **ArrayList**, but here's a general proof:

```
// collections/ForInCollections.java
```

```
// All collections work with for-in
import java.util.*;
public class ForInCollections {
public static void main(String[] args) {
Collection<String> cs = new LinkedList<>();
Collections.addAll(cs,
"Take the long way home".split(" "));
for(String s : cs)
System.out.print("'" + s + "' ");
}
}
/* Output:
'Take' 'the' 'long' 'way' 'home'
*/
```

Since **cs** is a **Collection**, this code shows that working with *for-in* is a characteristic of all **Collection** objects.

The reason this works is that Java 5 introduced an interface called **Iterable** containing an **iterator()** method that produces an **Iterator**. *for-in* uses this **Iterable** interface to move through a sequence. So if you create any class that implements **Iterable**, you

can use it in a *for-in* statement:

```
// collections/IterableClass.java
// Anything Iterable works with for-in
import java.util.*;
public class IterableClass implements Iterable<String> {
protected String[] words = ("And that is how " +
"we know the Earth to be banana-shaped."
).split(" ");
@Override
public Iterator<String> iterator() {
return new Iterator<String>() {
private int index = 0;
@Override
public boolean hasNext() {
return index < words.length;
}
@Override
public String next() { return words[index++]; }
@Override
public void remove() { // Not implemented
```

```
throw new UnsupportedOperationException();
}
};
}
public static void main(String[] args) {
for(String s : new IterableClass())
System.out.print(s + " ");
}
}
/* Output:
And that is how we know the Earth to be banana-shaped.
*/
```

iterator() returns an instance of an anonymous inner implementation of **Iterator<String>** which delivers each word in the array. In **main()** you see that **IterableClass** does indeed work in a *for-in* statement.

In Java 5, a number of classes were made **Iterable**, primarily all **Collection** classes (but not **Map**s). For example, this code displays all operating system environment variables:

```
// collections/EnvironmentVariables.java
```

```
// {VisuallyInspectOutput}

import java.util.*;

public class EnvironmentVariables {

public static void main(String[] args) {

for(Map.Entry entry: System.getenv().entrySet()) {

System.out.println(entry.getKey() + ": " +

entry.getValue());

}

}

}
```

System.getenv()[7] returns a **Map**, **entrySet()** produces a **Set** of **Map.Entry** elements, and a **Set** is **Iterable** so it can be used

in a *for-in* loop.

A *for-in* statement works with an array or anything **Iterable**, but

that doesn't mean that an array is automatically an **Iterable**, nor is

there any autoboxing that takes place:

```
// collections/ArrayIsNotIterable.java
```

```
import java.util.*;
public class ArrayIsNotIterable {
static <T> void test(Iterable<T> ib) {
for(T t : ib)
System.out.print(t + " ");
}
public static void main(String[] args) {
test(Arrays.asList(1, 2, 3));
String[] strings = { "A", "B", "C" };
// An array works in for-in, but it's not Iterable:
//- test(strings);
// You must explicitly convert it to an Iterable:
test(Arrays.asList(strings));
}
}
/* Output:
1 2 3 A B C
*/
```

Trying to pass an array as an **Iterable** argument fails. There is no automatic conversion to an **Iterable**; you must do it by hand.

The *Adapter Method* Idiom

What if you have an existing class that is **Iterable**, and you'd like to add one or more new ways to use this class in a *for-in* statement? For example, suppose you'd like to choose whether to iterate through a list of words in either a forward or reverse direction. If you inherit from the class and override the **iterator()** method, you replace the existing method and you don't get a choice.

One solution I call the *Adapter Method* idiom. The "Adapter" part comes from design patterns, because you must provide a particular interface to satisfy the *for-in* statement. When you have one interface and you need another one, writing an adapter solves the problem.

Here, I want to *add* the ability to produce a reverse iterator to the default forward iterator, so I can't override. Instead, I add a method that produces an **Iterable** object which can then be used in the *for-in* statement. As you see here, this allows us to provide multiple ways to use *for-in*:

```
// collections/AdapterMethodIdiom.java
// The "Adapter Method" idiom uses for-in
// with additional kinds of Iterables
import java.util.*;
class ReversibleArrayList<T> extends ArrayList<T> {
```

```
ReversibleArrayList(Collection<T> c) {
super(c);
}
public Iterable<T> reversed() {
return new Iterable<T>() {
public Iterator<T> iterator() {
return new Iterator<T>() {
int current = size() - 1;
public boolean hasNext() {
return current > -1;
}
public T next() { return get(current--); }
public void remove() { // Not implemented
throw new UnsupportedOperationException();
}
};
}
};
}
}
```

```
public class AdapterMethodIdiom {
public static void main(String[] args) {
ReversibleArrayList<String> ral =
new ReversibleArrayList<String>(
Arrays.asList("To be or not to be".split(" ")));
// Grabs the ordinary iterator via iterator():
for(String s : ral)
System.out.print(s + " ");
System.out.println();
// Hand it the Iterable of your choice
for(String s : ral.reversed())
System.out.print(s + " ");
}
}
/* Output:
To be or not to be
be to not or be To
*/
```

In **main()**, if you put the **ral** object in the *for-in* statement, you get the (default) forward iterator. But if you call **reversed()** on the

object, it produces different behavior.

Using this approach, I can add two adapter methods to the

IterableClass.java example:

```
// collections/MultiIterableClass.java
// Adding several Adapter Methods
import java.util.*;
public class MultiIterableClass extends IterableClass {
public Iterable<String> reversed() {
return new Iterable<String>() {
public Iterator<String> iterator() {
return new Iterator<String>() {
int current = words.length - 1;
public boolean hasNext() {
return current > -1;
}
public String next() {
return words[current--];
}
public void remove() { // Not implemented
throw new UnsupportedOperationException();
}
```

```
};
}
};
}
public Iterable<String> randomized() {
return new Iterable<String>() {
public Iterator<String> iterator() {
List<String> shuffled =
new ArrayList<String>(Arrays.asList(words));
Collections.shuffle(shuffled, new Random(47));
return shuffled.iterator();
}
};
}
public static void main(String[] args) {
MultiIterableClass mic = new MultiIterableClass();
for(String s : mic.reversed())
System.out.print(s + " ");
System.out.println();
for(String s : mic.randomized())
```

```
System.out.print(s + " ");
System.out.println();
for(String s : mic)
System.out.print(s + " ");
}
}
/* Output:
banana-shaped. be to Earth the know we how is that And
is banana-shaped. Earth that how the be And we know to
And that is how we know the Earth to be banana-shaped.
*/
```

Notice that the second method, **random()**, doesn't create its own **Iterator** but returns the one from the shuffled **List**.

The output shows that the **Collections.shuffle()** method doesn't affect the original array, but only shuffles the references in **shuffled**. This is only true because the **randomized()** method wraps an **ArrayList** around the result of **Arrays.asList()**. If the **List** produced by **Arrays.asList()** is shuffled directly, it will modify the underlying array, as shown here:

```
// collections/ModifyingArraysAsList.java
```

```
import java.util.*;
public class ModifyingArraysAsList {
public static void main(String[] args) {
Random rand = new Random(47);
Integer[] ia = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
List<Integer> list1 =
new ArrayList<>(Arrays.asList(ia));
System.out.println("Before shuffling: " + list1);
Collections.shuffle(list1, rand);
System.out.println("After shuffling: " + list1);
System.out.println("array: " + Arrays.toString(ia));
List<Integer> list2 = Arrays.asList(ia);
System.out.println("Before shuffling: " + list2);
Collections.shuffle(list2, rand);
System.out.println("After shuffling: " + list2);
System.out.println("array: " + Arrays.toString(ia));
}
}
/* Output:
Before shuffling: [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
```

After shuffling: [4, 6, 3, 1, 8, 7, 2, 5, 10, 9]

array: [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]

Before shuffling: [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]

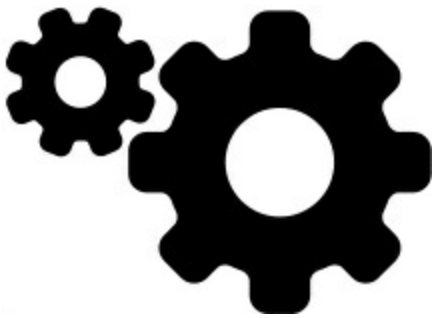
After shuffling: [9, 1, 6, 3, 7, 2, 5, 10, 4, 8]

array: [9, 1, 6, 3, 7, 2, 5, 10, 4, 8]

*/

In the first case, the output of **Arrays.asList()** is handed to the **ArrayList** constructor, and this creates an **ArrayList** that references the elements of **ia**. Shuffling these references doesn't modify the array. However, if you use the result of **Arrays.asList(ia)** directly, shuffling modifies the order of **ia**.

It's important to be aware that **Arrays.asList()** produces a **List** object that uses the underlying array as its physical implementation. If you do anything to that **List** that modifies it, and you don't want the original array modified, make a copy into another collection.



Summary

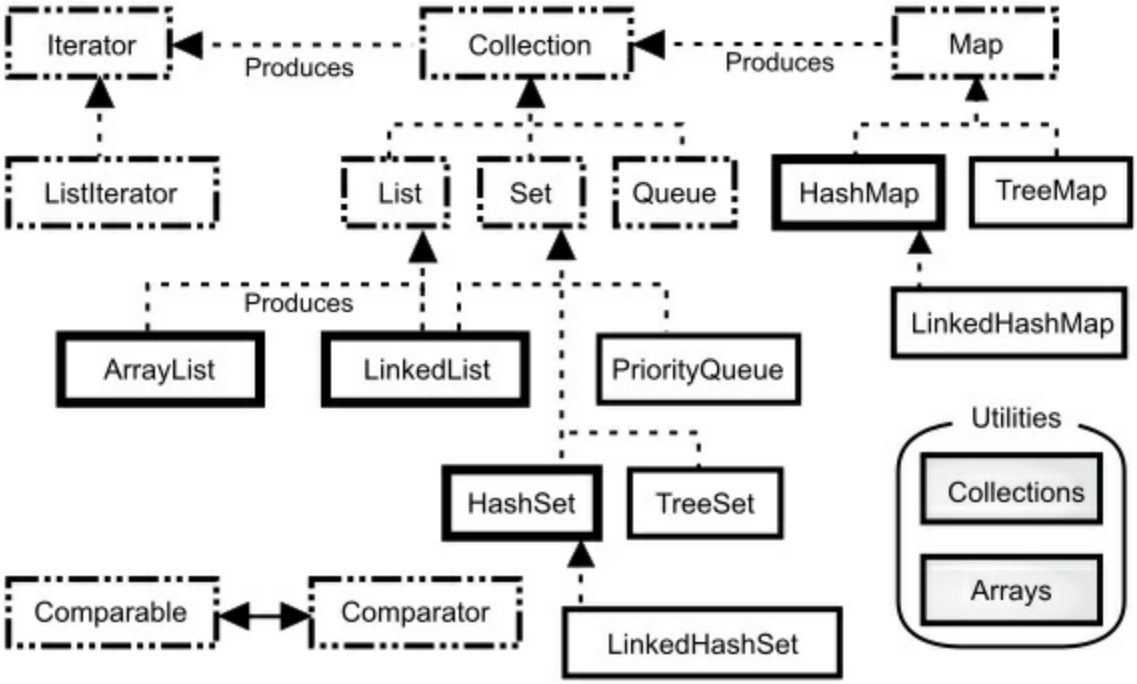
Java provides a number of ways to hold objects:

1. An array associates numerical indexes to objects. It holds objects of a known type so you don't have to cast the result when you're looking up an object. It can be multidimensional, and it can hold primitives. Although you can create arrays at run-time, the size of an array cannot be changed once you create it.
2. A **Collection** holds single elements, and a **Map** holds associated pairs. With Java generics, you specify the type of object held in the collections, so you can't put the wrong type into a collection and you don't have to cast elements when you fetch them out of a collection. Both **Collection**s and **Map**s automatically resize themselves as you add more elements. A collection won't hold primitives, but autoboxing takes care of translating primitives back and forth to the wrapper types held in the collection.
3. Like an array, a **List** also associates numerical indexes to objects —thus, arrays and **List**s are ordered collections.
4. Use an **ArrayList** if you perform many random accesses, but a **LinkedList** for many insertions and removals in the middle of

the list.

5. The behavior of **Queue**s and stacks is provided via the **LinkedList**.

6. A **Map** is a way to associate, not integral values, but *objects* with other objects. **HashMap**s are designed for rapid access, whereas a



TreeMap keeps its keys in sorted order, and thus is not as fast as a **HashMap**. A **LinkedHashMap** keeps its elements in insertion order, but provides rapid access with hashing.

7. A **Set** only accepts one of each type of object. **HashSet**s provide maximally fast lookups, whereas **TreeSet**s keep the elements in sorted order. **LinkedHashSet**s keep elements in insertion

order.

8. Don’t use the legacy classes **Vector**, **Hashtable**, and **Stack** in new code.

It’s helpful to look at a simplified diagram of the Java collections (without the abstract classes or legacy components). This only includes the interfaces and classes you encounter on a regular basis.

Simple Collection Taxonomy

You’ll see there are really only four basic collection components—**Map**, **List**, **Set**, and **Queue**—and only two or three implementations of each one (the **java.util.concurrent** implementations of **Queue** are not included in this diagram). The collections you use most often have heavy black lines around them.

The dotted boxes represent interfaces, and the solid boxes are regular (concrete) classes. The dotted lines with hollow arrows indicate that a particular class is implementing an interface. The solid arrows show that a class can produce objects of the class where the arrow is pointing. For example, any **Collection** can produce an **Iterator**, and a **List** can produce a **ListIterator** (as well as an ordinary **Iterator**, since **List** inherits **Collection**).

Here’s an example that shows the different methods between the various classes. The actual code is from the Generics chapter; I’m just calling

it here to produce the output. The output also shows the interfaces implemented in each class or interface:

```
// collections/CollectionDifferences.java
import onjava.*;
public class CollectionDifferences {
public static void main(String[] args) {
CollectionMethodDifferences.main(args);
}
}
/* Output:
Collection: [add, addAll, clear, contains, containsAll,
equals, forEach, hashCode, isEmpty, iterator,
parallelStream, remove, removeAll, removeIf, retainAll,
size, spliterator, stream, toArray]
Interfaces in Collection: [Iterable]
Set extends Collection, adds: []
Interfaces in Set: [Collection]
HashSet extends Set, adds: []
Interfaces in HashSet: [Set, Cloneable, Serializable]
LinkedHashSet extends HashSet, adds: []
```

Interfaces in LinkedHashSet: [Set, Cloneable,

Serializable]

TreeSet extends Set, adds: [headSet,

descendingIterator, descendingSet, pollLast, subSet,

floor, tailSet, ceiling, last, lower, comparator,

pollFirst, first, higher]

Interfaces in TreeSet: [NavigableSet, Cloneable,

Serializable]

List extends Collection, adds: [replaceAll, get,

indexOf, subList, set, sort, lastIndexOf, listIterator]

Interfaces in List: [Collection]

ArrayList extends List, adds: [trimToSize,

ensureCapacity]

Interfaces in ArrayList: [List, RandomAccess,

Cloneable, Serializable]

LinkedList extends List, adds: [offerFirst, poll,

getLast, offer, getFirst, removeFirst, element,

removeLastOccurrence, peekFirst, peekLast, push,

pollFirst, removeFirstOccurrence, descendingIterator,

pollLast, removeLast, pop, addLast, peek, offerLast,

addFirst]

Interfaces in LinkedList: [List, Deque, Cloneable,

Serializable]

Queue extends Collection, adds: [poll, peek, offer,

element]

Interfaces in Queue: [Collection]

PriorityQueue extends Queue, adds: [comparator]

Interfaces in PriorityQueue: [Serializable]

Map: [clear, compute, computeIfAbsent,

computeIfPresent, containsKey, containsValue, entrySet,

equals, forEach, get, getOrDefault, hashCode, isEmpty,

keySet, merge, put, putAll, putIfAbsent, remove,

replace, replaceAll, size, values]

HashMap extends Map, adds: []

Interfaces in HashMap: [Map, Cloneable, Serializable]

LinkedHashMap extends HashMap, adds: []

Interfaces in LinkedHashMap: [Map]

SortedMap extends Map, adds: [lastKey, subMap,

comparator, firstKey, headMap, tailMap]

Interfaces in SortedMap: [Map]

TreeMap extends Map, adds: [descendingKeySet, navigableKeySet, higherEntry, higherKey, floorKey, subMap, ceilingKey, pollLastEntry, firstKey, lowerKey, headMap, tailMap, lowerEntry, ceilingEntry, descendingMap, pollFirstEntry, lastKey, firstEntry, floorEntry, comparator, lastEntry]

Interfaces in TreeMap: [NavigableMap, Cloneable, Serializable]

*/

All **Set**s except **TreeSet** have exactly the same interface as **Collection**. **List** and **Collection** differ significantly, although **List** requires methods from **Collection**. On the other hand, the methods in the **Queue** interface stand alone; the **Collection** methods are not required to create a functioning **Queue** implementation. Finally, the only intersection between **Map** and **Collection** is the fact that a **Map** can produce **Collection**s using the **entrySet()** and **values()** methods.

Notice the tagging interface **java.util.RandomAccess**, which is attached to **ArrayList** but not to **LinkedList**. This provides information for algorithms that dynamically change their behavior

depending on a particular **List**.

It’s true this organization is somewhat odd, as object-oriented hierarchies go. However, as you learn more about the collections in **java.util** (in particular, in the Appendix: Collection Topics), you’ll see there are more issues than just a slightly odd inheritance structure.

Collection libraries have always been difficult design problems—solving these problems involves satisfying a set of forces that often oppose each other. So be prepared for some compromises here and there.

Despite these issues, the Java collections are fundamental tools you can use on a day-to-day basis to make your programs simpler, more powerful, and more effective. It might take you a little while to get comfortable with some aspects of the library, but I think you’ll find yourself rapidly acquiring and using the classes in this library.

1. A number of languages, such as Perl, Python, and Ruby, have native support for collections.↩

2. This is a place where operator overloading would have been nice. C++ and C# collection classes produce a cleaner syntax using operator overloading.↩

3. At the end of the Generics chapter, you’ll find a discussion about whether this is such a bad problem. However, the Generics

chapter also shows that Java generics are useful for more than just type-safe collections. ↩

4. **remove()** is a so-called “optional” method (there are other such methods), which means not all **Iterator** implementations must implement it. This topic is covered in the Appendix: Collection Topics. The standard Java library collections implement **remove()**, however, so you don’t need to worry about it until that chapter. ↩

5. This actually depends on the implementation. Priority queue algorithms typically sort on insertion (maintaining a *heap*), but they may also perform the selection of the most important element upon removal. The choice of algorithm can be important if an object’s priority can change while it is waiting in the queue. ↩

6. Some people advocate the automatic creation of an interface for every possible combination of methods in a class—sometimes for every single class. I believe that an interface should have more meaning than a mechanical duplication of method combinations, so I tend to wait until I see the value added by an interface before creating one.↩

7. This was not available before Java 5, because it was thought too

tightly coupled to the operating system, and thus to violate “write once, run anywhere.” The fact it is included now suggests that the Java designers became more pragmatic.↩

Functional

Programming

A functional programming language manipulates pieces of code as easily as it manipulates data. Although Java is not a functional language, Java 8 *Lambda Expressions* and *Method References* allow you to program in a functional style.

In the early days of the computer age, memory was scarce and precious. Nearly everyone programmed in assembly language. People knew about compilers, but the mere thought of the inefficient code generation from such a thing—many bytes would certainly be generated that hand-coded assembly would never produce!

Often, just to fit a program into limited memory, programmers saved code space by modifying in-memory code to make it do something

different, *while the program was executing*. This technique is called *self-modifying code*, and as long as a program was small enough for a handful of people to maintain all the tricky and arcane assembly code, you could probably get it to work.

Memory got cheaper and processors got faster. The C language appeared and was thought of as “high level” by most assembly-language programmers. Others discovered that C could make them significantly more productive. And with C, it still wasn’t that hard to create self-modifying code.

With cheaper hardware, programs grew in size and complexity. It became difficult just to get programs to work. We sought ways to make code more consistent and understandable. Self-modifying code, in its purest form, turns out to be a really bad idea because it’s very hard to be quite sure what it is doing. It’s also difficult to test, because are you testing the output, some code in transition, the process of modification, etc.?

And yet, the idea of using code to somehow manipulate other code remains intriguing, as long as there is some way to make it safer. From a code creation, maintenance, and reliability standpoint this idea is quite compelling. If, instead of writing lots of code from

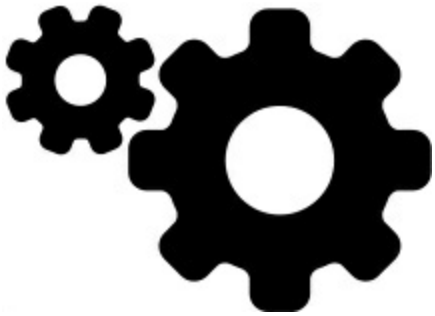
scratch, you start with existing small pieces that are understandable, well-tested, and reliable. Then compose them together to create new code. Wouldn't that make us more productive and at the same time create more robust code?

This is what *functional programming* (FP) is about. By incorporating existing code to produce new functionality instead of writing everything from scratch, you get more reliable code, faster. This theory seems to hold up, at least in some situations. On the way, functional languages have produced nice syntax which some non-functional languages have appropriated.

You can also think of it this way:

OO abstracts data, FP abstracts behavior.

A *pure functional* language goes further in its endeavor for safety. It imposes the additional constraint that all data must be *immutable*: set once and never changed. Values are handed to a function which then



produces new values but never modifies anything external to itself

(including its arguments or elements outside of that function's scope). When this is enforced, you know that any bugs are not caused by so-called *side effects*, because the function only creates and returns a result, nothing else.

Even better, the "immutable objects and no side effects" paradigm solves one of the most fundamental and vexing problems in parallel programming (when parts of your program are running simultaneously on multiple processors). This is the problem of *mutable shared state,* which means different parts of your code (running on different processors) can try to modify the same piece of memory at the same time (Who wins? Nobody knows). If functions never modify existing values but only produce new values—the definition of a pure functional language—there can be no contention over memory. Thus, pure functional languages are often put forward as the solution to parallel programming (there are also other viable solutions).

Be aware, then, that there are numerous motivations behind functional languages, which means describing them can be somewhat confusing. It often depends on perspective. The reasons span "it's for parallel programming," to "code reliability" and "code creation and

library reuse.” 1 Also remember that the arguments for FP—in particular, that programmers will create more robust code, faster—are still at least partly hypothetical. We have seen some good results,2 but we haven’t proven that a pure functional language is the best approach to solving the programming problem.

Ideas from FP are worth incorporating into non-FP languages. This happened in Python, for example, to the great benefit of that language. Java 8 adds its own features from FP, which we explore in this chapter.

Old vs. New

Ordinarily, methods produce different results depending on the data we pass. What if you want a method to behave differently from one call to the next? If we pass code to the method, we can control its behavior. Previously, we’ve done this by creating an object containing the desired behavior inside a method, then passing that object to the method we want to control. The following example shows this, then adds the Java 8 approaches: method references and lambda expressions.

```
// functional/Strategize.java
interface Strategy {
String approach(String msg);
```

```
}
class Soft implements Strategy {
public String approach(String msg) {
return msg.toLowerCase() + "?";
}
}
class Unrelated {
static String twice(String msg) {
return msg + " " + msg;
}
}
public class Strategize {
Strategy strategy;
String msg;
Strategize(String msg) {
strategy = new Soft(); // [1]
this.msg = msg;
}
void communicate() {
System.out.println(strategy.approach(msg));
```

```
}
void changeStrategy(Strategy strategy) {
this.strategy = strategy;
}
public static void main(String[] args) {
Strategy[] strategies = {
new Strategy() { // [2]
public String approach(String msg) {
return msg.toUpperCase() + "!";
}
},
msg -> msg.substring(0, 5), // [3]
Unrelated::twice // [4]
};
Strategize s = new Strategize("Hello there");
s.communicate();
for(Strategy newStrategy : strategies) {
s.changeStrategy(newStrategy); // [5]
s.communicate(); // [6]
}
```

}

}

/ *Output:*

hello there?

HELLO THERE!

Hello

Hello there Hello there

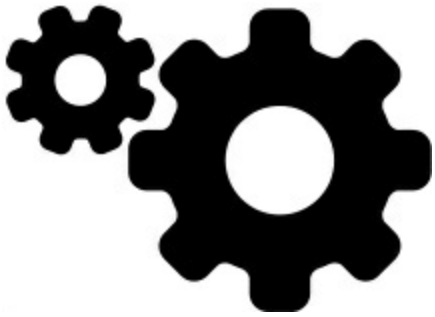
**/*

Strategy provides the interface that carries functionality in its single **approach()** method. By creating different **Strategy** objects you create different behavior.

Traditionally we implement this behavior by making a class that **implements** the **Strategy** interface, as in **Soft**.

[1] In **Strategize**, you can see that **Soft** is the default strategy, as it is assigned in the constructor.

[2] A slightly less verbose and more spontaneous approach is to create an anonymous inner class. There's still a fair amount of repetitious code, and you always have to look at it until you say "oh, I see, they're using an anonymous inner class."



[3] This is the Java 8 *lambda expression*, distinguished by the arrow **->** separating the argument and function body. To the right of the arrow is the expression that is returned from the lambda. This achieves the same effect as the class definition and anonymous inner class, but with a lot less code.

[4] This is the Java 8 *method reference*, distinguished by the **::**. To the left of the **::** is the name of a class or object, and to the right of the **::** is the name of a method, but without an argument list.

[5] After using the default **Soft** strategy, we step through all the strategies in the array and place each one into **s** using **changeStrategy()**.

[6] Now, each call to **communicate()** produces different behavior, depending on the strategy “code object” that’s being used at the moment. We pass behavior, rather than only passing data.3

Prior to Java 8, we *have* been able to pass functionality via **[1]** and **[2]** However, the syntax has been so awkward to write and read that we've only done it when forced. Method references and lambda expressions make it possible to pass functionality when you want to, instead of only when you must.

Lambda Expressions

Lambda Expressions are function definitions written using the minimum possible syntax:

1. Lambda expressions produce functions, not classes. On the Java Virtual Machine (JVM), everything is a class, so there are various manipulations performed behind the scenes that make lambdas look like functions—but as a programmer, you can happily pretend they are "just functions."

2. The lambda syntax is as spare as possible, precisely to make lambdas easy to write and use.

You saw one lambda expression in **Strategize.java**, but there are other syntax variations:

```
// functional/LambdaExpressions.java
interface Description {
String brief();
```

```
}
interface Body {
String detailed(String head);
}
interface Multi {
String twoArg(String head, Double d);
}
public class LambdaExpressions {
static Body bod = h -> h + " No Parens!"; // [1]
static Body bod2 = (h) -> h + " More details"; // [2]
static Description desc = () -> "Short info"; // [3]
static Multi mult = (h, n) -> h + n; // [4]
static Description moreLines = () -> { // [5]
System.out.println("moreLines()");
return "from moreLines()";
};
public static void main(String[] args) {
System.out.println(bod.detailed("Oh!"));
System.out.println(bod2.detailed("Hi!"));
System.out.println(desc.brief());
```

```
System.out.println(mult.twoArg("Pi! ", 3.14159));
System.out.println(moreLines.brief());
}
}
/* Output:
Oh! No Parens!
Hi! More details
Short info
Pi! 3.14159
moreLines()
from moreLines()
*/
```

We start with three interfaces, each with a single method (you'll understand the significance of this shortly). However, each method has a different number of arguments, in order to demonstrate lambda expression syntax.

The basic syntax of any lambda expression is:

1. The arguments.
2. Followed by the -> , which you might choose to read as "produces."

3. Everything after the -> is the method body.

[1] With a single argument, you can just say it without parentheses. This, however, is a special case.

[2] The normal case is to use parentheses around the arguments. For consistency, you can also use parentheses around a single argument, although this is not commonly done.

[3] With no arguments, you *must* use parentheses to indicate an empty argument list.

[4] For more than one argument, place them in a parenthesized argument list.

So far, all the lambda expression method bodies have been a single line. The result of that expression automatically becomes the return value of the lambda expression, and it's illegal to use the **return** keyword here. This is another way that lambda expressions abbreviate the syntax for describing functionality.

[5] If you do need multiple lines in your lambda expression, you must put those lines inside curly braces. In this situation, you

revert to using **return** to produce a value from the lambda expression.

Lambda expressions typically produce more readable code than anonymous inner classes, so we'll use them when possible in this book.

Recursion

A *recursive* function is one that calls itself. It's possible to write recursive lambda expressions, with a caveat: The recursive method must be an instance variable or a **static** variable, otherwise you'll get a compile-time error. We'll create an example for each case.

Both examples need an interface that accepts an **int** and produces an **int**:

```
// functional/IntCall.java
interface IntCall {
int call(int arg);
}
```

A *factorial* for an integer **n** multiplies together all the positive integers less than or equal to **n**. A factorial function is a common recursive example:

```
// functional/RecursiveFactorial.java
public class RecursiveFactorial {
static IntCall fact;
```

```
public static void main(String[] args) {
fact = n -> n == 0 ? 1 : n * fact.call(n - 1);
for(int i = 0; i <= 10; i++)
System.out.println(fact.call(i));
}
}
/* Output:
1
1
2
6
24
120
720
5040
40320
362880
3628800
*/
```

Here, **fact** is a **static** variable. Note the use of the ternary if-else.

The recursive function will keep calling itself until **i == 0**. All

recursive functions have some kind of “stop condition,” otherwise

they’ll recurse infinitely and produce an exception.

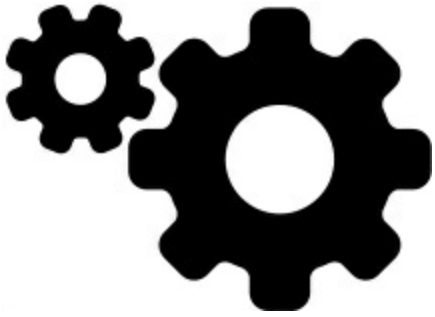
We can implement a Fibonacci sequence as a recursive lambda expression, this time using an instance variable:

// functional/RecursiveFibonacci.java

public class RecursiveFibonacci {

IntCall fib;

RecursiveFibonacci() {



fib = n -> n == 0 ? 0 :

n == 1 ? 1 :

fib.call(n - 1) + fib.call(n - 2);

}

int fibonacci(int n) { **return** fib.call(n); }

public static void main(String[] args) {

RecursiveFibonacci rf = **new** RecursiveFibonacci();

```
for(int i = 0; i <= 10; i++)
System.out.println(rf.fibonacci(i));
}
}
/* Output:
0
1
1
2
3
5
8
13
21
34
55
*/
```

The Fibonacci sequence sums the last two elements in the sequence to produce the next one.

Method References

Java 8 *Method References* refer to methods without the extra baggage required by previous versions of Java. A method reference is a class name or an object name, followed by a **::**4, then the name of the method:

```
// functional/MethodReferences.java
import java.util.*;
interface Callable { // [1]
void call(String s);
}
class Describe {
void show(String msg) { // [2]
System.out.println(msg);
}
}
public class MethodReferences {
static void hello(String name) { // [3]
System.out.println("Hello, " + name);
}
static class Description {
String about;
Description(String desc) { about = desc; }
```

```
void help(String msg) { // [4]
System.out.println(about + " " + msg);
}
}
static class Helper {
static void assist(String msg) { // [5]
System.out.println(msg);
}
}
public static void main(String[] args) {
Describe d = new Describe();
Callable c = d::show; // [6]
```

```
c.call("call()"); // [7]
c = MethodReferences::hello; // [8]
c.call("Bob");
c = new Description("valuable")::help; // [9]
c.call("information");
c = Helper::assist; // [10]
c.call("Help!");
}
}
/* Output:
call()
Hello, Bob
valuable information
Help!
*/
```

[1] We start out with a single-method interface (again, you'll soon learn the importance of this).

[2] The *signature* (argument types and return type) of **show()** conforms to the signature of **Callable**'s **call()**.

[3] hello() is also signature-conformant to **call()**.

[4] … as is **help()**, a non-**static** method within a **static** inner class.

[5] assist() is a **static** method inside a **static** inner class.

[6] We assign a method reference for the **Describe** object to a **Callable**—which doesn't have a **show()** method but rather a **call()** method. However, Java seems fine with this seemingly-odd assignment, because the method reference is signature-conformant to **Callable**'s **call()** method.

[7] We can now invoke **show()** by calling **call()**, because Java maps **call()** onto **show()**.

[8] This is a **static** method reference.

[9] This is another version of **[6]**: a method reference for a method attached to a live object, which is sometimes called a *bound method reference*.

[10] Finally, getting a method reference for a **static** method of

a **static** inner class looks just like the outer-class version at

[8].

This isn’t an exhaustive example; we’ll look at all the variations of method references shortly.

Runnable

The **Runnable** interface has been in Java since version 1.0, so no **import** is necessary. It also conforms to the special single-method interface format: Its method **run()** takes no arguments and has no return value. We can therefore use a lambda expression and a method reference as a **Runnable**:

```
// functional/RunnableMethodReference.java
// Method references with interface Runnable
class Go {
static void go() {
System.out.println("Go::go()");
}
}
public class RunnableMethodReference {
public static void main(String[] args) {
new Thread(new Runnable() {
public void run() {
```

```
System.out.println("Anonymous");
}
}).start();
new Thread(
() -> System.out.println("lambda")
).start();
new Thread(Go::go).start();
```

```
}
}
/* Output:
Anonymous
lambda
Go::go()
*/
```

A **Thread** object takes a **Runnable** as its constructor argument, and has a method **start()** which calls **run()**. Notice that only the anonymous inner class is required to have a method named **run()**.

Unbound Method References

An *unbound method reference* refers to an ordinary (non-static) method, without an associated object. To apply an unbound reference, you must supply the object:

```
// functional/UnboundMethodReference.java
// Method reference without an object
class X {
String f() { return "X::f()"; }
}
interface MakeString {
String make();
}
interface TransformX {
String transform(X x);
}
public class UnboundMethodReference {
public static void main(String[] args) {
// MakeString ms = X::f; // [1]
TransformX sp = X::f;
X x = new X();
```

```
System.out.println(sp.transform(x)); // [2]
System.out.println(x.f()); // Same effect
}
}
/* Output:
X::f()
X::f()
*/
```

So far, we've seen references to methods that have the same signature as their associated interface. At **[1]**, we try to do the same thing for **f()** in **X**, attempting to assign to a **MakeString**. This produces an error from the compiler about an "invalid method reference," even though **make()** has the same signature as **f()**. The problem is that there's actually another (hidden) argument involved: our old friend **this**. You can't call **f()** without an **X** object to call it upon. Thus, **X::f** represents an unbound method reference, because it hasn't been "bound" to an object.

To solve the problem we need an **X** object, so our interface actually needs an extra argument, as you see in **TransformX**. If you assign **X::f** to a **TransformX**, Java is happy. We must now make a second

mental adjustment—with an unbound reference, the signature of the *functional method* (the single method in the interface) no longer quite matches the signature of the method reference. There's a good reason, which is that you need an object to call the method on.

The result at **[2]** is a bit of a brain-teaser. I take the unbound reference and call **transform()** on it, passing it an **X**, and somehow that results in the call to **x.f()**. Java knows it must take the first argument, which is effectively **this**, and call the method on it.

If your method has more arguments, just follow the pattern of the first argument taking **this**:

```
// functional/MultiUnbound.java
// Unbound methods with multiple arguments
class This {
void two(int i, double d) {}
void three(int i, double d, String s) {}
void four(int i, double d, String s, char c) {}
}
```

```
interface TwoArgs {
void call2(This athis, int i, double d);
}
interface ThreeArgs {
void call3(This athis, int i, double d, String s);
}
interface FourArgs {
void call4(
This athis, int i, double d, String s, char c);
}
public class MultiUnbound {
public static void main(String[] args) {
TwoArgs twoargs = This::two;
ThreeArgs threeargs = This::three;
FourArgs fourargs = This::four;
This athis = new This();
twoargs.call2(athis, 11, 3.14);
threeargs.call3(athis, 11, 3.14, "Three");
fourargs.call4(athis, 11, 3.14, "Four", 'Z');
}
```

}

To make a point, I named the class **This** and the first arguments for the functional methods **athis**, but you should choose other names to prevent confusion in production code.

Constructor Method

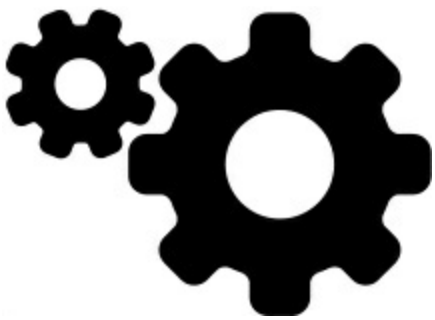
References

You can also capture a reference for a constructor, and later call that constructor via the reference.

```
// functional/CtorReference.java
class Dog {
String name;
int age = -1; // For "unknown"
Dog() { name = "stray"; }
Dog(String nm) { name = nm; }
Dog(String nm, int yrs) { name = nm; age = yrs; }
}
interface MakeNoArgs {
Dog make();
}
interface Make1Arg {
```

```
Dog make(String nm);
}
interface Make2Args {
Dog make(String nm, int age);
}
public class CtorReference {
public static void main(String[] args) {
MakeNoArgs mna = Dog::new; // [1]
Make1Arg m1a = Dog::new; // [2]
Make2Args m2a = Dog::new; // [3]
Dog dn = mna.make();
Dog d1 = m1a.make("Comet");
Dog d2 = m2a.make("Ralph", 4);
}
}
```

Dog has three constructors, and the **make()** methods inside the



functional interfaces reflect the constructor argument lists (the **make()** methods can have different names).

Notice how we use **Dog::new** for each of **[1]**, **[2]**, and **[3]**. There's only one name for all three constructors: **::new**. But the constructor reference is assigned to a different interface in each case, and the compiler can detect from that which constructor reference to use.

The compiler can see that calling your functional method (**make()**, in this example) means to call the constructor.

Functional Interfaces

Both method references and lambda expressions must be assigned, and those assignations require type information for the compiler to ensure type correctness. Lambda expressions in particular introduce new requirements. Consider:

```
x -> x.toString()
```

We see that the return type must be a **String**, but what type is **x**? Because lambda expressions include a form of *type inference* (the compiler figures some things out about types instead of requiring the programmer to be explicit), the compiler must somehow be able to deduce the type of **x**.

Here's a second example:

```
(x, y) -> x + y
```

Now **x** and **y** can be any types that support the **+** operator, including two different numeric types or a **String** and some other type that will automatically convert to a **String** (this includes most types). But when this lambda expression is assigned, the compiler must determine the exact types of **x** and **y** to generate the correct code.

The same issue holds true for method references. Suppose you want to pass

System.out::println

to a method you are writing—what type do you give for the method's argument?

To solve this problem, Java 8 introduces **java.util.function** containing a set of interfaces which are target types for lambda expressions and method references. Each interface contains only one abstract method, called the *functional method*.

This "functional method" pattern can be enforced by using the **@FunctionalInterface** annotation when you write interfaces:

```
// functional/FunctionalAnnotation.java
@FunctionalInterface
interface Functional {
String goodbye(String arg);
```

```
}
interface FunctionalNoAnn {
String goodbye(String arg);
}
/*
@FunctionalInterface
interface NotFunctional {
String goodbye(String arg);
String hello(String arg);
}
Produces error message:
NotFunctional is not a functional interface
multiple non-overriding abstract methods
found in interface NotFunctional
*/
public class FunctionalAnnotation {
public String goodbye(String arg) {
return "Goodbye, " + arg;
}
public static void main(String[] args) {
```

```
FunctionalAnnotation fa =
new FunctionalAnnotation();
Functional f = fa::goodbye;
FunctionalNoAnn fna = fa::goodbye;
// Functional fac = fa; // Incompatible
Functional fl = a -> "Goodbye, " + a;
FunctionalNoAnn fnal = a -> "Goodbye, " + a;
}
}
```

The **@FunctionalInterface** annotation is optional; Java treats both **Functional** and **FunctionalNoAnn** as functional interfaces in **main()**. The value of **@FunctionalInterface** is seen in the definition of **NotFunctional**: More than one method in your interface produces a compile-time error message.

Look closely at what happens in the definitions of **f** and **fna**. **Functional** and **FunctionalNoAnn** define interfaces. Yet what is assigned is just the method **goodbye**. First, this is only a method and not a class. Second, it's not even a method of a class that implements one of those interfaces. This is a bit of magic that was added to Java 8: if you assign a method reference or a lambda

expression to a functional interface (and the types fit), Java will adapt your assignment to the target interface. Under the covers, the compiler wraps your method reference or lambda expression in an instance of a class that implements the target interface.

Even though **FunctionalAnnotation** does fit the **Functional** mold, if we try to assign a **FunctionalAnnotation** directly to a **Functional** as in the definition for **fac**, Java won't let us—which we expect, since it doesn't explicitly implement **Functional**. The only surprise is that Java 8 allows us to assign functions to interfaces, which results in a much nicer, simpler syntax.

The goal of **java.util.function** is to create a complete-enough set of target interfaces that you don't ordinarily need to define your own. Mostly because of primitive types, this produces a small explosion of interfaces. If you understand the naming pattern, you can generally detect what a particular interface does by looking at the name. Here are the basic naming guidelines:

1. If it only deals with objects, not primitives, then it's just a straightforward name, like **Function**, **Consumer**, **Predicate**, etc. The argument types are added via generics.
2. If it takes a primitive argument, this is denoted by the first part of the name, as in **LongConsumer**, **DoubleFunction**,

IntPredicate, etc. An exception to this is the primitive **Supplier** types.

3. If it returns a primitive result, this is indicated with **To**, as in **ToLongFunction<T>** and **IntToLongFunction**.

4. If it returns the same type as its argument(s), it's an **Operator**, with **UnaryOperator** for one argument and **BinaryOperator** for two arguments.

5. If it takes two arguments and returns a **boolean**, it's a **Predicate**.

6. If it takes two arguments of different types, there's a **Bi** in the name.

This table describes the target types in **java.util.function** (with noted exceptions):

Name

Characteristic

Functional

Usage

Method

Runnable

No arguments;

(java.lang)

Runnable

Returns nothing

run()

Supplier<T>

Supplier

BooleanSupplier

No arguments;

get()

IntSupplier

Returns any type

getAstype**()**

LongSupplier

DoubleSupplier

Callable

No arguments;

(java.util.concurrent)

Callable<V>

Returns any type

call()

Consumer<T>

One argument;

Consumer

IntConsumer

Returns nothing

accept()

LongConsumer

DoubleConsumer

Two-argument

BiConsumer

BiConsumer<T,U>

Consumer

accept()

Two-argument

Consumer;

ObjIntConsumer<T>

First arg is a

Objtype**Consumer**

ObjLongConsumer<T>

reference;

accept()

Second arg is a

ObjDoubleConsumer<T>

primitive

Function<T,R>

IntFunction<R>

LongFunction<R>

DoubleFunction<R>

ToIntFunction<T>

Function

One argument;

ToLongFunction<T>

apply()

Returns a different

ToDoubleFunction<T>

type

Totype & type**To**type:

IntToLongFunction

applyAstype**()**

IntToDoubleFunction

LongToIntFunction

LongToDoubleFunction

DoubleToIntFunction

DoubleToLongFunction

UnaryOperator<T>

One argument;

UnaryOperator

IntUnaryOperator

Returns the same

type

apply()

LongUnaryOperator

DoubleUnaryOperator

BinaryOperator<T>

Two arguments,

same type;

BinaryOperator

IntBinaryOperator

Returns the same

apply()

LongBinaryOperator

type

DoubleBinaryOperator

Two arguments,

Comparator

same type;

(java.util)

Comparator<T>

Returns **int**

compare()

Predicate<T>

BiPredicate<T,U>

Two arguments;

Predicate

IntPredicate

Returns **boolean**

test()

LongPredicate

DoublePredicate

IntToLongFunction

IntToDoubleFunction

Primitive argument;

type**To**type**Function**

LongToIntFunction

Returns a primitive

applyAstype**()**

LongToDoubleFunction

DoubleToIntFunction

DoubleToLongFunction

BiFunction<T,U,R>

BiConsumer<T,U>

Two arguments;

Bioperation

BiPredicate<T,U>

Different types

(method name varies)

ToIntBiFunction<T,U>

ToLongBiFunction<T,U>

ToDoubleBiFunction<T,U>

You might imagine additional rows for further illumination, but this

table gives the general idea, and should allow you to, more or less, deduce the functional interface you need.

You can see that some choices were made in creating **java.util.function**. For example, why no **IntComparator**, **LongComparator** and **DoubleComparator**? There's a **BooleanSupplier** but no other interfaces where **Boolean** is represented. There's a generic **BiConsumer**, but no **BiConsumer**s for all the **int**, **long** and **double** variations (I can sympathize with why they gave up on that one). Are these oversights or did someone decide that the usage of the other permutations were too small (and how did they come to that conclusion)?

You can also see how much complexity the primitive types add to Java. They were included in the first version of the language because of efficiency concerns—which were mitigated fairly soon. Now, for the lifetime of the language, we are stuck with the effects of a poor language design choice.

Here's an example that enumerates all the different **Function** variants, applied to lambda expressions:

```
// functional/FunctionVariants.java
import java.util.function.*;
```

```
class Foo {}
class Bar {
Foo f;
Bar(Foo f) { this.f = f; }
}
class IBaz {
int i;
IBaz(int i) {
this.i = i;
}
}
class LBaz {
long l;
LBaz(long l) {
this.l = l;
}
}
class DBaz {
double d;
DBaz(double d) {
```

```
this.d = d;
}
}
public class FunctionVariants {
static Function<Foo,Bar> f1 = f -> new Bar(f);
static IntFunction<IBaz> f2 = i -> new IBaz(i);
static LongFunction<LBaz> f3 = l -> new LBaz(l);
static DoubleFunction<DBaz> f4 = d -> new DBaz(d);
static ToIntFunction<IBaz> f5 = ib -> ib.i;
static ToLongFunction<LBaz> f6 = lb -> lb.l;
static ToDoubleFunction<DBaz> f7 = db -> db.d;
static IntToLongFunction f8 = i -> i;
static IntToDoubleFunction f9 = i -> i;
static LongToIntFunction f10 = l -> (int)l;
static LongToDoubleFunction f11 = l -> l;
static DoubleToIntFunction f12 = d -> (int)d;
static DoubleToLongFunction f13 = d -> (long)d;
public static void main(String[] args) {
Bar b = f1.apply(new Foo());
IBaz ib = f2.apply(11);
```

```
LBaz lb = f3.apply(11);
DBaz db = f4.apply(11);
int i = f5.applyAsInt(ib);
long l = f6.applyAsLong(lb);
double d = f7.applyAsDouble(db);
l = f8.applyAsLong(12);
d = f9.applyAsDouble(12);
i = f10.applyAsInt(12);
d = f11.applyAsDouble(12);
i = f12.applyAsInt(13.0);
l = f13.applyAsLong(13.0);
}
}
```

These lambda expressions attempt to produce the simplest code that will fit the signature. In some cases casts were necessary, otherwise the compiler complains about truncation errors.

Each test in **main()** shows the different kinds of **apply** methods in the **Function** interfaces. Each one produces a call to its associated lambda expression.

Method references have their own magic:

```
// functional/MethodConversion.java
import java.util.function.*;
class In1 {}
class In2 {}
public class MethodConversion {
static void accept(In1 i1, In2 i2) {
System.out.println("accept()");
}
static void someOtherName(In1 i1, In2 i2) {
System.out.println("someOtherName()");
}
public static void main(String[] args) {
BiConsumer<In1,In2> bic;
bic = MethodConversion::accept;
bic.accept(new In1(), new In2());
bic = MethodConversion::someOtherName;
// bic.someOtherName(new In1(), new In2()); // Nope
bic.accept(new In1(), new In2());
}
}
```

/ *Output:*

accept()

someOtherName()

**/*

Look up the documentation for **BiConsumer**. You'll see its functional method is **accept()**. Indeed, if we name our method **accept()**, it works as a method reference. But we can give it a completely different name like **someOtherName()** and it works as well, as long as the argument types and return type are the same as **BiConsumer**'s **accept()**.

Thus, when working with functional interfaces, the name doesn't matter—only the argument types and return type. Java performs a mapping of your name onto the functional method of the interface. To invoke your method, you call the functional method name (**accept()**, in this case), not your method name.

Now we'll look at all the class-based functionals (that is, those that don't involve primitives), applied to method references. Again, I've created the simplest methods that fit the functional signatures:

// functional/ClassFunctionals.java

import java.util.*;

```
import java.util.function.*;
class AA {}
class BB {}
class CC {}
public class ClassFunctionals {
static AA f1() { return new AA(); }
static int f2(AA aa1, AA aa2) { return 1; }
static void f3(AA aa) {}
static void f4(AA aa, BB bb) {}
static CC f5(AA aa) { return new CC(); }
static CC f6(AA aa, BB bb) { return new CC(); }
static boolean f7(AA aa) { return true; }
static boolean f8(AA aa, BB bb) { return true; }
static AA f9(AA aa) { return new AA(); }
static AA f10(AA aa1, AA aa2) { return new AA(); }
public static void main(String[] args) {
Supplier<AA> s = ClassFunctionals::f1;
s.get();
Comparator<AA> c = ClassFunctionals::f2;
c.compare(new AA(), new AA());
```

```
Consumer<AA> cons = ClassFunctionals::f3;
cons.accept(new AA());
BiConsumer<AA,BB> bicons = ClassFunctionals::f4;
bicons.accept(new AA(), new BB());
Function<AA,CC> f = ClassFunctionals::f5;
CC cc = f.apply(new AA());
BiFunction<AA,BB,CC> bif = ClassFunctionals::f6;
cc = bif.apply(new AA(), new BB());
Predicate<AA> p = ClassFunctionals::f7;
boolean result = p.test(new AA());
BiPredicate<AA,BB> bip = ClassFunctionals::f8;
result = bip.test(new AA(), new BB());
UnaryOperator<AA> uo = ClassFunctionals::f9;
AA aa = uo.apply(new AA());
BinaryOperator<AA> bo = ClassFunctionals::f10;
aa = bo.apply(new AA(), new AA());
}
}
```

Note that each method name is arbitrary (**f1()**, **f2()**, etc.), but as you just saw, once the method reference is assigned to a functional

interface, you can call the functional method associated with that interface. In this example, these are **get()**, **compare()**, **accept()**, **apply()**, and **test()**.

Functional Interfaces with More Arguments

The interfaces in **java.util.functional** are limited. There's a **BiFunction**, but it stops there. What if you need an interface for three-argument functions? Those interfaces are fairly straightforward, so it's easy to look at the Java library source code and make our own:

```
// functional/TriFunction.java
@FunctionalInterface
public interface TriFunction<T, U, V, R> {
R apply(T t, U u, V v);
```

```
}
```

A short test will verify it works:

```
// functional/TriFunctionTest.java
public class TriFunctionTest {
static int f(int i, long l, double d) { return 99; }
public static void main(String[] args) {
TriFunction<Integer, Long, Double, Integer> tf =
TriFunctionTest::f;
tf = (i, l, d) -> 12;
}
}
```

We test both a method reference and a lambda expression.

Missing Primitive Functionals

Let’s revisit **BiConsumer**, to see how we would create the various missing permutations involving **int**, **long** and **double**:

```
// functional/BiConsumerPermutations.java
import java.util.function.*;
public class BiConsumerPermutations {
static BiConsumer<Integer, Double> bicid = (i, d) ->
System.out.format("%d, %f%n", i, d);
```

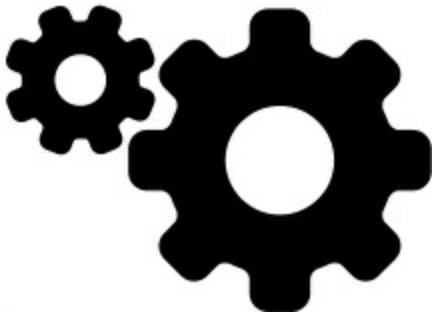
```
static BiConsumer<Double, Integer> bicdi = (d, i) ->
System.out.format("%d, %f%n", i, d);
static BiConsumer<Integer, Long> bicil = (i, l) ->
System.out.format("%d, %d%n", i, l);
public static void main(String[] args) {
bicid.accept(47, 11.34);
bicdi.accept(22.45, 92);
bicil.accept(1, 11L);
}
}
/* Output:
47, 11.340000
92, 22.450000
1, 11
*/
```

For display, I use **System.out.format()** which is like **System.out.println()** except it provides far more display options. Here, the **%f** says I'm giving it **n** as a floating-point value, and the **%d** says that **n** is an integral value. I'm able to include spaces, and it doesn't add a newline unless you put in a **%n**—it will also accept the

traditional **\n** for newlines, but **%n** is automatically cross-platform, which is another reason to use **format()**.

The example simply uses the appropriate wrapper types, and boxing and unboxing takes care of converting back and forth between primitives. We can also use wrapped types with, for example, **Function**, instead of its predefined primitive variations:

```
// functional/FunctionWithWrapped.java
import java.util.function.*;
```



```
public class FunctionWithWrapped {
public static void main(String[] args) {
Function<Integer, Double> fid = i -> (double)i;
IntToDoubleFunction fid2 = i -> i;
}
}
```

Without the cast, you get an error message: “Integer cannot be converted to Double,” whereas the **IntToDoubleFunction**

version has no such problem. The Java library code for **IntToDoubleFunction** looks like this:

```
@FunctionalInterface
public interface IntToDoubleFunction {
double applyAsDouble(int value);
}
```

Because we can simply write **Function<Integer,Double>** and produce working results, it's clear that the only reason for the primitive variants of the functionals is to prevent the autoboxing and autounboxing involved with passing arguments and returning results. That is, for performance.

It seems safe to conjecture that the reason some of the functional types have definitions and others don't is because of projected frequency of use.

Of course, if performance actually becomes a problem because of a missing primitive functional, you can easily write your own interface(using the Java library sources for reference)—although it seems unlikely this is your performance bottleneck.

Higher-Order Functions

This name can sound intimidating, but:

A higher-order function is simply a function that consumes or produces functions.

Let’s first look at producing a function:

```
// functional/ProduceFunction.java
import java.util.function.*;
interface
FuncSS extends Function<String, String> {} // [1]
public class ProduceFunction {
static FuncSS produce() {
return s -> s.toLowerCase(); // [2]
}
public static void main(String[] args) {
FuncSS f = produce();
System.out.println(f.apply("YELLING"));
}
}
/* Output:
yelling
*/
```

Here, **produce()** is the higher-order function.

[1] Using inheritance, you can easily create an alias for a specialized interface.

[2] With lambda expressions, it becomes almost effortless to create and return a function from within a method.

To consume a function, the consuming method must describe the function type correctly in its argument list:

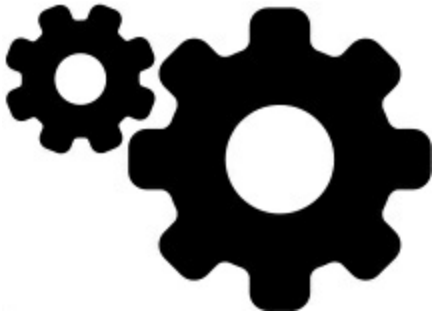
```
// functional/ConsumeFunction.java
import java.util.function.*;
class One {}
class Two {}
public class ConsumeFunction {
static Two consume(Function<One,Two> onetwo) {
return onetwo.apply(new One());
}
public static void main(String[] args) {
Two two = consume(one -> new Two());
}
}
```

Things get particularly interesting when you produce a new function

based on the consumed function:

```
// functional/TransformFunction.java
import java.util.function.*;
class I {
@Override
public String toString() { return "I"; }
}
class O {
@Override
public String toString() { return "O"; }
}
public class TransformFunction {
static Function<I,O> transform(Function<I,O> in) {
return in.andThen(o -> {
System.out.println(o);
return o;
});
}
public static void main(String[] args) {
Function<I,O> f2 = transform(i -> {
```

```
System.out.println(i);
return new O();
});
```



```
O o = f2.apply(new I());
}
}
/* Output:
I
O
*/
```

here, **transform()** produces a function with the same signature as the one passed in, but you can produce any kind you'd like.

This uses a **default** method in the **Function** interface called **andThen()** which is specifically designed for manipulating functions. As the name implies, **andThen()** is invoked *after* the **in** function is called (there's also **compose()**, which applies the new

function before the **in** function). To attach an **andThen()** function, we simply pass that function as an argument. What comes out of **transform()** is a new function, which combines the action of **in** with that of the **andThen()** argument.

Closures

In **ProduceFunction.java** in the previous section, we returned a lambda function from a method. That example kept things simple, but there are some issues we must explore around returning lambdas. These issues are summarized by the term *closure*. Closures are important because they make it easy to produce functions.

Consider a more complex lambda, one that uses variables outside its function scope. What happens when you return that function? That is, what does it reference for those "outside" variables when you call the function? It becomes quite challenging if the language doesn't automatically solve this problem. Languages that do solve it are said to support closures, or to be *lexically scoped* (the term *variable capture* is also used). Java 8 provides limited, but reasonable, closure support, which we'll examine using some simple examples.

First, here's a method to return a function that accesses an object field and a method argument:

// functional/Closure1.java

```
import java.util.function.*;

public class Closure1 {

int i;

IntSupplier makeFun(int x) {

return () -> x + i++;

}

}
```

Upon reflection, however, this use of **i** isn't that big of a challenge,

because the object is likely to exist after you call **makeFun()**—indeed,

the garbage collector almost certainly preserves an object with extant

functions tied back to it this way.5 Of course, if you call **makeFun()** multiple times for the same object, you'll end up with several functions

all sharing the same storage for **i**:

```
// functional/SharedStorage.java

import java.util.function.*;

public class SharedStorage {

public static void main(String[] args) {

Closure1 c1 = new Closure1();

IntSupplier f1 = c1.makeFun(0);

IntSupplier f2 = c1.makeFun(0);

IntSupplier f3 = c1.makeFun(0);
```

```
System.out.println(f1.getAsInt());
System.out.println(f2.getAsInt());
System.out.println(f3.getAsInt());
}
}
/* Output:
0
1
2
*/
```

Every call to **getAsInt()** increments **i**, demonstrating that the storage is shared.

What if **i** is local to **makeFun()**? Under normal circumstances, **i** is gone when **makeFun()** completes. It still compiles, however:

```
// functional/Closure2.java
import java.util.function.*;
public class Closure2 {
IntSupplier makeFun(int x) {
int i = 0;
return () -> x + i;
```

```
}
}
```

The **IntSupplier** returned by **makeFun()** “closes over” **i** and **x**, thus both are still valid when you invoke the returned function. Notice, however, I didn’t increment **i** as in **Closure1.java**. Trying to increment it produces a compile-time error:

```
// functional/Closure3.java
// {WillNotCompile}
import java.util.function.*;
public class Closure3 {
IntSupplier makeFun(int x) {
int i = 0;
// Neither x++ nor i++ will work:
return () -> x++ + i++;
}
}
```

The error, repeated for both **x** and **i**, is:

local variables referenced from a lambda

expression must be final or effectively final

Clearly, if we make **x** and **i final** it will work, because then we can’t increment either one:

// functional/Closure4.java

import java.util.function.*;

public class Closure4 {

IntSupplier makeFun(final int x) {

final int i = 0;

return () -> x + i;

}

}

But why did **Closure2.java** work when **x** and **i** were not **final**?

This is where the meaning of “effectively” **final** appears. The term was created for Java 8 to say you haven’t explicitly declared a variable to be **final** but you’re still treating it that way—you aren’t changing it. A local variable is effectively final if its initial value is never changed.

If **x** and **i** are changed elsewhere in the method (but not inside of the returned function), the compiler still considers it an error. Each increment produces a separate error message:

// functional/Closure5.java

// {WillNotCompile}

import java.util.function.*;

```
public class Closure5 {
IntSupplier makeFun(int x) {
int i = 0;
i++;
x++;
return () -> x + i;
}
}
```

To be “effectively final” means you *could* apply the **final** keyword to the variable declaration without changing any of the rest of the code. It’s actually **final**, you just haven’t bothered to say so.

We can actually fix the issue in **Closure5.java** by assigning **x** and **i** to **final** variables before using them in the closure:

```
// functional/Closure6.java
import java.util.function.*;
public class Closure6 {
IntSupplier makeFun(int x) {
int i = 0;
i++;
x++;
```

```
final int iFinal = i;
final int xFinal = x;
return () -> xFinal + iFinal;
}
}
```

Since we never change **iFinal** and **xFinal** after assignment, the use of **final** here is redundant.

What if you're using references? We can change from **int** to **Integer**:

```
// functional/Closure7.java
// {WillNotCompile}
import java.util.function.*;
public class Closure7 {
IntSupplier makeFun(int x) {
Integer i = 0;
i = i + 1;
return () -> x + i;
}
}
```

The compiler is still smart enough to see that **i** is being changed. The

wrapper types might be getting special treatment, so let’s try a **List**:

```
// functional/Closure8.java
import java.util.*;
import java.util.function.*;
public class Closure8 {
Supplier<List<Integer>> makeFun() {
final List<Integer> ai = new ArrayList<>();
ai.add(1);
return () -> ai;
}
public static void main(String[] args) {
Closure8 c7 = new Closure8();
List<Integer>
l1 = c7.makeFun().get(),
l2 = c7.makeFun().get();
System.out.println(l1);
System.out.println(l2);
l1.add(42);
l2.add(96);
System.out.println(l1);
```

```
System.out.println(l2);
}
}
/* Output:
[1]
[1]
[1, 42]
[1, 96]
*/
```

This time it works: we modify the contents of the **List** without producing a compile-time error. When you look at the output from this example, it does seem pretty safe, because each time **makeFun()** is called, a brand new **ArrayList** is created and returned—which means it is not shared, so each generated closure has its own separate **ArrayList** and they can't interfere with each other.

And notice I've declared **ai** to be **final**, although for this example you can take **final** off and get the same results (try it!). The **final** keyword applied to object references only says that the reference doesn't get reassigned. It doesn't say you can't modify the object itself.

Looking at the difference between **Closure7.java** and

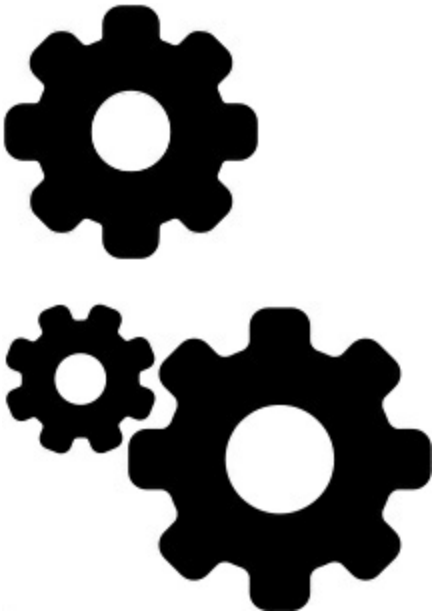
Closure8.java, we see that **Closure7.java** actually has a reassignment of **i**. Maybe that's the trigger for the "effectively final" error message:

```
// functional/Closure9.java
// {WillNotCompile}
import java.util.*;
import java.util.function.*;
public class Closure9 {
Supplier<List<Integer>> makeFun() {
List<Integer> ai = new ArrayList<>();
ai = new ArrayList<>(); // Reassignment
return () -> ai;
}
}
```

The reassignment does indeed trigger the message. If you only modify the object that's pointed to, Java accepts it. And that's probably safe as long as no one else ever gets the reference to that object (that would mean you have more than one entity that can modify the object, at which point things can get very confusing).6

There's a conundrum, however, if we now look back at

Closure1.java. **i** is modified without compiler complaints. It is neither **final** nor "effectively final." Because **i** is a member of the surrounding class, it's certainly safe to do this (other than the fact you



are creating multiple functions that share mutable memory). Indeed, you can argue that no variable capture occurs in that case. And to be sure, the error message for **Closure3.java** specifically refers to *local* variables. Thus, the rule isn't as simple as saying "any variable defined outside the lambda must be final or effectively final." Instead, you must think in terms of *captured* variables being effectively final. If it's a field in an object, it has an independent lifetime and doesn't need any special capturing in order to exist later, when the lambda is called.

Inner Classes as Closures

We can duplicate our example using an anonymous inner class:

```
// functional/AnonymousClosure.java
import java.util.function.*;
public class AnonymousClosure {
IntSupplier makeFun(int x) {
int i = 0;
// Same rules apply:
// i++; // Not "effectively final"
// x++; // Ditto
return new IntSupplier() {
public int getAsInt() { return x + i; }
};
}
}
```

It turns out that as long as there have been inner classes, there have been closures (Java 8 just makes closures easier). Prior to Java 8, the requirement was that **x** and **i** be explicitly declared **final**. With Java 8, the rule for inner classes has been relaxed to include "effectively **final**."

Function Composition

Function composition basically means "pasting functions together to create new functions," and it's commonly considered a part of

functional programming. You saw one example of function composition in **TransformFunction.java** with the use of **andThen()**. Some of the **java.util.function** interfaces contain methods to support function composition.[7]

Compositional Supporting Method	Interfaces
Function	
BiFunction	
Consumer	
BiConsumer	
IntConsumer	
andThen(argument)	Performs the original
LongConsumer	operation followed by
DoubleConsumer	the argument operation.
UnaryOperator	

IntUnaryOperator

LongUnaryOperator

DoubleUnaryOperator

BinaryOperator

Function

compose(argument)

UnaryOperator

Performs the argument

IntUnaryOperator

operation followed by

the original operation.

LongUnaryOperator

DoubleUnaryOperator

Predicate

and(argument)

BiPredicate

Short-circuiting logical

IntPredicate

AND of the original

predicate and the

LongPredicate

argument predicate.

DoublePredicate

Predicate

or(argument)

BiPredicate

Short-circuiting logical

OR of the original

IntPredicate

predicate and the

LongPredicate

argument predicate.

DoublePredicate

Predicate

negate()

BiPredicate

A predicate that is the

IntPredicate

logical negation of this

predicate.

LongPredicate

DoublePredicate

This example uses both **compose()** and **andThen()** from

Function:

```
// functional/FunctionComposition.java
import java.util.function.*;
public class FunctionComposition {
static Function<String, String>
f1 = s -> {
System.out.println(s);
return s.replace('A', '_');
},
f2 = s -> s.substring(3),
f3 = s -> s.toLowerCase(),
f4 = f1.compose(f2).andThen(f3);
public static void main(String[] args) {
System.out.println(
f4.apply("GO AFTER ALL AMBULANCES"));
}
}
```

/ *Output:*

AFTER ALL AMBULANCES

_fter _ll _mbul_nces

**/*

The important thing to see here is that we are creating a new function **f4**, which can then be called using **apply()** (almost) like any other function. 8

By the time **f1** gets the **String**, it's already had the first three characters stripped off by **f2**. That's because the call to **compose(f2)** means **f2** gets called before **f1**.

Here's a demonstration of the logical operations for **Predicate**:

// functional/PredicateComposition.java

import java.util.function.*;

import java.util.stream.*;

public class PredicateComposition {

static Predicate<String>

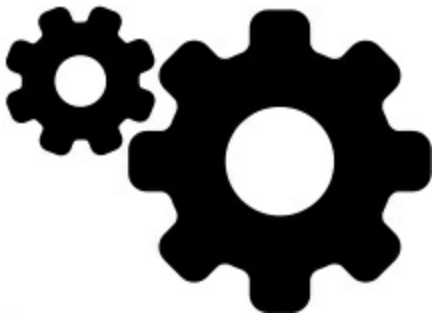
p1 = s -> s.contains("bar"),

p2 = s -> s.length() < 5,

p3 = s -> s.contains("foo"),

p4 = p1.negate().and(p2).or(p3);

```
public static void main(String[] args) {
Stream.of("bar", "foobar", "foobaz", "fongopuckey")
.filter(p4)
.forEach(System.out::println);
}
}
```



```
/* Output:
foobar
foobaz
*/
```

p4 takes all the predicates and combines them into a more complex predicate, which reads: “If the **String** does NOT contain ‘bar’ AND the length is less than 5, OR it contains ‘foo’, the result is **true**.” Because it produces such clear syntax, I’ve cheated a bit in **main()** and borrowed from the next chapter. First I create a “stream” (a sequence) of **String** objects, then feed each one to the **filter()**

operation. **filter()** uses our **p4** predicate to decide which object in the stream to keep, and which to throw away. Finally, I use **forEach()** to apply the **println** method reference to each of the surviving objects.

You can see from the output how **p4** works: anything with a “foo” survives, even if its length is greater than five. “fongopuckey” is too long and doesn’t have a “bar” to save it.

Currying and Partial Evaluation

Currying is named after Haskell Curry, one of its inventors and possibly the only computer person to have an important thing named after each of his names (the other is the *Haskell* programming language). Currying means starting with a function that takes multiple arguments and turning it into a sequence of functions, each of which only takes a single argument.

```
// functional/CurryingAndPartials.java
import java.util.function.*;
public class CurryingAndPartials {
// Uncurried:
static String uncurried(String a, String b) {
return a + b;
```

```
}
public static void main(String[] args) {
// Curried function:
Function<String, Function<String, String>> sum =
a -> b -> a + b; // [1]
System.out.println(uncurried("Hi ", "Ho"));
Function<String, String>
hi = sum.apply("Hi "); // [2]
System.out.println(hi.apply("Ho"));
// Partial application:
Function<String, String> sumHi =
sum.apply("Hup ");
System.out.println(sumHi.apply("Ho"));
System.out.println(sumHi.apply("Hey"));
}
}
/* Output:
Hi Ho
Hi Ho
Hup Ho
```

Hup Hey

*/

[1] This is the tricky line: a cascade of arrows. And notice how, in the function interface declaration, **Function** has another **Function** as its second argument.

[2] The goal of currying is to be able to create a new function by providing a single argument, so you now have an “argumented function” and the remaining “free argument.” In effect, you start with a two-argument function and end up with a one-argument function.

You can curry a three-argument function by adding another level:

```
// functional/Curry3Args.java
import java.util.function.*;
public class Curry3Args {
public static void main(String[] args) {
Function<String,
Function<String,
Function<String, String>>> sum =
a -> b -> c -> a + b + c;
Function<String,
```

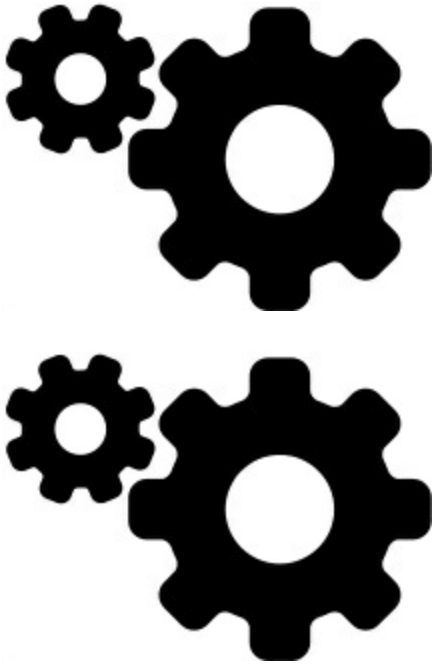
```
Function<String, String>> hi =
sum.apply("Hi ");
Function<String, String> ho =
hi.apply("Ho ");
System.out.println(ho.apply("Hup"));
}
}
/* Output:
Hi Ho Hup
*/
```

For each level of arrow-cascading, you wrap another **Function** around the type declaration.

When dealing with primitives and boxing, use the appropriate functional interfaces:

```
// functional/CurriedIntAdd.java
import java.util.function.*;
public class CurriedIntAdd {
public static void main(String[] args) {
IntFunction<IntUnaryOperator>
curriedIntAdd = a -> b -> a + b;
```

```
IntUnaryOperator add4 = curriedIntAdd.apply(4);
System.out.println(add4.applyAsInt(5));
}
}
/* Output:
9
```



```
*/
```

You can find more examples of currying on the Internet. Usually these are in languages other than Java, but if you understand the basic concepts they should be fairly easy to translate.

Pure Functional Programming

It’s possible, with much discipline, to write pure functional programs in languages without functional support, even in a language as primitive as C. Java makes it easier than that, but you must carefully make everything **final** and ensure that all your methods and functions have no side effects. Because Java is by nature *not* an immutable language, you don’t get any help from the compiler if you make a mistake.

There are third-party tools to help you[9], but it’s arguably easier to use a language like Scala or Clojure, designed from the start for immutability. These languages make it possible to have part of your project in Java, and if you must write in a pure functional style, other parts in Scala (which requires some discipline) or Clojure (which requires much less). Although you’ll see in the Concurrent Programming chapter that Java does support parallelism, if that is a core part of your project you might consider using something like Scala or Clojure for at least part of the project.

Summary

Lambda expressions and method references do not turn Java into a functional language, but rather provide support for programming in a more functional style. They are a huge improvement to Java because they allow you to write more succinct, cleaner, and easier-to-

understand code. In the following chapter you'll see how they enable *streams*. If you're like me, you'll love streams.

These features are likely to satisfy a large portion of Java programmers who have become antsy and jealous about new, more functional languages like Clojure and Scala, and stem the flow of Java programmers to those languages (or at least prepare them better if they still decide to move).

Lambdas and method references are far from perfect, however—we forever pay the price of the rash decisions made by the Java designers in the heady, early days of the language. In particular, there is no generic lambda, so lambdas really aren't first class citizens in Java. This doesn't mean Java 8 isn't a big improvement, but it does mean that, like many Java features, you eventually reach a point where you start getting frustrated.

As you come up the learning curve, remember you can get help from IDEs like NetBeans, IntelliJ Idea, and Eclipse, which will suggest when you can use a lambda expression or method reference (and often rewrite the code for you!).

1. Pasting functionality together is a rather different approach, but it still enables a kind of library.↩

2. For example, this eBook was produced using Pandoc, a program written in the pure functional language Haskell↩

3. Sometimes functional languages describe this as “code as data.” ↩

4. This syntax came from C++. ↩

5. I have not tested this statement. ↩

6. This will make additional sense in the Concurrent Programming chapter, when you’ll understand that mutating shared variables is “not thread-safe.” ↩

7. The reason interfaces can support methods is that they are Java 8 **default** methods, which you’ll learn about in the next chapter. ↩

8. Some languages, Python for example, allow composed functions to be called *exactly* like any other function. But this is Java, so we take what we can get. ↩

9. See, for example, Immutables and Mutability Detector.↩

Streams

Collections optimize the storage of objects. *Streams* are about processing groups of objects.

A stream is a sequence of elements that is not associated with any

particular storage mechanism—indeed, we say that streams have “no storage.”

Instead of iterating through elements in a collection, with a stream you draw elements from a pipe and operate on them. These pipes are typically strung together to form a pipeline of operations upon the stream.

Most of the time, the reason you store objects in a collection is to process them, so you’ll find yourself moving away from collections as the primary focus of your programming, and towards streams.

One of the core benefits of streams is that they make your programs smaller and easier to understand. Lambda expressions and method references come into their own when used with streams. Streams make Java 8 particularly attractive.1

For example, suppose you want to display a random selection of unique **int**s between 5 and 20, sorted. The fact that you’re sorting them might make you focus first on choosing a sorted collection, and work around that. But with streams, you simply state what you want done:

```
// streams/Randoms.java
import java.util.*;
```

```
public class Randoms {
public static void main(String[] args) {
new Random(47)
.ints(5, 20)
.distinct()
.limit(7)
.sorted()
.forEach(System.out::println);
}
}
/* Output:
6
10
13
16
17
18
19
*/
```

We start by seeding the **Random** object (to produce identical output

when the program runs). The **ints()** method produces a stream and is overloaded in a number of ways—two arguments set the bounds of the values produced. This produces a stream of random **ints**. We tell it to make them unique using the *intermediate stream operation* **distinct()**, then choose the first seven using **limit()**. Then we tell it we want the elements to be **sorted()**. Finally, we'd like to display each item so we use **forEach()**, which performs an operation on each stream object, according to the function we pass it. Here, we pass a method reference **System.out::println** which it uses to show each item on the console.

Note that **Randoms.java** declares no variables. Streams can model systems that have state without ever using assignment or mutable data, and this can be very helpful.

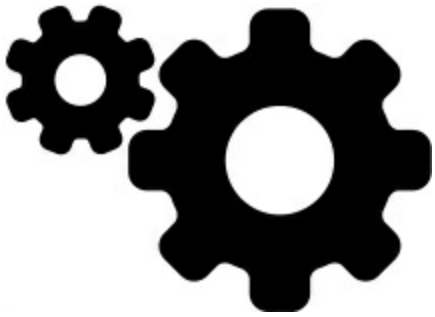
Declarative programming is a style where we state *what* we want done, rather than specifying *how*, and it's what you see in functional programming. Notice it's much more difficult to understand the *imperative* form:

```
// streams/ImperativeRandoms.java
import java.util.*;
public class ImperativeRandoms {
```

```
public static void main(String[] args) {
Random rand = new Random(47);
SortedSet<Integer> rints = new TreeSet<>();
while(rints.size() < 7) {
int r = rand.nextInt(20);
if(r < 5) continue;
rints.add(r);
}
System.out.println(rints);
}
}
/* Output:
[7, 8, 9, 11, 13, 15, 18]
*/
```

In **Randoms.java**, we didn't have to define any variables at all, but here we have three: **rand**, **rints** and **r**. The code is further complicated by the fact that **nextInt()** has no option for a lower bound—its built-in lower bound is always zero, so we must generate extra values and filter out the ones that are less than five.

Notice how you must study the code to figure out what's going on,



whereas in **Randoms.java**, the code just *tells* you what it's doing. This clarity is one of the most compelling reasons for using Java 8 streams.

Explicitly writing the mechanics of iteration as in **ImperativeRandoms.java** is called *external iteration*. In **Randoms**, you don't see any of these mechanisms and so it is called *internal iteration*, a core characteristic of streams programming. Internal iteration produces more readable code, but it also makes it easier to use multiple processors: By loosening control of how iteration happens, you can hand that control over to a parallelizing mechanism. You'll learn about this in the Concurrent Programming chapter.

Another important aspect of streams is that they are *lazy*, which means they are only evaluated when absolutely necessary. You can think of a stream as a "delayed list." Because of *delayed evaluation*, streams enable us to represent very large (even infinite) sequences

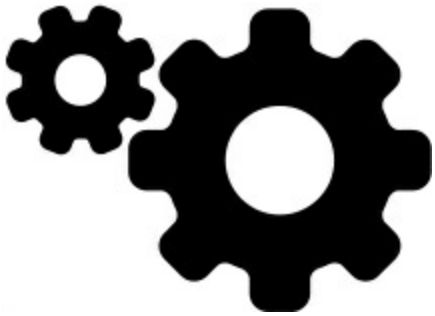
without memory concerns.

Java 8 Stream Support

The Java designers faced a conundrum. They had an existing set of libraries, used not only within the Java libraries themselves, but in millions of lines of code written by users. How would they integrate the new, fundamental concept of streams into existing libraries?

In simple cases like **Random**, they could just add more methods. As long as the existing methods were not changed, legacy code would not get disturbed.

The big challenge came from libraries that used interfaces. Collection classes are an essential part of this, because you want to convert collections into streams. But if you add a new method to an interface,



you break every class that implements your interface but doesn't implement your new method.

The solution, introduced in Java 8, is **default** methods in interfaces, which were covered in the Interfaces chapter. With **default** methods, the Java

designers could shoehorn stream methods into existing classes, and they added virtually every operation you might need. There are three types of operations: creating streams, modifying elements of a stream (*intermediate operations*), and consuming stream elements (*terminal operations*). This last type often means collecting elements of a stream (typically into a collection).

We'll look at each type of operation.

Stream Creation

You can easily turn a group of items into a stream using **Stream.of()** (**Bubble** is defined later in the chapter):

```
// streams/StreamOf.java
import java.util.stream.*;
public class StreamOf {
public static void main(String[] args) {
Stream.of(
new Bubble(1), new Bubble(2), new Bubble(3))
.forEach(System.out::println);
Stream.of("It's ", "a ", "wonderful ",
"day ", "for ", "pie!")
.forEach(System.out::print);
```

```
System.out.println();
Stream.of(3.14159, 2.718, 1.618)
.forEach(System.out::println);
}
}
/* Output:
Bubble(1)
Bubble(2)
Bubble(3)
It's a wonderful day for pie!
3.14159
2.718
1.618
*/
```

In addition, every **Collection** can produce a stream using the **stream()** method:

```
// streams/CollectionToStream.java
import java.util.*;
import java.util.stream.*;
public class CollectionToStream {
```

```
public static void main(String[] args) {
List<Bubble> bubbles = Arrays.asList(
new Bubble(1), new Bubble(2), new Bubble(3));
System.out.println(
bubbles.stream()
.mapToInt(b -> b.i)
.sum());
Set<String> w = new HashSet<>(Arrays.asList(
"It's a wonderful day for pie!".split(" ")));
w.stream()
.map(x -> x + " ")
.forEach(System.out::print);
System.out.println();
Map<String, Double> m = new HashMap<>();
m.put("pi", 3.14159);
m.put("e", 2.718);
m.put("phi", 1.618);
m.entrySet().stream()
.map(e -> e.getKey() + ": " + e.getValue())
.forEach(System.out::println);
```

}

}

/ *Output:*

6

a pie! It's for wonderful day

phi: 1.618

e: 2.718

pi: 3.14159

**/*

After creating a **List<Bubble>** , we simply ask it for a **stream()**, the common method for all collections. The intermediate **map()** operation takes each element in a stream and applies an operation to create a new element, which it then passes on down the stream. The normal **map()** takes objects and produces objects, but there are special versions when the output stream holds a numeric type. Here, **mapToInt()** converts from an object stream to an **IntStream** containing **Integer**s. There are similarly-named operations for

Float and **Double**.

To define **w** we take a **String** and apply the **split()** function, which splits the **String** according to its argument. You'll see later that this argument can be quite sophisticated, but here we are just telling it to split at spaces.

To produce a stream from a **Map** collection, we first call **entrySet()** to produce a stream of objects that each contains both a key and its associated value, then pull that apart using **getKey()** and **getValue()**.

Random Number Streams

The **Random** class has been enhanced with a set of methods to produce streams:

```
// streams/RandomGenerators.java
import java.util.*;
import java.util.stream.*;
public class RandomGenerators {
public static <T> void show(Stream<T> stream) {
stream
.limit(4)
.forEach(System.out::println);
```

```
System.out.println("++++++++");
}
public static void main(String[] args) {
Random rand = new Random(47);
show(rand.ints().boxed());
show(rand.longs().boxed());
show(rand.doubles().boxed());
// Control the lower and upper bounds:
show(rand.ints(10, 20).boxed());
show(rand.longs(50, 100).boxed());
show(rand.doubles(20, 30).boxed());
// Control the stream size:
show(rand.ints(2).boxed());
show(rand.longs(2).boxed());
show(rand.doubles(2).boxed());
// Control the stream size and bounds:
show(rand.ints(3, 3, 9).boxed());
show(rand.longs(3, 12, 22).boxed());
show(rand.doubles(3, 11.5, 12.3).boxed());
}
```

}

/ Output:*

-1172028779

1717241110

-2014573909

229403722

++++++++

2955289354441303771

3476817843704654257

-8917117694134521474

4941259272818818752

++++++++

0.2613610344283964

0.0508673570556899

0.8037155449603999

0.7620665811558285

++++++++

16

10

11

12

++++++++

65

99

54

58

++++++++

29.86777681078574

24.83968447804611

20.09247112332014

24.046793846338723

++++++++

1169976606

1947946283

++++++++

2970202997824602425

-23253269202728303 66

++++++++

0.7024254510631527

0.6648552384607359

++++++++

6

7

7

++++++++

17

12

20

++++++++

12.27872414236691

11.732085449736195

12.196509449817267

++++++++

*/

To eliminate redundant code, I created the generic method **show(Stream<T> stream)** (I'm cheating a bit here by using the generics feature before its chapter, but the payoff is worth it). The **T** type parameter can be anything, so it works with **Integer**, **Long** and **Double**. However, the **Random** class only produces the primitive types **int**, **long** and **double**. Fortunately, the **boxed()** stream

operation automatically converts the primitives to their boxed counterparts, thus enabling **show()** to accept the stream.

We can use **Random** to create a **Supplier** for any set of objects. Here's an example that supplies **String** objects, taken from this text file:

// streams/Cheese.dat

Not much of a cheese shop really, is it?

Finest in the district, sir.

And what leads you to that conclusion?

Well, it's so clean.

It's certainly uncontaminated by cheese.

We use the **Files** class to read all the lines from a file into a **List<String>** :

// streams/RandomWords.java

```
import java.util.*;
import java.util.stream.*;
import java.util.function.*;
import java.io.*;
import java.nio.file.*;
public class RandomWords implements Supplier<String> {
```

```
List<String> words = new ArrayList<>();
Random rand = new Random(47);
RandomWords(String fname) throws IOException {
List<String> lines =
Files.readAllLines(Paths.get(fname));
// Skip the first line:
for(String line : lines.subList(1, lines.size())) {
for(String word : line.split("[ .?,]+"))
words.add(word.toLowerCase());
}
}
public String get() {
return words.get(rand.nextInt(words.size()));
}
@Override
public String toString() {
return words.stream()
.collect(Collectors.joining(" "));
}
public static void
```

```
main(String[] args) throws Exception {
System.out.println(
Stream.generate(new RandomWords("Cheese.dat"))
.limit(10)
.collect(Collectors.joining(" ")));
}
}
/* Output:
it shop sir the much cheese by conclusion district is
*/
```

Here you see a slightly more sophisticated use of **split()**. In the constructor, each **line** is **split()** on either a space or any of the punctuation characters defined within the square brackets. The **+** after the closing square bracket indicates “the previous thing, one or more times.”

You’ll note that the constructor uses imperative programming (external iteration) for its loops. In future examples you’ll see how we eliminate even this. The older forms are not particularly bad, but it often just feels nicer to use streams everywhere.

In **toString()** and **main()** you see the **collect()** operation,

which combines all the stream elements according to its argument.

When you use **Collectors.joining()**, you get a **String** result, with each element separated by the argument to **joining()**. There are numerous other **Collectors** to produce different results.

In **main()**, we see a preview of **Stream.generate()**, which takes any **Supplier<T>** and produces a stream of **T** objects.

Ranges of int

The **IntStream** class provides a **range()** method to produce a stream that is a sequence of **int**s. This can be convenient when writing loops:

```
// streams/Ranges.java
import static java.util.stream.IntStream.*;
public class Ranges {
public static void main(String[] args) {
// The traditional way:
int result = 0;
for(int i = 10; i < 20; i++)
```

```
result += i;
System.out.println(result);
// for-in with a range:
result = 0;
for(int i : range(10, 20).toArray())
result += i;
System.out.println(result);
// Use streams:
System.out.println(range(10, 20).sum());
}
}
/* Output:
145
145
145
*/
```

The first approach shown in **main()** is the traditional way of writing a **for** loop. In the second approach, we create a **range()** and turn it into an array which then works in a *for-in* statement. If you're able, however, it's always nice to go full-streams as in the third approach. In

each case, we sum the integers in the range, and, conveniently, there's a **sum()** operation for streams.

Note that **IntStream.range()** is more limited than **onjava.Range.range()**. Because of its optional third *step* argument, the latter has the ability to generate ranges that step by more than one, and that can count down from a higher value to a lower one.

To replace simple **for** loops, here's a **repeat()** utility:

```
// onjava/Repeat.java
package onjava;
import static java.util.stream.IntStream.*;
public class Repeat {
public static void repeat(int n, Runnable action) {
range(0, n).forEach(i -> action.run());
}
}
```

The resulting loops are arguably cleaner:

```
// streams/Looping.java
import static onjava.Repeat.*;
public class Looping {
```

```
static void hi() { System.out.println("Hi!"); }
public static void main(String[] args) {
repeat(3, () -> System.out.println("Looping!"));
```

```
repeat(2, Looping::hi);
}
}
/* Output:
Looping!
Looping!
Looping!
Hi!
Hi!
*/
```

It might not be worth it, however, to include and explain **repeat()** in your code. It seems like a reasonably transparent tool, but it depends on how your team and company works.

generate()

RandomWords.java used **Supplier<T>** with

Stream.generate(). Here’s a second example:

```
// streams/Generator.java
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
public class Generator implements Supplier<String> {
Random rand = new Random(47);
char[] letters =
"ABCDEFGHIJKLMNOPQRSTUVWXYZ".toCharArray();
public String get() {
return "" + letters[rand.nextInt(letters.length)];
}
public static void main(String[] args) {
String word = Stream.generate(new Generator())
.limit(30)
.collect(Collectors.joining());
System.out.println(word);
}
}
```

/ *Output:*

YNZBRNYGCFOWZNTCQRGSEGZMMJMROE

**/*

The uppercase letters of the alphabet are selected using **Random.nextInt()**. The argument tells it the largest acceptable random number, so the array bounds are respected.

If you want to create a stream of identical objects, simply pass a lambda that produces those objects to **generate()**:

```
// streams/Duplicator.java
import java.util.stream.*;
public class Duplicator {
public static void main(String[] args) {
Stream.generate(() -> "duplicate")
.limit(3)
.forEach(System.out::println);
}
}
/* Output:
duplicate
duplicate
```

duplicate

*/

Here's the **Bubble** class used in earlier examples in this chapter. Note it contains its own **static** generator method:

```
// streams/Bubble.java
import java.util.function.*;
public class Bubble {
public final int i;
public Bubble(int n) { i = n; }
@Override
public String toString() {
return "Bubble(" + i + ")";
```

```
}
private static int count = 0;
public static Bubble bubbler() {
return new Bubble(count++);
}
```

}

Because **bubbler()** is interface-compatible with

Supplier<Bubble> , we can pass its method reference to

Stream.generate():

```
// streams/Bubbles.java
import java.util.stream.*;
public class Bubbles {
public static void main(String[] args) {
Stream.generate(Bubble::bubbler)
.limit(5)
.forEach(System.out::println);
}
}
/* Output:
Bubble(0)
Bubble(1)
Bubble(2)
Bubble(3)
Bubble(4)
*/
```

This is an alternative approach to creating a separate factory class. In many ways it's neater, but it's a matter of taste and code organization—you can always just create a completely different factory class.

iterate()

Stream.iterate() starts with a seed (the first argument) and passes it to the method (the second argument). The result is added to the stream and also stored for use as the first argument the next time **iterate()** is called, and so on. We can **iterate()** a Fibonacci sequence (which you first encountered in the last chapter):

```
// streams/Fibonacci.java
import java.util.stream.*;
public class Fibonacci {
int x = 1;
Stream<Integer> numbers() {
return Stream.iterate(0, i -> {
int result = x + i;
x = i;
return result;
});
}
```

```
public static void main(String[] args) {
new Fibonacci().numbers()
.skip(20) // Don't use the first 20
.limit(10) // Then take 10 of them
.forEach(System.out::println);
}
}
/* Output:
6765
10946
17711
28657
46368
75025
121393
196418
317811
514229
*/
```

The Fibonacci sequence sums the last *two* elements in the sequence to

produce the next one. **iterate()** only remembers the result, so we must use **x** to keep track of the other element.

In **main()**, we use the **skip()** operation, which you haven't seen before. It simply discards the number of stream elements specified by its argument. Here, we throw away the first 20 items.

Stream Builders

In the *Builder* design pattern, you create a builder object, give it multiple pieces of construction information, and finally perform the "build" act. The **Stream** library provides such a **Builder**. Here, we revisit the process of reading a file and turning it into a stream of words:

```
// streams/FileToWordsBuilder.java
import java.io.*;
import java.nio.file.*;
import java.util.stream.*;
public class FileToWordsBuilder {
Stream.Builder<String> builder = Stream.builder();
```

```
public FileToWordsBuilder(String filePath)
throws Exception {
Files.lines(Paths.get(filePath))
.skip(1) // Skip the comment line at the beginning
.forEach(line -> {
for(String w : line.split("[ .?,]+"))
builder.add(w);
});
}
Stream<String> stream() { return builder.build(); }
public static void
main(String[] args) throws Exception {
new FileToWordsBuilder("Cheese.dat").stream()
.limit(7)
.map(w -> w + " ")
.forEach(System.out::print);
}
}
/* Output:
```

Not much of a cheese shop really

*/

Notice that the constructor adds all the words from the file (except the first line, which is the comment containing the file path information), but it doesn't call **build()**. This means, as long as you don't call **stream()**, you can continue to add words to the **builder** object. In a more complete version of this class, you might add a flag to see whether **build()** has been called, and a method to add further words if possible. Trying to add to a **Stream.Builder** after calling **build()** produces an exception.

Arrays

The **Arrays** class contains **static** methods named **stream()** that convert arrays to streams. We can rewrite **main()** from **interfaces/Machine.java** to create a stream and apply **execute()** to each element:

// streams/Machine2.java

import java.util.*;

```
import onjava.Operations;
public class Machine2 {
public static void main(String[] args) {
Arrays.stream(new Operations[] {
() -> Operations.show("Bing"),
() -> Operations.show("Crack"),
() -> Operations.show("Twist"),
() -> Operations.show("Pop")
}).forEach(Operations::execute);
}
}
/* Output:
Bing
Crack
Twist
Pop
*/
```

The **new Operations[]** expression dynamically creates a typed array of **Operations** objects.

The **stream()** methods can also produce an **IntStream**,

LongStream and **DoubleStream**:

```
// streams/ArrayStreams.java
import java.util.*;
import java.util.stream.*;
public class ArrayStreams {
public static void main(String[] args) {
Arrays.stream(
new double[] { 3.14159, 2.718, 1.618 })
.forEach(n -> System.out.format("%f ", n));
System.out.println();
Arrays.stream(new int[] { 1, 3, 5 })
.forEach(n -> System.out.format("%d ", n));
System.out.println();
Arrays.stream(new long[] { 11, 22, 44, 66 })
.forEach(n -> System.out.format("%d ", n));
System.out.println();
// Select a subrange:
Arrays.stream(
new int[] { 1, 3, 5, 7, 15, 28, 37 }, 3, 6)
.forEach(n -> System.out.format("%d ", n));
```

```
}
}
/* Output:
3.141590 2.718000 1.618000
1 3 5
11 22 44 66
7 15 28
*/
```

The last call to **stream()** has two additional arguments: the first tells **stream()** where to start selecting elements from the array, and the second tells it where to stop. Each different type of **stream()** method also has this version.

Regular Expressions

Java's *regular expressions* are covered in the Strings chapter. Java 8 added a new method **splitAsStream()** to the **java.util.regex.Pattern** class, which takes a sequence of characters and splits it into a stream, according to the formula you

hand it. There's a constraint, which is that the input is a **CharSequence**, so you cannot feed a stream into **splitAsStream()**.

We'll look again at the process of turning a file into words. This time, we use streams to turn the file into a single **String**, then *regular expressions* to split the **String** into a stream of words:

```
// streams/FileToWordsRegexp.java
import java.io.*;
import java.nio.file.*;
import java.util.stream.*;
import java.util.regex.Pattern;
public class FileToWordsRegexp {
private String all;
public FileToWordsRegexp(String filePath)
throws Exception {
all = Files.lines(Paths.get(filePath))
.skip(1) // First (comment) line
.collect(Collectors.joining(" "));
}
public Stream<String> stream() {
```

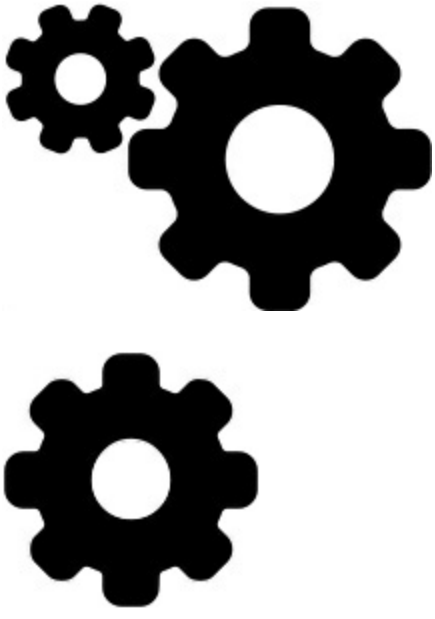
```
return Pattern
.compile("[ .,?]+").splitAsStream(all);
}
public static void
main(String[] args) throws Exception {
FileToWordsRegexp fw =
new FileToWordsRegexp("Cheese.dat");
fw.stream()
.limit(7)
.map(w -> w + " ")
.forEach(System.out::print);
fw.stream()
.skip(7)
.limit(2)
.map(w -> w + " ")
.forEach(System.out::print);
}
}
/* Output:
Not much of a cheese shop really is it
```

*/

The constructor reads all the lines in the file (again, skipping the first comment line) and turns them into a single **String**). Now, when you call **stream()**, you get a stream as before, but this time you can come back and call **stream()** multiple times, creating a new stream from the stored **String** each time. The limit here is that the whole file must be stored in memory; most of the time that probably won't be an issue but it loses important benefits of streams:

1. They "don't require storage." Of course they actually require some internal storage, but it's only a fraction of the sequence, and nothing like what it takes to hold the entire sequence.
2. They are lazily evaluated.

Fortunately, we'll see how to solve this problem a bit later.



Intermediate

Operations

These operations take objects in from one stream and feed objects out the back end as another stream, to be connected to other operations.

Tracing and Debugging

The **peek()** operation is intended as an aid to debugging. It allows you to view stream objects without modifying them:

```
// streams/Peeking.java
class Peeking {
public static void
main(String[] args) throws Exception {
FileToWords.stream("Cheese.dat")
.skip(21)
.limit(4)
.map(w -> w + " ")
.peek(System.out::print)
.map(String::toUpperCase)
.peek(System.out::print)
.map(String::toLowerCase)
.forEach(System.out::print);
```

```
}
}
/* Output:
Well WELL well it IT it s S s so SO so
*/
```

FileToWords is defined shortly, but it acts like the versions we've seen already: producing a stream of **String** objects. We **peek()** at them as they travel through the pipeline.

Because **peek()** takes a function that conforms to the **Consumer** functional interface, which has no return value, it's not possible to replace the objects in the stream with different ones. You can only look at them.

Sorting Stream Elements

You saw the use of **sorted()** with the default comparison in **Randoms.java**. There's a second form of **sorted()** that takes a **Comparator** argument:

```
// streams/SortedComparator.java
import java.util.*;
public class SortedComparator {
public static void
main(String[] args) throws Exception {
FileToWords.stream("Cheese.dat")
.skip(10)
.limit(10)
.sorted(Comparator.reverseOrder())
.map(w -> w + " ")
.forEach(System.out::print);
}
}
/* Output:
you what to the that sir leads in district And
```

*/

You can pass in a lambda function as the argument for **sorted()**, but there are also pre-defined **Comparator**s—here we use one that reverses the “natural order.”

Removing Elements

distinct(): In **Randoms.java**, **distinct()** removed duplicates from the stream. Using **distinct()** is far less work than creating a **Set** to eliminate duplicates.

filter(Predicate): The filter operation keeps only the elements that produce **true** when passed to the argument: the *filter function*.

In this example, the filter function **isPrime()** detects prime numbers:

```
// streams/Prime.java
import java.util.stream.*;
import static java.util.stream.LongStream.*;
public class Prime {
public static boolean isPrime(long n) {
return rangeClosed(2, (long)Math.sqrt(n))
.noneMatch(i -> n % i == 0);
```

```
}
public LongStream numbers() {
return iterate(2, i -> i + 1)
.filter(Prime::isPrime);
}
public static void main(String[] args) {
new Prime().numbers()
.limit(10)
.forEach(n -> System.out.format("%d ", n));
System.out.println();
new Prime().numbers()
.skip(90)
.limit(10)
.forEach(n -> System.out.format("%d ", n));
}
}
/* Output:
2 3 5 7 11 13 17 19 23 29
467 479 487 491 499 503 509 521 523 541
*/
```

rangeClosed() includes the top boundary value. The **noneMatch()** operation returns **true** if no modulus produces zero, and **false** if any equal zero. **noneMatch()** quits after the first failure rather than trying them all.

Applying a function to every element

map(Function): Applies **Function** to every object in the input stream, passing on the result values as the output stream.

mapToInt(ToIntFunction): As above, but results in an **IntStream**.

mapToLong(ToLongFunction): As above, but results in a **LongStream**.

mapToDouble(ToDoubleFunction): As above, but results in a **DoubleStream**.

Here, we **map()** various **Function**s onto a stream of **String**s:

// streams/FunctionMap.java

import java.util.*;

```
import java.util.stream.*;

import java.util.function.*;

class FunctionMap {

static String[] elements = { "12", "", "23", "45" }; static Stream<String>
testStream() {

return Arrays.stream(elements);

}

static void

test(String descr, Function<String, String> func) {

System.out.println(" ---( " + descr + " )---");

testStream()

.map(func)

.forEach(System.out::println);

}

public static void main(String[] args) {

test("add brackets", s -> "[" + s + "]");

test("Increment", s -> {

try {

return Integer.parseInt(s) + 1 + "";

} catch(NumberFormatException e) {

return s;
```

```
}
});
test("Replace", s -> s.replace("2", "9"));
test("Take last digit", s -> s.length() > 0 ?
s.charAt(s.length() - 1) + "" : s);
}
}
/* Output:
---( add brackets )---
[12]
[]
[23]
[45]
---( Increment )---
13
24
46
---( Replace )---
19
93
```

45

---(Take last digit)---

2

3

5

**/*

In the “Increment” test, we use **Integer.parseInt()** to attempt to turn the **String** into an **Integer**. If the **String** can’t be represented as an **Integer** it throws a **NumberFormatException** and we just fall back to putting the original **String** back on the output stream.

In the above example, the **map()** maps from a **String** to a **String**, but there’s no reason you can’t produce a different type than you take in, thus changing the type of the stream from that point on. Here’s what it looks like:

```
// streams/FunctionMap2.java
// Different input and output types
import java.util.*;
import java.util.stream.*;
class Numbered {
```

```
final int n;
Numbered(int n) { this.n = n; }
@Override
public String toString() {
return "Numbered(" + n + ")";
}
}
class FunctionMap2 {
public static void main(String[] args) {
Stream.of(1, 5, 7, 9, 11, 13)
.map(Numbered::new)
.forEach(System.out::println);
}
}
/* Output:
Numbered(1)
Numbered(5)
Numbered(7)
Numbered(9)
Numbered(11)
```

Numbered(13)

*/

We take **int**s and turn them into **Numbered**s using the constructor **Numbered::new**.

If the result type produced by **Function** is one of the numeric types, you must use the appropriate **mapTo-**operations instead:

```
// streams/FunctionMap3.java
// Producing numeric output streams
import java.util.*;
import java.util.stream.*;
class FunctionMap3 {
public static void main(String[] args) {
Stream.of("5", "7", "9")
.mapToInt(Integer::parseInt)
.forEach(n -> System.out.format("%d ", n));
System.out.println();
Stream.of("17", "19", "23")
.mapToLong(Long::parseLong)
.forEach(n -> System.out.format("%d ", n));
System.out.println();
```

```
Stream.of("17", "1.9", ".23")
.mapToDouble(Double::parseDouble)
.forEach(n -> System.out.format("%f ", n));
}
}
/* Output:
5 7 9
17 19 23
17.000000 1.900000 0.230000
*/
```

It’s unfortunate that the Java designers didn’t make the initial effort to eliminate primitive types.

Combining Streams During

map()

Suppose you’ve got a stream of incoming elements, and you’re applying a **map()** function to them. You’ve found some lovely functionality for your function you can’t find anywhere else, but

there’s a problem: that functionality produces a stream. What you want is to produce a stream of elements, but instead you’re producing a stream of streams of elements.

flatMap() does two things: it takes your stream-producing function and applies it to incoming elements (just like **map()** does), then it takes each stream and “flattens” it into elements. So what comes out is just elements.

flatMap(Function): Use when **Function** produces a stream.

flatMapToInt(Function): For a **Function** that produces an **IntStream**.

flatMapToLong(Function): For a **Function** that produces a **LongStream**.

flatMapToDouble(Function): For a **Function** that produces a **DoubleStream**.

To see how this works, we’ll start with a contrived function for **map()**, which takes in an **Integer** and produces a stream of **String**s:

```
// streams/StreamOfStreams.java
import java.util.stream.*;
public class StreamOfStreams {
```

```
public static void main(String[] args) {
Stream.of(1, 2, 3)
.map(i -> Stream.of("Gonzo", "Kermit", "Beaker"))
.map(e-> e.getClass().getName())
.forEach(System.out::println);
}
}
/* Output:
java.util.stream.ReferencePipeline$Head
java.util.stream.ReferencePipeline$Head
java.util.stream.ReferencePipeline$Head
*/
```

We were naively hoping for a stream of **String**, but what we got instead was a stream of “heads” to other streams. We can easily solve this with **flatMap()**:

```
// streams/FlatMap.java
import java.util.stream.*;
public class FlatMap {
public static void main(String[] args) {
Stream.of(1, 2, 3)
```

```
.flatMap(
i -> Stream.of("Gonzo", "Fozzie", "Beaker"))
.forEach(System.out::println);
}
}
/* Output:
Gonzo
Fozzie
Beaker
Gonzo
Fozzie
Beaker
Gonzo
Fozzie
Beaker
*/
```

So each stream that comes back from the mapping is automatically flattened into its component **String**s.

Here’s another demonstration. We start with a stream of integer, then use each one to create that many random numbers:

```
// streams/StreamOfRandoms.java
import java.util.*;
import java.util.stream.*;
public class StreamOfRandoms {
static Random rand = new Random(47);
public static void main(String[] args) {
Stream.of(1, 2, 3, 4, 5)
.flatMapToInt(i -> IntStream.concat(
rand.ints(0, 100).limit(i), IntStream.of(-1)))
.forEach(n -> System.out.format("%d ", n));
}
}
/* Output:
58 -1 55 93 -1 61 61 29 -1 68 0 22 7 -1 88 28 51 89 9
-1
*/
```

I've introduced **concat()** here, which combines two streams in argument order. So, at the end of each stream of random **Integer**, I'm adding a **-1** to use as a marker, so you can see that the final stream is indeed being created from a group of flattened streams.

Because **rand.ints()** produces an **IntStream**, I must use the special **Integer** versions of **flatMap()**, **concat()**, and **of()**.

Let's take one more look at the task of breaking a file into a stream of words. Our last encounter was **FileToWordsRegexp.java**, which had the problem that it required us to read the whole file into a **List** of lines—thus requiring storage for that **List**. What we really want is to create a stream of words without requiring intermediate storage. Once again, this is exactly the problem solved by **flatMap()**:

```
// streams/FileToWords.java
import java.nio.file.*;
import java.util.stream.*;
import java.util.regex.Pattern;
public class FileToWords {
public static Stream<String> stream(String filePath)
throws Exception {
return Files.lines(Paths.get(filePath))
.skip(1) // First (comment) line
.flatMap(line ->
Pattern.compile("\\W+").splitAsStream(line));
}
```

}

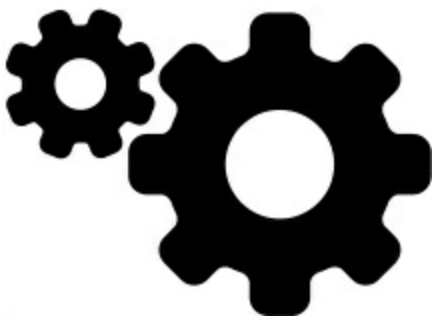
stream() is now a static method because it can accomplish the whole stream-creation process by itself.

Note the use of **\\W+** as the regular-expression pattern. The **\\W** means a “non-word character,” and the **+** means “one or more.” Lowercase **\\w** refers to a “word character.”

The problem we had before was that **Pattern.compile().splitAsStream()** produces a stream result, which means invoking **map()** on the incoming stream of lines produces a stream of streams of words, when what we want is simply a stream of words. Fortunately, **flatMap()** flattens a stream of streams of elements into a simple stream of elements. Alternatively, we could have used **String.split()**, which produces an array, which can be converted using **Arrays.stream()**:

```
.flatMap(line -> Arrays.stream(line.split("\\W+"))))
```

Because we have a true stream (rather than a stream based on a stored



collection as in **FileToWordsRegexp.java**), every time we want a new stream we must create it from scratch, because it can't be reused:

```
// streams/FileToWordsTest.java
import java.util.stream.*;
public class FileToWordsTest {
public static void
main(String[] args) throws Exception {
FileToWords.stream("Cheese.dat")
.limit(7)
.forEach(s -> System.out.format("%s ", s));
System.out.println();
FileToWords.stream("Cheese.dat")
.skip(7)
.limit(2)
.forEach(s -> System.out.format("%s ", s));
}
}
/* Output:
Not much of a cheese shop really
```

is it

*/

Here, the **%s** in **System.out.format()** indicates that the argument is a **String**.

Optional

Before we can look at terminal operations, we must consider what happens if you ask for an object in a stream and there's nothing there. We like to connect up our streams for the "happy path" and assume nothing will break. Putting a **null** in a stream is a good way to break it. Is there some kind of object we can use that will act as a holder for a stream element, but can also kindly tell us (that is, no exceptions) if the element we're looking for isn't there?

This idea is implemented as the **Optional** type. Certain standard stream operations return **Optional** objects because they cannot guarantee the desired result will exist. These include:

findFirst() returns an **Optional** containing the first element, or **Optional.empty** if the stream is empty.

findAny() returns an **Optional** containing any element, or **Optional.empty** if the stream is empty.

max() and **min()** return an **Optional** containing the

maximum or minimum values in the stream, or an **Optional.empty** if the stream is empty.

The version of **reduce()** that does *not* start with an "identity" object (the "identity" object becomes the default result in the other version of **reduce()** so there's no risk of an empty result) wraps its return value in an **Optional**.

For the numerical streams **IntStream**, **LongStream** and **DoubleStream**, the **average()** operation wraps its result in an **Optional** in case the stream is empty.

Here are simple tests of all of these operations upon empty streams:

```
// streams/OptionalsFromEmptyStreams.java
import java.util.*;
import java.util.stream.*;
class OptionalsFromEmptyStreams {
public static void main(String[] args) {
System.out.println(Stream.<String>empty()
.findFirst());
System.out.println(Stream.<String>empty()
.findAny());
System.out.println(Stream.<String>empty()
```

```
.max(String.CASE_INSENSITIVE_ORDER));
System.out.println(Stream.<String>empty()
.min(String.CASE_INSENSITIVE_ORDER));
System.out.println(Stream.<String>empty()
.reduce((s1, s2) -> s1 + s2));
System.out.println(IntStream.empty()
.average());
}
}
/* Output:
Optional.empty
Optional.empty
Optional.empty
Optional.empty
Optional.empty
OptionalDouble.empty
*/
```

Instead of throwing an exception because the stream is empty, you get an **Optional.empty** object. **Optional** has a **toString()** which displays useful information.

Note the creation of the empty stream via **Stream.**

<String>empty(). If you just say **Stream.empty()** without any context information, Java doesn't know what the type is; this syntax solves the problem. If the compiler has enough context information, as in:

Stream<String> s = Stream.empty();

It can infer the type for the **empty()** call.

This example shows the two basic activities for an **Optional**:

// streams/OptionalBasics.java

import java.util.*;

import java.util.stream.*;

class OptionalBasics {

static void test(Optional<String> optString) {

if(optString.isPresent())

System.out.println(optString.get());

else

System.out.println("Nothing inside!");

```
}
public static void main(String[] args) {
test(Stream.of("Epithets").findFirst());
test(Stream.<String>empty().findFirst());
}
}
/* Output:
Epithets
Nothing inside!
*/
```

When you receive an **Optional**, you first discover whether there's anything inside by calling **isPresent()**. If there is, you fetch it using **get()**.

Convenience Functions

There are a number of convenience functions for unpacking **Optional**s, which simplify the above process of "checking and doing something with the contained object":

ifPresent(Consumer): Call the **Consumer** with the value if it's there, otherwise do nothing.

orElse(otherObject): Produce the object if it's there,

otherwise produce **otherObject**.

orElseGet(Supplier): Produce the object if it's there, otherwise produce a replacement object using the **Supplier** function.

orElseThrow(Supplier): Produce the object if it's there, otherwise produce an exception using the **Supplier** function.

Here are simple demonstrations for the different convenience functions:

```
// streams/Optionals.java
import java.util.*;
import java.util.stream.*;
import java.util.function.*;
public class Optionals {
static void basics(Optional<String> optString) {
if(optString.isPresent())
System.out.println(optString.get());
else
System.out.println("Nothing inside!");
}
static void ifPresent(Optional<String> optString) {
```

```
optString.ifPresent(System.out::println);
}
static void orElse(Optional<String> optString) {
System.out.println(optString.orElse("Nada"));
}
static void orElseGet(Optional<String> optString) {
System.out.println(
optString.orElseGet(() -> "Generated"));
}
static void orElseThrow(Optional<String> optString) {
try {
System.out.println(optString.orElseThrow(
() -> new Exception("Supplied")));
} catch(Exception e) {
System.out.println("Caught " + e);
}
}
static void test(String testName,
Consumer<Optional<String>> cos) {
```

```
System.out.println(" === " + testName + " === ");
cos.accept(Stream.of("Epithets").findFirst());
cos.accept(Stream.<String>empty().findFirst());
}
public static void main(String[] args) {
test("basics", Optionals::basics);
test("ifPresent", Optionals::ifPresent);
test("orElse", Optionals::orElse);
test("orElseGet", Optionals::orElseGet);
test("orElseThrow", Optionals::orElseThrow);
}
}
/* Output:
=== basics ===
Epithets
Nothing inside!
=== ifPresent ===
```

Epithets

=== orElse ===

Epithets

Nada

=== orElseGet ===

Epithets

Generated

=== orElseThrow ===

Epithets

Caught java.lang.Exception: Supplied

*/

The **test()** method prevents code duplication by taking a **Consumer** that matches all the example methods.

orElseThrow() uses the **catch** keyword in order to capture the exception that is thrown by **orElseThrow()**. You'll learn about this in detail in the Exceptions chapter.

Creating Optionals

When you're writing your own code that produces **Optional**s, there are three **static** methods you can use:

empty(): Produces an **Optional** with nothing inside.

of(value): If you already know that **value** is not **null**, use this to wrap it in an **Optional**.

ofNullable(value): Use this if you don’t know that **value** is not **null**. It automatically produces **Optional.empty** if **value** is **null**, and otherwise wraps **value** inside an **Optional**.

You can see how these work:

```
// streams/CreatingOptionals.java
import java.util.*;
import java.util.stream.*;
import java.util.function.*;
class CreatingOptionals {
static void
test(String testName, Optional<String> opt) {
System.out.println(" === " + testName + " === ");
System.out.println(opt.orElse("Null"));
}
public static void main(String[] args) {
test("empty", Optional.empty());
test("of", Optional.of("Howdy"));
```

```
try {
test("of", Optional.of(null));
} catch(Exception e) {
System.out.println(e);
}
test("ofNullable", Optional.ofNullable("Hi"));
test("ofNullable", Optional.ofNullable(null));
}
}
```

```
/* Output:
=== empty ===
Null
=== of ===
Howdy
java.lang.NullPointerException
=== ofNullable ===
Hi
```

=== ofNullable ===

Null

*/

If we try to create an **Optional** by passing **null** to **of()**, it blows up. **ofNullable()** handles **null** gracefully, so it seems the safest one to use.

Operations on Optional

Objects

Three methods enable post-processing on **Optional**s, so if your stream pipeline produces an **Optional** you can do one more thing at the end:

filter(Predicate): Apply the **Predicate** to the contents of the **Optional** and return the result. If the **Optional** fails the **Predicate**, convert it to **empty**. If the **Optional** is already **empty**, just pass it through.

map(Function): If the **Optional** is not **empty**, apply **Function** to the contents of the **Optional** and return the result. Otherwise, pass through the **Optional.empty**.

flatMap(Function): Just like **map()**, but the supplied mapping function wraps the results in **Optional** objects so

flatMap() doesn’t do any wrapping at the end.

None of these are available for the numeric **Optional**s.

The normal stream **filter()** removes elements from the stream if the **Predicate** returns **false**. **Optional.filter()** doesn’t delete the **Optional** if the **Predicate** fails—it leaves it, but converts it to **empty**. This example explores **filter()**:

```
// streams/OptionalFilter.java
import java.util.*;
import java.util.stream.*;
import java.util.function.*;
class OptionalFilter {
static String[] elements = {
"Foo", "", "Bar", "Baz", "Bingo"
};
static Stream<String> testStream() {
return Arrays.stream(elements);
}
static void
test(String descr, Predicate<String> pred) {
System.out.println(" ---( " + descr + " )---");
```

```
for(int i = 0; i <= elements.length; i++) {
System.out.println(
testStream()
.skip(i)
.findFirst()
.filter(pred));
}
}
public static void main(String[] args) {
test("true", str -> true);
test("false", str -> false);
test("str != \"\"", str -> str != "");
test("str.length() == 3", str -> str.length() == 3);
test("startsWith(\"B\")",
str -> str.startsWith("B"));
}
}
/* Output:
---( true )---
Optional[Foo]
```

Optional[]

Optional[Bar]

Optional[Baz]

Optional[Bingo]

Optional.empty

---(false)---

Optional.empty

Optional.empty

Optional.empty

Optional.empty

Optional.empty

Optional.empty

---(str != "")---

Optional[Foo]

Optional.empty

Optional[Bar]

Optional[Baz]

Optional[Bingo]

Optional.empty

---(str.length() == 3)---

Optional[Foo]

Optional.empty

Optional[Bar]

Optional[Baz]

Optional.empty

Optional.empty

---(startsWith("B"))---

Optional.empty

Optional.empty

Optional[Bar]

Optional[Baz]

Optional[Bingo]

Optional.empty

**/*

Although the output looks like a stream, pay special attention to the **for** loop inside **test()**. It's restarting the stream each time through the **for** loop, and skipping the number of elements set by the **for**-loop index, which is what makes it end up on each successive element in the stream. Then it does a **findFirst()** to take the first remaining element, which comes back wrapped in an **Optional**.

Note that, unlike the usual **for** loop, this index isn’t bounded by **i < elements.length**, but rather **i <= elements.length**, so the final element actually overruns the stream. Conveniently, this automatically becomes an **Optional.empty**, which you see at the end of each test.

Like **map()**, **Optional.map()** applies a function, but in the case of **Optional**, it only applies the mapping function if the **Optional** is not **empty**. It also extracts the contents of the **Optional** to hand to the mapping function:

```
// streams/OptionalMap.java
import java.util.*;
import java.util.stream.*;
import java.util.function.*;
class OptionalMap {
static String[] elements = { "12", "", "23", "45" }; static Stream<String>
testStream() {
return Arrays.stream(elements);
}
static void
test(String descr, Function<String, String> func) {
System.out.println(" ---( " + descr + " )---");
```

```
for(int i = 0; i <= elements.length; i++) {
System.out.println(
testStream()
.skip(i)
.findFirst() // Produces an Optional
.map(func));
}
}
public static void main(String[] args) {
// If Optional is not empty, map() first extracts
// the contents which it then passes
// to the function:
test("Add brackets", s -> "[" + s + "]");
test("Increment", s -> {
try {
return Integer.parseInt(s) + 1 + "";
} catch(NumberFormatException e) {
return s;
}
});
```

```
test("Replace", s -> s.replace("2", "9"));
test("Take last digit", s -> s.length() > 0 ?
s.charAt(s.length() - 1) + "" : s);
}
// After the function is finished, map() wraps the
// result in an Optional before returning it:
}
/* Output:
---( Add brackets )---
Optional[[12]]
Optional[[]]
Optional[[23]]
Optional[[45]]
Optional.empty
---( Increment )---
Optional[13]
Optional[]
Optional[24]
Optional[46]
Optional.empty
```

---(Replace)---

Optional[19]

Optional[]

Optional[93]

Optional[45]

Optional.empty

---(Take last digit)---

Optional[2]

Optional[]

Optional[3]

Optional[5]

Optional.empty

**/*

The result of the mapping function is automatically wrapped back into an **Optional**. As you can see, an **Optional.empty** is simply passed through, without applying the mapping function.

The **flatMap()** for **Optional** is applied to a mapping function that already produces an **Optional**, so **flatMap()** doesn't wrap the result in an **Optional**, the way **map()** does:

// streams/OptionalFlatMap.java

```
import java.util.*;

import java.util.stream.*;

import java.util.function.*;

class OptionalFlatMap {

static String[] elements = { "12", "", "23", "45" }; static Stream<String>
testStream() {

return Arrays.stream(elements);

}

static void test(String descr,

Function<String, Optional<String>> func) {

System.out.println(" ---( " + descr + " )---");

for(int i = 0; i <= elements.length; i++) {

System.out.println(

testStream()

.skip(i)

.findFirst()

.flatMap(func));

}

}

public static void main(String[] args) {

test("Add brackets",
```

```
s -> Optional.of("[" + s + "]"));
test("Increment", s -> {
try {
return Optional.of(
Integer.parseInt(s) + 1 + "");
} catch(NumberFormatException e) {
return Optional.of(s);
}
});
test("Replace",
s -> Optional.of(s.replace("2", "9")));
test("Take last digit",
s -> Optional.of(s.length() > 0 ?
s.charAt(s.length() - 1) + ""
: s));
}
}
/* Output:
---( Add brackets )---
Optional[[12]]
```

Optional[[]]

Optional[[23]]

Optional[[45]]

Optional.empty

---(Increment)---

Optional[13]

Optional[]

Optional[24]

Optional[46]

Optional.empty

---(Replace)---

Optional[19]

Optional[]

Optional[93]

Optional[45]

Optional.empty

---(Take last digit)---

Optional[2]

Optional[]

Optional[3]

Optional[5]

Optional.empty

/

Like **map()**, **flatMap()** unpacks the contents of non-**empty Optional**s to hand to the mapping function. The only difference is that **flatMap()** doesn't wrap the result in an **Optional**, because the mapping function has already done that. In the above example, I've explicitly done the wrapping inside each mapping function, but clearly **Optional.flatMap()** is designed for functions already producing **Optional**s by themselves.

Streams of Optionals

Suppose you have a generator that might produce **null** values. If you create a stream of these using that generator, you'll naturally want to wrap the elements in **Optional**s. Here's what it looks like:

// streams/Signal.java

import java.util.*;

import java.util.stream.*;

```
import java.util.function.*;
public class Signal {
private final String msg;
public Signal(String msg) { this.msg = msg; }
public String getMsg() { return msg; }
@Override
public String toString() {
return "Signal(" + msg + ")";
}
static Random rand = new Random(47);
public static Signal morse() {
switch(rand.nextInt(4)) {
case 1: return new Signal("dot");
case 2: return new Signal("dash");
default: return null;
}
}
public static Stream<Optional<Signal>> stream() {
return Stream.generate(Signal::morse)
.map(signal -> Optional.ofNullable(signal));
```

```
}
}
```

When you use this stream, you'll have to figure out how you want to unpack the **Optional**s:

```
// streams/StreamOfOptionals.java
import java.util.*;
import java.util.stream.*;
public class StreamOfOptionals {
public static void main(String[] args) {
Signal.stream()
.limit(10)
.forEach(System.out::println);
System.out.println(" ---");
Signal.stream()
.limit(10)
.filter(Optional::isPresent)
.map(Optional::get)
.forEach(System.out::println);
}
}
```

/ Output:*

Optional[Signal(dash)]

Optional[Signal(dot)]

Optional[Signal(dash)]

Optional.empty

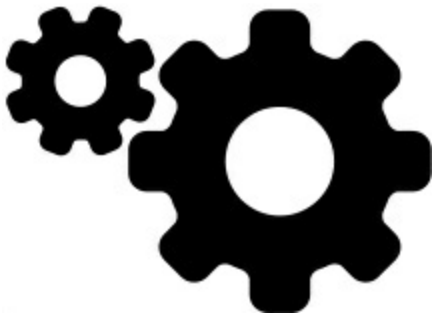
Optional.empty

Optional[Signal(dash)]

Optional.empty

Optional[Signal(dot)]

Optional[Signal(dash)]



Optional[Signal(dash)]

Signal(dot)

Signal(dot)

Signal(dash)

Signal(dash)

*/

Here, I use **filter()** to keep only the non-**empty Optional**s, then use **map()** to **get()** the values. Because each situation requires you to decide the meaning of “no value,” you usually need a different approach for each application.

Terminal Operations

These operations take a stream and produce a final result; they do not feed anything to a back-end stream. Thus, a terminal operation is always the last thing you can do within a pipeline.

Convert to an Array

toArray(): Converts the stream elements into an array of the proper type.

toArray(generator): The **generator** is for allocating your own array storage, in special cases.

This is useful if the stream operations produce something you must use in array form. For example, suppose we want to capture random numbers in a way that we can reuse them as a stream, such that we get

the identical stream each time. We can do this by storing them in an array:

// streams/RandInts.java

```
package streams;
import java.util.*;
import java.util.stream.*;
public class RandInts {
private static int[] rints =
new Random(47).ints(0, 1000).limit(100).toArray();
public static IntStream rands() {
return Arrays.stream(rints);
}
}
```

A stream of 100 random **int**s between 0 and 1000 is converted to an array and stored in **rints** so that each time you call **rands()** you get a repeat of the same stream.

Apply a Final Operation to

Every Element

forEach(Consumer): You've already seen this used many times with **System.out::println** as the **Consumer** function.

forEachOrdered(Consumer): This version ensures that the order on which the elements are operated on by **forEach** is the original stream order.

The first form is explicitly designed to operate on elements in any order, which only makes sense if you introduce the **parallel()** operation. We won't look at this in depth until the Concurrent Programming chapter, but here's a quick introduction: **parallel()** tells Java to try to run operations on multiple processors. It can do this precisely because we use streams—it can split the stream into multiple streams (often, one stream per processor) and run each stream on a different processor. Because we use internal iteration rather than external iteration, this is possible.

Before you get too excited about the seeming ease of **parallel()**, it's actually rather tricky to use, so hold off until we get to the Concurrent Programming chapter.

We can, however, get an idea of the effect and of the need for **forEachOrdered(Consumer)** by introducing **parallel()** into

an example:

```
// streams/ForEach.java
import java.util.*;
import java.util.stream.*;
import static streams.RandInts.*;
public class ForEach {
static final int SZ = 14;
public static void main(String[] args) {
rands().limit(SZ)
.forEach(n -> System.out.format("%d ", n));
System.out.println();
rands().limit(SZ)
.parallel()
.forEach(n -> System.out.format("%d ", n));
System.out.println();
rands().limit(SZ)
.parallel()
.forEachOrdered(n -> System.out.format("%d ", n));
}
}
```

/ *Output:*

258 555 693 861 961 429 868 200 522 207 288 128 551 589

551 861 429 589 200 522 555 693 258 128 868 288 961 207

258 555 693 861 961 429 868 200 522 207 288 128 551 589

**/*

I've isolated **sz** to make it easy to try different sizes. However, even a **sz** of **14** produces interesting results. In the first stream, we don't use

parallel() and so display the results in the order they appear from **rands()**. The second stream *does* introduce **parallel()** and, even for such a small stream, you see that the output is not in the same order as before. That's because multiple processors are working on the problem, and if you run the program multiple times you'll see that this output is different, due to the non-deterministic factors produced by having more than one processor working on the problem at the same time.

The final stream still uses **parallel()** but forces the result back into its original order using **forEachOrdered()**. Thus, using

forEachOrdered() for non-**parallel()** streams doesn't have any effect.

Collecting

collect(Collector): Uses the **Collector** to accumulate stream elements into a result collection.

collect(Supplier, BiConsumer, BiConsumer): As above, but **Supplier** creates a new result collection, the first **BiConsumer** is a function for including the next element into the result, and the second **BiConsumer** is used for combining two values.

You've only seen a few examples of **Collectors** objects. If you look at the documentation for **java.util.stream.Collectors**, you'll see that some of them are quite sophisticated. For example, we can collect into any specific kind of collection. Suppose we want our items to end up inside of a **TreeSet** so they are always sorted. There's no specific **toTreeSet()** method in **Collectors**, but you can use **Collectors.toCollection()** and hand it the constructor reference for any type of **Collection**. This program pulls the words from a file into a **TreeSet**:

// streams/TreeSetOfWords.java

```
import java.util.*;
import java.nio.file.*;
import java.util.stream.*;
public class TreeSetOfWords {
public static void
main(String[] args) throws Exception {
Set<String> words2 =
Files.lines(Paths.get("TreeSetOfWords.java"))
.flatMap(s -> Arrays.stream(s.split("\\W+")))
.filter(s -> !s.matches("\\d+")) // No numbers
.map(String::trim)
.filter(s -> s.length() > 2)
.limit(100)
.collect(Collectors.toCollection(TreeSet::new));
System.out.println(words2);
}
}
/* Output:
[Arrays, Collectors, Exception, Files, Output, Paths,
Set, String, System, TreeSet, TreeSetOfWords, args,
```

class, collect, file, filter, flatMap, get, import,

java, length, limit, lines, main, map, matches, new,

nio, numbers, out, println, public, split, static,

stream, streams, throws, toCollection, trim, util,

void, words2]

**/*

Files.lines() opens the **Path** and turns it into a **Stream** of lines. The next line splits those lines on boundaries of one or more non-word characters (**\\W+**), which produces an array which is turned into a **Stream** with **Arrays.stream()**, and the result is flat-mapped back into a **Stream** of words. The **matches(\\d+)** finds and removes **Strings** that are *all* digits (note that **words2** makes it through). Next we apply **String.trim()** to shave off any surrounding whitespace, **filter()** out any words less than a length of three, take only the first 100 words, and finally put them into a **TreeSet**.

We can produce a **Map** from a stream:

```
// streams/MapCollector.java
import java.util.*;
import java.util.stream.*;
class Pair {
```

```
public final Character c;
public final Integer i;
Pair(Character c, Integer i) {
this.c = c;
this.i = i;
}
public Character getC() { return c; }
public Integer getI() { return i; }
@Override
public String toString() {
return "Pair(" + c + ", " + i + ")";
}
}
class RandomPair {
Random rand = new Random(47);
// An infinite iterator of random capital letters:
Iterator<Character> capChars = rand.ints(65,91)
.mapToObj(i -> (char)i)
.iterator();
public Stream<Pair> stream() {
```

```
return rand.ints(100, 1000).distinct()
.mapToObj(i -> new Pair(capChars.next(), i));
}
}
public class MapCollector {
public static void main(String[] args) {
Map<Integer, Character> map =
new RandomPair().stream()
.limit(8)
.collect(
Collectors.toMap(Pair::getI, Pair::getC));
System.out.println(map);
}
}
/* Output:
{688=W, 309=C, 293=B, 761=N, 858=N, 668=G, 622=F,
751=N}
*/
```

Pair is just a basic data object. **RandomPair** creates a stream of randomly-generated **Pair** objects. It would be nice if we could just

somehow combine two streams, but Java fights us on this one. So I create a stream of **int**s and use **mapToObj** to turn that into a stream of **Pair**s. The **capChars** randomly-generated **Iterator** of capital letters starts as a stream, then the **iterator()** method allows us to use it in the **stream()** method. As far as I can tell, this is the only way to combine more than one stream to produce a new stream of objects.

Here, we use the simplest form of **Collectors.toMap()**, which just needs functions to fetch keys and values from the stream. There are additional forms, one of which takes a function to handle the case when you get a key collision.

Most of the time, you'll be able to find a predefined **Collector** that will do what you need by looking through **java.util.stream.Collectors**. In the rare situation when you don't, you can use the second form of **collect()**. I'll basically leave that as a more advanced exercise, but here's one example to give the basic idea:

```
// streams/SpecialCollector.java
import java.util.*;
import java.util.stream.*;
public class SpecialCollector {
public static void
main(String[] args) throws Exception {
ArrayList<String> words =
FileToWords.stream("Cheese.dat")
.collect(ArrayList::new,
ArrayList::add,
ArrayList::addAll);
words.stream()
.filter(s -> s.equals("cheese"))
.forEach(System.out::println);
}
}
/* Output:
cheese
cheese
*/
```

Here, the **ArrayList** methods already do what you need but it seems more likely that if you must use this form of **collect()** you'll have to create special definitions.

Combining All Stream Elements

reduce(BinaryOperator): Uses **BinaryOperator** to combine all stream elements. Returns an **Optional** because the stream might be empty.

reduce(identity, BinaryOperator): As above, but using **identity** as the initial value for the combination. Thus, if the stream is empty, you still get **identity** as the result.

reduce(identity, BiFunction, BinaryOperator):
This is more complicated (so we won't cover it), but is included because it can be more efficient. You can usually express this more simply by combining explicit **map()** and **reduce()** operations.

Here's a contrived example to demonstrate **reduce()**:

```
// streams/Reduce.java
import java.util.*;
import java.util.stream.*;
```

```
class Frobnitz {
int size;
Frobnitz(int sz) { size = sz; }
@Override
public String toString() {
return "Frobnitz(" + size + ")";
}
// Generator:
static Random rand = new Random(47);
static final int BOUND = 100;
static Frobnitz supply() {
return new Frobnitz(rand.nextInt(BOUND));
}
}
public class Reduce {
public static void main(String[] args) {
Stream.generate(Frobnitz::supply)
.limit(10)
.peek(System.out::println)
.reduce((fr0, fr1) -> fr0.size < 50 ? fr0 : fr1)
```

```
.ifPresent(System.out::println);
}
}
/* Output:
Frobnitz(58)
Frobnitz(55)
Frobnitz(93)
Frobnitz(61)
Frobnitz(61)
Frobnitz(29)
Frobnitz(68)
Frobnitz(0)
Frobnitz(22)
Frobnitz(7)
Frobnitz(29)
*/
```

Frobnitz contains its own generator named **supply()**; we can pass a method reference to **Stream.generate()** because it is signature-compatible as a **Supplier<Frobnitz>** (This signature compatibility is called *structural conformance*). We use the

reduce() method without the first-argument “starter value”, which means it produces an **Optional**. The **Optional.ifPresent()** method calls a **Consumer<Frobnitz>** (**println** conforms because it can take a **String** by converting the **Frobnitz** via **toString()**) only if the result is non-**empty**.

The first argument in the lambda expression, **fr0**, is the result that is carried over from the last invocation of this **reduce()**, and the second argument, **fr1**, is the new value that’s coming in from the stream.

The **reduce()** lambda uses a ternary if-else to take **fr0** if its **size** is less than 50, otherwise it takes **fr1**, the next one in the sequence. As a result, you get the *first* **Frobnitz** with a **size** less than 50—it just keeps holding onto that one once you’ve found it, even though other candidates appear. Although this is a rather odd constraint, it does give you a bit more insight into **reduce()**.

Matching

allMatch(Predicate): Returns **true** if *every* element of

the stream produces **true** when provided to the supplied **Predicate**. This will short-circuit upon the first **false**; it won't continue the calculation once it finds one **false**.

anyMatch(Predicate): Returns **true** if *any* element of the stream produces **true** when provided to the supplied **Predicate**. This will short-circuit upon the first **true**.

noneMatch(Predicate): Returns **true** if *no* elements of the stream produce **true** when provided to the supplied **Predicate**. This will short-circuit upon the first **true**.

You've seen an example of **noneMatch()** in **Prime.java**; the usage of **allMatch()** and **anyMatch()** are virtually identical.

Let's explore the short-circuiting behavior. To create a **show()** method that eliminates repeated code, we must first discover how to generically describe all three of the matcher operations, which we then turn into an interface called **Matcher**:

```
// streams/Matching.java
// Demonstrates short-circuiting of *Match() operations
import java.util.stream.*;
import java.util.function.*;
import static streams.RandInts.*;
```

```
interface Matcher extends
BiPredicate<Stream<Integer>, Predicate<Integer>> {}
public class Matching {
static void show(Matcher match, int val) {
System.out.println(
match.test(
IntStream.rangeClosed(1, 9)
.boxed()
.peek(n -> System.out.format("%d ", n)),
n -> n < val));
}
public static void main(String[] args) {
show(Stream::allMatch, 10);
show(Stream::allMatch, 4);
show(Stream::anyMatch, 2);
show(Stream::anyMatch, 0);
show(Stream::noneMatch, 5);
show(Stream::noneMatch, 0);
}
}
```

/ *Output:*

1 2 3 4 5 6 7 8 9 true

1 2 3 4 false

1 true

1 2 3 4 5 6 7 8 9 false

1 false

1 2 3 4 5 6 7 8 9 true

**/*

BiPredicate is a binary predicate, which only means it takes two arguments and returns **true** or **false**. The first argument is the stream of numbers we are going to test, and the second argument is the **Predicate** itself. Because **Matcher** fits the pattern of all the **Stream::*Match** functions, we can pass each one to **show()**. The call to **match.test()** is translated into an invocation of the **Stream::*Match** function.

show() takes a **Matcher** and a **val** indicating the maximum number in the predicate's test **n < val**. It generates a stream of **Integer**s from 1 through 9. The **peek()** is to show us how far the

test gets before it short-circuits. You can see from the output that the short-circuiting happens every time.

Selecting an Element

findFirst(): returns an **Optional** containing the first element of the stream, or **Optional.empty** if the stream has no elements.

findAny(): returns an **Optional** containing some element of the stream, or **Optional.empty** if the stream has no elements.

```
// streams/SelectElement.java
import java.util.*;
import java.util.stream.*;
import static streams.RandInts.*;
public class SelectElement {
public static void main(String[] args) {
System.out.println(rands().findFirst().getAsInt());
System.out.println(
rands().parallel().findFirst().getAsInt());
```

```
System.out.println(rands().findAny().getAsInt());
System.out.println(
rands().parallel().findAny().getAsInt());
}
}
/* Output:
258
258
258
242
*/
```

findFirst() will always select the first element in the stream, whether or not the stream is **parallel()**. For a non-**parallel()**

stream, **findAny()** chooses the first element (although from the definition it has the option to choose any element). In this example, making the stream **parallel()** introduces the possibility that **findAny()** chooses other than the first element.

If you must select the last element in a stream, use **reduce()**:

```
// streams/LastElement.java
import java.util.*;
import java.util.stream.*;
public class LastElement {
public static void main(String[] args) {
OptionalInt last = IntStream.range(10, 20)
.reduce((n1, n2) -> n2);
System.out.println(last.orElse(-1));
// Non-numeric object:
Optional<String> lastobj =
Stream.of("one", "two", "three")
.reduce((n1, n2) -> n2);
System.out.println(
lastobj.orElse("Nothing there!"));
}
}
/* Output:
19
three
```

*/

The argument to **reduce()** just replaces the last two elements with the last element, ultimately producing only the last element. If the stream is numeric, you must use the appropriate numeric optional type, otherwise you use a typed **Optional** as in **Optional<String>** .

Informational

count(): The number of elements in this stream.

max(Comparator): The “maximum” element of this stream as determined by the **Comparator**.

min(Comparator): The “minimum” element of this stream as determined by the **Comparator**.

Strings have a predefined **Comparator**, which simplifies our example:

```
// streams/Informational.java
import java.util.stream.*;
import java.util.function.*;
public class Informational {
public static void
main(String[] args) throws Exception {
```

```
System.out.println(
FileToWords.stream("Cheese.dat").count());
System.out.println(
FileToWords.stream("Cheese.dat")
.min(String.CASE_INSENSITIVE_ORDER)
.orElse("NONE"));
System.out.println(
FileToWords.stream("Cheese.dat")
.max(String.CASE_INSENSITIVE_ORDER)
.orElse("NONE"));
}
}
/* Output:
32
a
you
*/
```

min() and **max()** return **Optional**s, which I unpack using **orElse()**;

Information for Numeric Streams

average(): The usual meaning.

max() & **min()**: These don't need a **Comparator** because they work on numeric streams.

sum(): Add up the values in the stream.

summaryStatistics(): Produces potentially useful data. It's not quite clear why they felt the need for this one, since you can produce all the data yourself with the direct methods.

```
// streams/NumericStreamInfo.java
import java.util.stream.*;
import static streams.RandInts.*;
public class NumericStreamInfo {
public static void main(String[] args) {
System.out.println(rands().average().getAsDouble());
System.out.println(rands().max().getAsInt());
System.out.println(rands().min().getAsInt());
System.out.println(rands().sum());
System.out.println(rands().summaryStatistics());
}
}
/* Output:
```

507.94

998

8

50794

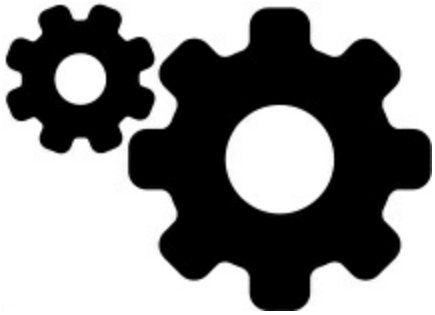
IntSummaryStatistics{count=100, sum=50794, min=8,

average=507.940000, max=998}

**/*

The same operations are available for **LongStream**s and

DoubleStreams.



Summary

Streams change—and greatly improve—the nature of Java programming, and are likely to significantly stem the flow of Java programmers to functional JVM languages like Scala. We will use streams whenever possible throughout the rest of this book.

1. I found a number of sites very useful when creating this chapter, including Java2s and LambdaFAQ↩

Exceptions

The basic philosophy of Java is that

“badly formed code will not run.”

(At least, that’s what I infer.)

Improved error recovery is one of the most powerful ways you can increase the robustness of your code. Error recovery is a fundamental concern for every program you write, but it’s especially important in Java, a primary goal is to create program components for others to use.

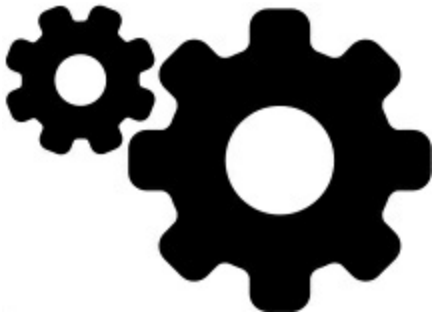
The ideal time to catch an error is at compile time, before you even try to run the program. However, not all errors can be detected at compile time. Other problems must be dealt with at run time through some formality that allows the originator of the error to pass appropriate information to a recipient who will know how to handle the difficulty properly.

To create a robust system, each

component must be robust.

By providing a consistent error-reporting model using exceptions,

Java allows components to reliably communicate problems to client



code.

The goals for exception handling in Java are to simplify the creation of large, reliable programs using less code than currently possible, and to do so with more confidence that your application doesn’t have an unhandled error. Exceptions are not terribly difficult to learn, and can provide immediate and significant benefits to your project.

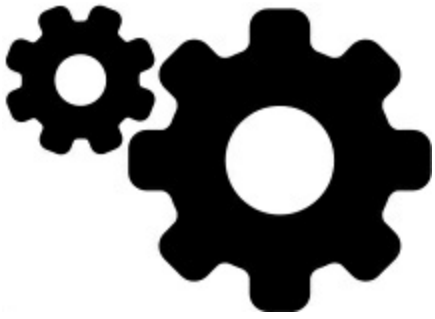
Because exception handling is the only official way that Java reports errors, and is enforced by the Java compiler, you can only go so far without learning about exception handling. This chapter teaches you to write code to properly handle exceptions, and to generate your own exceptions if one of your methods gets into trouble.

Concepts

C and other earlier languages often had multiple error-handling schemes, and these were generally established by convention and not as part of the programming language. Typically, you returned a special

value or set a flag, and the recipient determined that something was amiss by looking at the value or flag. Over time, we realized that programmers who use a library tend to think of themselves as invincible—as in "Yes, errors might happen to others, but not in *my* code." So, not too surprisingly, they wouldn't check for the error conditions (and sometimes the error conditions were too silly to check for1). If you *did* thoroughly check for errors every time you called a method, your code turned into an unreadable nightmare. Because programmers could still coax systems out of these languages, they resisted the truth: that this approach to handling errors is a major limitation to creating large, robust, maintainable programs.

One solution is to take the casual nature out of error handling and to enforce formality. This actually has a long history, because implementations of *exception handling* go back to operating systems in the 1960s, and even to BASIC's "**on error goto**." But C++



exception handling was based on Ada, and Java's is based primarily on

C++ (although it looks more like Object Pascal).

The word “exception” is meant in the sense of “I take exception to that.” When the problem occurs, you might not know what to do with it, but you do know you can’t just continue on merrily; you must stop, and somebody, somewhere, must figure out what to do. But you don’t have enough information in the current context to fix the problem. So you hand the problem to a higher context where someone is qualified to make the proper decision.

Exceptions can reduce some of the complexity of error-handling code. Without exceptions, you must check for a particular error and deal with it, possibly at multiple places in your program. With exceptions, you no longer check for errors at the point of the method call, since the exception will guarantee that someone catches it. Ideally, you only handle the problem in one place, in the so-called *exception handler*. This can save code, and separate the code that describes your goal during normal execution from the code executed when things go awry. Used carefully, reading, writing, and debugging code can be clearer with exceptions than when using the old ways of error handling.

Basic Exceptions

An *exceptional condition* is a problem that prevents the continuation

of the current method or scope. It's important to distinguish an exceptional condition from a normal problem, when you have enough information in the current context to somehow cope with the difficulty. With an exceptional condition, you cannot continue processing because you don't have the information necessary to deal with the problem *in the current context*. All you can do is jump out of the current context and relegate that problem to a higher context. This is what happens when you throw an exception.

Division is a simple example. If you're about to divide by zero, it's worth checking for that condition. But what does it mean that the denominator is zero? Maybe you know, in the context of the problem you're trying to solve in that particular method, how to deal with a zero denominator. But if it's an unexpected value, you can't deal with it and so must throw an exception rather than continuing along that execution path.

When you throw an exception, several things happen. First, the exception object is created in the same way as any Java object: on the heap, with **new**. Then the current path of execution (the one you can't continue) is stopped and the reference for the exception object is ejected from the current context. Now the exception-handling

mechanism takes over and begins to look for an appropriate place to continue executing the program. This appropriate place is the *exception handler*, whose job is to recover from the problem so the program can either try another tack or just continue.

As a simple example of throwing an exception, consider an object reference called **t**. You might receive a reference that hasn't been initialized, so you check before using that reference. You can send information about the error into a larger context by creating an object representing your information and "throwing" it out of your current context. This is called *throwing an exception*. Here's what it looks like:

```
if(t == null)
throw new NullPointerException();
```

This throws the exception, which allows you—in the current context—to abdicate responsibility for the issue. It's just magically handled somewhere else. Precisely *where* is shown shortly.

Exceptions allow you to think of everything you do as a transaction, and the exceptions guard those transactions: "…the fundamental premise of transactions is that we needed exception handling in distributed computations. Transactions are the computer equivalent of contract law. If anything goes wrong, we'll just blow away the whole

computation. ”2 You can also think about exceptions as a built-in

“undo” system, because (with some care) you can have various recovery points in your program. If a part of the program fails, the exception will “undo” back to a known stable point in the program. If something bad happens, exceptions don’t allow a program to continue along its ordinary path. This is a real problem in languages like C and C++; especially C, which had no way to force a program to stop going down a path if a problem occurred, so it was possible to ignore problems for a long time and get into a completely inappropriate state. Exceptions allow you to (if nothing else) force the program to stop and tell you what went wrong, or (ideally) force the program to deal with the problem and return to a stable state.

Exception Arguments

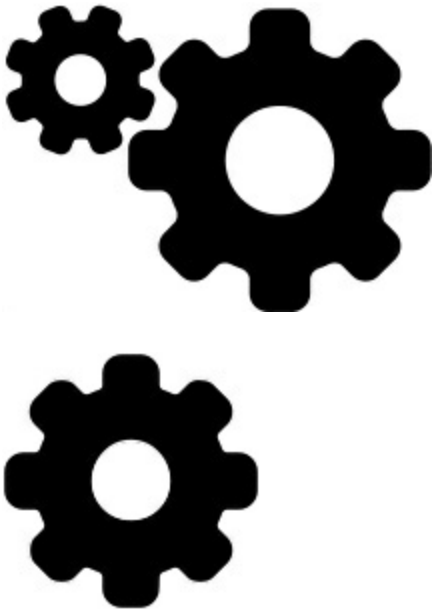
As with any object in Java, you always create exceptions on the heap using **new**, which allocates storage and calls a constructor. There are two constructors in all standard exceptions: The first is the no-arg constructor, and the second takes a **String** argument to place

pertinent information in the exception:

throw new NullPointerException("t = null");

This **String** can later be extracted using various methods, as you'll see.

The keyword **throw** produces a number of interesting results. After creating an exception object with **new**, you give the resulting reference to **throw**. The object is, in effect, "returned" from the method, even though that object type isn't normally what the method is designed to return. A simplistic way to think about exception handling is as a different kind of return mechanism, although you'll have trouble if you take that analogy too far. You can also exit from ordinary scopes by throwing an exception. In either case, an exception object is returned,



and the method or scope exits.

Any similarity to an ordinary return from a method ends here, because *where* you return to is someplace completely different from where you return for a normal method call. You end up in an appropriate exception handler that might be far away—many levels on the call stack—from where the exception was thrown.

In addition, you can throw any type of **Throwable**, the exception root class. Typically, you'll throw a different class of exception for each different type of error. The information about the error is represented both inside the exception object and implicitly in the name of the exception class, so someone in the bigger context can figure out what to do with your exception. (Often, the only information is the type name of the exception, and nothing meaningful is stored within the exception object itself.)

Catching an Exception

To see how an exception is caught, you must first understand the concept of a *guarded region*. This is a section of code that might produce exceptions, and is followed by the code to handle those exceptions.

The try Block

If you're inside a method and you throw an exception (or another

method you call within this method throws an exception), that method will exit in the process of throwing. If you don't want a **throw** to exit the method, you can set up a special block within that method to capture the exception. This is called the *try block* because you "try" your various method calls there. The try block is an ordinary scope

preceded by the keyword **try**:

```
try {
// Code that might generate exceptions
}
```

If you are carefully checking for errors in a programming language that doesn't support exception handling, you surround every method call with setup and error-testing code, even if you call the same method several times. With exception handling, you put everything in a **try** block and capture all the exceptions in one place. This means your code can be much easier to write and read, because the goal of the code is not confused with the error checking.

Exception Handlers

The thrown exception ends up someplace. This “place” is the exception handler, and you write one for every exception type. Exception handlers immediately follow the **try** block and are denoted by the keyword **catch**:

```
try {
// Code that might generate exceptions
} catch(Type1 id1) {
// Handle exceptions of Type1
} catch(Type2 id2) {
// Handle exceptions of Type2
} catch(Type3 id3) {
// Handle exceptions of Type3
}
// etc.
```

Each **catch** clause (exception handler) is like a little method that takes one and only one argument of a particular type. The identifier (**id1**, **id2**, and so on) can be used inside the handler, just like a method argument. Sometimes you never use the identifier because the type of the exception gives you enough information to deal with the exception, but the identifier must still be there.

The handlers must appear directly after the **try** block. If an exception is thrown, the exception-handling mechanism goes hunting for the first handler with an argument that matches the type of the exception. Then it enters that **catch** clause, and the exception is considered handled. The search for handlers stops once the **catch** clause is finished. Only the matching **catch** clause executes; it's not like a **switch** statement when you need a **break** after each **case** to prevent the remaining ones from executing.

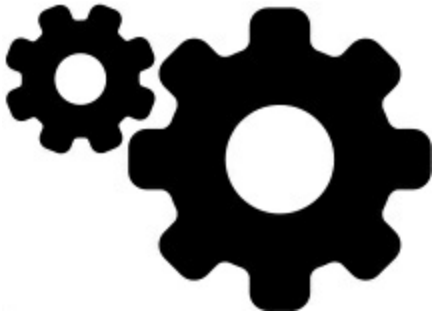
Note that within the **try** block, a number of different method calls might generate the same exception, but you need only one handler.

Termination vs. Resumption

There are two basic models in exception-handling theory. Java supports *termination*, [3] where you assume that the error is so critical there's no way to get back to where the exception occurred. Whoever threw the exception decided there was no way to salvage the situation, and they don't *want* to come back.

The alternative is called *resumption*. It means the exception handler is expected to do something to rectify the situation, then the faulting method is retried, presuming success the second time. If you want resumption, it means you still hope to continue execution after the exception is handled.

If you want resumption-like behavior in Java, don’t throw an exception when you encounter an error. Instead, call a method that fixes the problem. Alternatively, place your **try** block inside a **while**



loop that keeps reentering the **try** block until the result is satisfactory.

Historically, programmers using operating systems that supported resumptive exception handling eventually ended up using termination-like code and skipping resumption. So although resumption sounds attractive at first, it isn’t so useful in practice. The dominant reason is probably the coupling that results: A resumptive handler would be aware of where the exception is thrown, and contain non-generic code specific to the throwing location. This makes the code difficult to write and maintain, especially for large systems where the exception can be generated from many points.

Creating Your Own

Exceptions

You’re not stuck using the existing Java exceptions. The Java exception hierarchy can’t foresee all the errors you might report, so you can create your own to denote a special problem that your library might encounter.

To create your own exception class, inherit from an existing exception class, preferably one that is close in meaning to your new exception (although this is often not possible). The most trivial way to create a new type of exception is just to let the compiler create the no-arg constructor for you, so it requires almost no code at all:

```
// exceptions/InheritingExceptions.java
// Creating your own exceptions
class SimpleException extends Exception {}
public class InheritingExceptions {
public void f() throws SimpleException {
System.out.println(
"Throw SimpleException from f()");
throw new SimpleException();
}
public static void main(String[] args) {
InheritingExceptions sed =
```

```
new InheritingExceptions();
try {
sed.f();
} catch(SimpleException e) {
System.out.println("Caught it!");
}
}
}
/* Output:
Throw SimpleException from f()
Caught it!
*/
```

The compiler creates a no-arg constructor, which automatically (and invisibly) calls the base-class no-arg constructor. Here you don't get a **SimpleException(String)** constructor, but in practice that isn't used much. As you'll see, the most important thing about an exception is the class name, so most of the time an exception like the one shown here is satisfactory.

Here, the result is displayed on the console. You can also send error output to the *standard error* stream by writing to **System.err**. This

is usually a better place to send error information than **System.out**, which can be redirected. If you send output to **System.err**, it is not redirected along with **System.out** so the user is more likely to notice it.

You can also create an exception class that has a constructor with a **String** argument:

```
// exceptions/FullConstructors.java
class MyException extends Exception {
MyException() {}
MyException(String msg) { super(msg); }
}
public class FullConstructors {
public static void f() throws MyException {
System.out.println("Throwing MyException from f()");
throw new MyException();
}
public static void g() throws MyException {
System.out.println("Throwing MyException from g()");
throw new MyException("Originated in g()");
}
```

```
public static void main(String[] args) {
try {
f();
} catch(MyException e) {
e.printStackTrace(System.out);
}
try {
g();
} catch(MyException e) {
e.printStackTrace(System.out);
}
}
}
/* Output:
Throwing MyException from f()
MyException
at FullConstructors.f(FullConstructors.java:11)
at
FullConstructors.main(FullConstructors.java:19)
Throwing MyException from g()
```

MyException: Originated in g()

at FullConstructors.g(FullConstructors.java:15)

at

FullConstructors.main(FullConstructors.java:24)

**/*

The added code is small: two constructors that define the way you create **MyException**. In the second constructor, the base-class

constructor with a **String** argument is explicitly invoked using the **super** keyword.

In the handlers, one of the **Throwable** (from which **Exception** is inherited) methods is called: **printStackTrace()**. As shown in the output, this produces information about the sequence of method calls to get to the point where the exception happened. Here, the information is sent to **System.out**, and automatically captured and displayed in the output. However, if you call the default version:

e.printStackTrace();

the information goes to the standard error stream.

Exceptions and Logging

You might also *log* the output using the **java.util.logging**

facility. Basic logging is straightforward enough to show here.

```
// exceptions/LoggingExceptions.java
// An exception that reports through a Logger
// {ErrorOutputExpected}
import java.util.logging.*;
import java.io.*;
class LoggingException extends Exception {
private static Logger logger =
Logger.getLogger("LoggingException");
LoggingException() {
StringWriter trace = new StringWriter();
printStackTrace(new PrintWriter(trace));
logger.severe(trace.toString());
}
}
public class LoggingExceptions {
public static void main(String[] args) {
try {
```

```
throw new LoggingException();
} catch(LoggingException e) {
System.err.println("Caught " + e);
}
try {
throw new LoggingException();
} catch(LoggingException e) {
System.err.println("Caught " + e);
}
}
}
/* Output:
___[ Error Output ]___
May 09, 2017 6:07:17 AM LoggingException <init>
SEVERE: LoggingException
at
LoggingExceptions.main(LoggingExceptions.java:20)
Caught LoggingException
May 09, 2017 6:07:17 AM LoggingException <init>
SEVERE: LoggingException
```

at

LoggingExceptions.main(LoggingExceptions.java:25)

Caught LoggingException

**/*

The **static Logger.getLogger()** method creates a **Logger** object associated with the **String** argument (usually the name of the package and class that the errors are about) which sends its output to **System.err**. The easiest way to write to a **Logger** is just to call the method associated with the level of logging message; here, **severe()** is used. To produce the **String** for the logging message, we'd like the stack trace to appear where the exception is thrown, but **printStackTrace()** doesn't produce a **String** by default. To get a **String**, we use the overloaded **printStackTrace()** that takes a **java.io.PrintWriter** object as an argument (**PrintWriter** is fully explained in the Appendix: I/O Streams). If we hand the **PrintWriter** constructor a **java.io.StringWriter** object, the output can be extracted as a **String** by calling **toString()**.

The approach used by **LoggingException** is convenient because it builds all the logging infrastructure into the exception itself, and thus it works automatically without client programmer intervention.

However, it's more common to catch and log someone else's exception,

so you must generate the log message in the exception handler:

```
// exceptions/LoggingExceptions2.java
// Logging caught exceptions
// {ErrorOutputExpected}
import java.util.logging.*;
import java.io.*;
public class LoggingExceptions2 {
private static Logger logger =
Logger.getLogger("LoggingExceptions2");
static void logException(Exception e) {
StringWriter trace = new StringWriter();
e.printStackTrace(new PrintWriter(trace));
logger.severe(trace.toString());
}
public static void main(String[] args) {
try {
throw new NullPointerException();
} catch(NullPointerException e) {
logException(e);
}
```

```
}
}
/* Output:
___[ Error Output ]___
May 09, 2017 6:07:17 AM LoggingExceptions2 logException
SEVERE: java.lang.NullPointerException
at
LoggingExceptions2.main(LoggingExceptions2.java:17)
*/
```

The process of creating your own exceptions can be taken further. You can add extra constructors and members:

```
// exceptions/ExtraFeatures.java
// Further embellishment of exception classes
class MyException2 extends Exception {
private int x;
MyException2() {}
MyException2(String msg) { super(msg); }
MyException2(String msg, int x) {
super(msg);
this.x = x;
```

```
}
public int val() { return x; }
@Override
public String getMessage() {
return "Detail Message: "+ x
+ " "+ super.getMessage();
}
}
public class ExtraFeatures {
public static void f() throws MyException2 {
System.out.println(
"Throwing MyException2 from f()");
throw new MyException2();
}
public static void g() throws MyException2 {
System.out.println(
"Throwing MyException2 from g()");
throw new MyException2("Originated in g()");
}
public static void h() throws MyException2 {
```

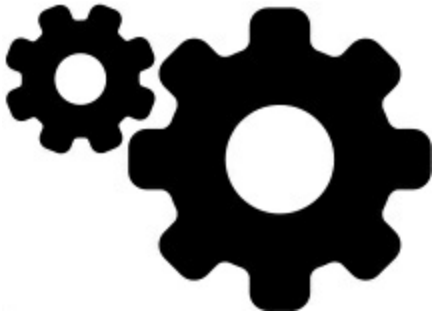
```
System.out.println(
"Throwing MyException2 from h()");
throw new MyException2("Originated in h()", 47);
}
public static void main(String[] args) {
try {
f();
} catch(MyException2 e) {
e.printStackTrace(System.out);
}
try {
g();
} catch(MyException2 e) {
e.printStackTrace(System.out);
}
try {
h();
} catch(MyException2 e) {
e.printStackTrace(System.out);
System.out.println("e.val() = " + e.val());
```

```
}
}
}
/* Output:
Throwing MyException2 from f()
MyException2: Detail Message: 0 null
at ExtraFeatures.f(ExtraFeatures.java:24)
at ExtraFeatures.main(ExtraFeatures.java:38)
Throwing MyException2 from g()
MyException2: Detail Message: 0 Originated in g()
at ExtraFeatures.g(ExtraFeatures.java:29)
at ExtraFeatures.main(ExtraFeatures.java:43)
Throwing MyException2 from h()
MyException2: Detail Message: 47 Originated in h()
at ExtraFeatures.h(ExtraFeatures.java:34)
at ExtraFeatures.main(ExtraFeatures.java:48)
e.val() = 47
*/
```

A field **x** is added, along with a method to reads that value and an additional constructor that sets it. In addition,

Throwable.getMessage() is overridden to produce a more helpful detail message. **getMessage()** is something like **toString()** for exception classes.

Since an exception is just another kind of object, you can continue this process of embellishing the power of your exception classes. Keep in mind, however, that all this dressing-up might be lost on the client



programmers using your packages, since they might simply look for the exception to be thrown and nothing more. (That’s the way most of the Java library exceptions are used.)

The Exception Specification

In Java, you’re encouraged to inform the client programmer, who calls your method, of the exceptions that might be thrown from your method. This is civilized, because the caller can then know exactly what code to write to catch all potential exceptions. If the source code is available, the client programmer can hunt through and look for

throw statements, but a library might not come with sources. To prevent this from being a problem, Java requires syntax that politely tells the client programmer what exceptions this method throws, so the client programmer can handle them. This is the *exception specification* and it's part of the method declaration, appearing after the argument list.

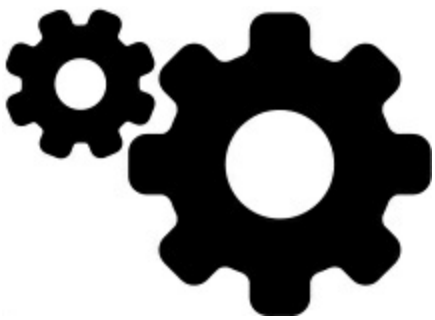
The exception specification uses an additional keyword, **throws**, followed by a list of all the potential exception types. So your method definition might look like this:

void f() **throws** TooBig, TooSmall, DivZero { // ...

However, if you say

void f() { // ...

it means no exceptions are thrown from the method (*except* for the exceptions inherited from **RuntimeException**, which can be thrown anywhere without exception specifications—these are described later).



You can’t lie about an exception specification. If the code within your method causes exceptions, but your method doesn’t handle them, the compiler will detect this and declare you must either handle the exception or indicate with an exception specification that it might be thrown from your method. By enforcing exception specifications from top to bottom, Java guarantees that a certain level of exception correctness can be ensured at compile time.

There is one place you can lie: You can claim to throw an exception you really don’t. The compiler takes your word for it, and forces the users of your method to treat it as if it really does throw that exception. This has the beneficial effect of being a placeholder for that exception, so you can actually start throwing the exception later without requiring changes to existing code. It’s also important for creating **abstract** base classes and interfaces whose derived classes or implementations might throw exceptions.

Exceptions that are checked and enforced at compile time are called *checked exceptions*.

Catching Any

Exception

You can create a handler that catches any type of exception by catching

the base-class exception type **Exception**. There are other types of base exceptions, but **Exception** is the base that's pertinent to virtually all programming activities:

```
catch(Exception e) {
System.out.println("Caught an exception");
}
```

This will catch any exception, so if you use it, put it at the *end* of your list of handlers to avoid preempting any exception handlers that might otherwise follow.

Since the **Exception** class is the base of all the exception classes important to the programmer, you don't get much specific information about the exception, but you can call the methods that come from *its* base type **Throwable**:

String getMessage()

String getLocalizedMessage()

: Gets the detail message, or a message adjusted for this particular locale.

String toString()

Returns a short description of the **Throwable**, including the detail message if there is one.

void printStackTrace()

void printStackTrace(PrintStream)

void printStackTrace(java.io.PrintWriter)

: Prints the **Throwable** and the **Throwable**s call stack trace. The call stack shows the sequence of method calls that brought you to the point at which the exception was thrown. The first version prints to standard error, the second and third print to a stream of your choice (in the Appendix: I/O Streams, you'll understand why there are two types of streams).

Throwable fillInStackTrace()

Records information within this **Throwable** object about the current state of the stack frames. Useful when an application is rethrowing an error or exception (more about this shortly).

In addition, you get some other methods from **Throwable**s base type **Object** (everybody's base type). The one that might come in handy for exceptions is **getClass()**, which returns an object representing the class of this object. You can in turn query this **Class** object for its name with **getName()**, which includes package information, or **getSimpleName()**, which produces the class name alone.

Here's an example that shows the basic **Exception** methods:

// exceptions/ExceptionMethods.java

```
// Demonstrating the Exception Methods
public class ExceptionMethods {
public static void main(String[] args) {
try {
throw new Exception("My Exception");
} catch(Exception e) {
System.out.println("Caught Exception");
System.out.println(
"getMessage():" + e.getMessage());
System.out.println("getLocalizedMessage():" +
e.getLocalizedMessage());
System.out.println("toString():" + e);
System.out.println("printStackTrace():");
e.printStackTrace(System.out);
}
}
}
/* Output:
Caught Exception
getMessage():My Exception
```

getLocalizedMessage():My Exception

toString():java.lang.Exception: My Exception

printStackTrace():

java.lang.Exception: My Exception

at

ExceptionMethods.main(ExceptionMethods.java:7)

**/*

The methods provide successively more information—each is effectively a superset of the previous one.

Multi-Catch

If there are a set of exceptions you want to handle the same way and they have a common base type, you just catch that. But if those exceptions don’t have a base type in common, before Java 7 you must write a catch for each one:

// exceptions/SameHandler.java

class EBase1 **extends** Exception {}

class Except1 **extends** EBase1 {}

```
class EBase2 extends Exception {}
class Except2 extends EBase2 {}
class EBase3 extends Exception {}
class Except3 extends EBase3 {}
class EBase4 extends Exception {}
class Except4 extends EBase4 {}
public class SameHandler {
void x() throws Except1, Except2, Except3, Except4 {}
void process() {}
void f() {
try {
x();
} catch(Except1 e) {
process();
} catch(Except2 e) {
process();
} catch(Except3 e) {
process();
} catch(Except4 e) {
process();
```

```
}
}
}
```

With Java 7 multi-catch handlers, you can “OR” together different types of exceptions in a single **catch**:

```
// exceptions/MultiCatch.java
public class MultiCatch {
void x() throws Except1, Except2, Except3, Except4 {}
void process() {}
void f() {
try {
x();
} catch(Except1 | Except2 | Except3 | Except4 e) {
process();
}
}
}
```

Or in other combinations:

```
// exceptions/MultiCatch2.java
public class MultiCatch2 {
void x() throws Except1, Except2, Except3, Except4 {}
void process1() {}
void process2() {}
void f() {
try {
x();
} catch(Except1 | Except2 e) {
process1();
} catch(Except3 | Except4 e) {
process2();
}
}
}
```

This is a nice contribution to clearer code.

The Stack Trace

The information provided by **printStackTrace()** can also be

accessed directly using **getStackTrace()**. This method returns an array of stack trace elements, each representing one stack frame. Element zero is the top of the stack, and is the last method invocation in the sequence (the point this **Throwable** was created and thrown). The last element of the array and the bottom of the stack is the first method invocation in the sequence. This program provides a simple demonstration:

```
// exceptions/WhoCalled.java
// Programmatic access to stack trace information
public class WhoCalled {
static void f() {
// Generate an exception to fill in the stack trace
try {
throw new Exception();
} catch(Exception e) {
for(StackTraceElement ste : e.getStackTrace())
System.out.println(ste.getMethodName());
}
}
static void g() { f(); }
```

```
static void h() { g(); }
public static void main(String[] args) {
f();
System.out.println("*******");
g();
System.out.println("*******");
h();
}
}
/* Output:
f
main
*******
f
g
main
*******
```

f

g

h

main

*/

Here, we just print the method name, but you can also print the entire **StackTraceElement**, which contains additional information.

Rethrowing an Exception

Sometimes you'll rethrow the exception you just caught, particularly when you use **Exception** to catch any exception. Since you already have the reference to the current exception, you can rethrow that reference:

```
catch(Exception e) {
System.out.println("An exception was thrown");
throw e;
}
```

Rethrowing an exception causes it to go to the exception handlers in the next-higher context. Any further **catch** clauses for the same **try** block are still ignored. In addition, everything about the exception object is preserved, so the handler at the higher context that catches

the specific exception type can extract all the information from that object.

If you rethrow the current exception, the information you print about that exception in **printStackTrace()** will pertain to the exception's origin, not the place where you rethrow it. To install new stack trace information, you can call **fillInStackTrace()**, which returns a **Throwable** object it creates by stuffing the current stack information into the old exception object. Here's what it looks like:

```
// exceptions/Rethrowing.java
// Demonstrating fillInStackTrace()
public class Rethrowing {
public static void f() throws Exception {
System.out.println(
"originating the exception in f()");
throw new Exception("thrown from f()");
}
public static void g() throws Exception {
try {
f();
} catch(Exception e) {
```

```
System.out.println(
"Inside g(), e.printStackTrace()");
e.printStackTrace(System.out);
throw e;
}
}
public static void h() throws Exception {
try {
f();
} catch(Exception e) {
System.out.println(
"Inside h(), e.printStackTrace()");
e.printStackTrace(System.out);
throw (Exception)e.fillInStackTrace();
}
}
public static void main(String[] args) {
try {
g();
} catch(Exception e) {
```

```
System.out.println("main: printStackTrace()");
e.printStackTrace(System.out);
}
try {
h();
} catch(Exception e) {
System.out.println("main: printStackTrace()");
e.printStackTrace(System.out);
}
}
}
/* Output:
originating the exception in f()
Inside g(), e.printStackTrace()
java.lang.Exception: thrown from f()
at Rethrowing.f(Rethrowing.java:8)
at Rethrowing.g(Rethrowing.java:12)
at Rethrowing.main(Rethrowing.java:32)
main: printStackTrace()
java.lang.Exception: thrown from f()
```

at Rethrowing.f(Rethrowing.java:8)

at Rethrowing.g(Rethrowing.java:12)

at Rethrowing.main(Rethrowing.java:32)

originating the exception in f()

Inside h(), e.printStackTrace()

java.lang.Exception: thrown from f()

at Rethrowing.f(Rethrowing.java:8)

at Rethrowing.h(Rethrowing.java:22)

at Rethrowing.main(Rethrowing.java:38)

main: printStackTrace()

java.lang.Exception: thrown from f()

at Rethrowing.h(Rethrowing.java:27)

at Rethrowing.main(Rethrowing.java:38)

**/*

The line where **fillInStackTrace()** is called becomes the new point of origin of the exception.

It's also possible to rethrow a different exception from the one you caught. If you do this, you get a similar effect as when you use **fillInStackTrace()**—the information about the original site of the exception is lost, and what you're left with is the information

pertaining to the new **throw**:

```
// exceptions/RethrowNew.java
// Rethrow a different object from the one you caught
class OneException extends Exception {
OneException(String s) { super(s); }
}
class TwoException extends Exception {
TwoException(String s) { super(s); }
}
public class RethrowNew {
public static void f() throws OneException {
System.out.println(
"originating the exception in f()");
throw new OneException("thrown from f()");
}
public static void main(String[] args) {
try {
try {
f();
} catch(OneException e) {
```

```
System.out.println(
"Caught in inner try, e.printStackTrace()");
e.printStackTrace(System.out);
throw new TwoException("from inner try");
}
} catch(TwoException e) {
System.out.println(
"Caught in outer try, e.printStackTrace()");
e.printStackTrace(System.out);
}
}
}
/* Output:
originating the exception in f()
Caught in inner try, e.printStackTrace()
OneException: thrown from f()
at RethrowNew.f(RethrowNew.java:16)
at RethrowNew.main(RethrowNew.java:21)
Caught in outer try, e.printStackTrace()
TwoException: from inner try
```

at RethrowNew.main(RethrowNew.java:26)

*/

The final exception knows only it came from the inner **try** block and not from **f()**.

Don’t worry about cleaning up the previous exception, or any exceptions. They’re all heap-based objects created with **new**, so the garbage collector automatically cleans them all up.

Precise Rethrow

Before Java 7, if you caught an exception, you could only rethrow that type of exception. This caused imprecisions in code that were fixed in Java 7. So before, this would not compile:

// exceptions/PreciseRethrow.java

class BaseException **extends** Exception {}

class DerivedException **extends** BaseException {}

public class PreciseRethrow {

void catcher() **throws** DerivedException {

try {

```
throw new DerivedException();
} catch(BaseException e) {
throw e;
}
}
}
```

Because the **catch** caught a **BaseException**, the compiler forced you to declare that **catcher() throws BaseException**, even though it's actually throwing the more specific **DerivedException**. Since Java 7, this code *does* compile, which is a small but useful fix.

Exception Chaining

Sometimes you catch one exception and throw another, but still keep the information about the originating exception—this is called *exception chaining*. Prior to Java 1.4, programmers wrote their own code to preserve the original exception information, but now all **Throwable** subclasses have the option to take a *cause* object in their constructor. The *cause* is intended as the originating exception, and by passing it in you maintain the stack trace back to its origin, even though you're creating and throwing a new exception.

The only **Throwable** subclasses providing the *cause* argument in the

constructor are the three fundamental exception classes **Error** (used by the JVM to report system errors), **Exception**, and **RuntimeException**. To chain any other exception types, use the **initCause()** method rather than the constructor.

Here's an example that dynamically adds fields to a **DynamicFields** object at run time:

```
// exceptions/DynamicFields.java
// A Class that dynamically adds fields to itself to
// demonstrate exception chaining
class DynamicFieldsException extends Exception {}
public class DynamicFields {
private Object[][] fields;
public DynamicFields(int initialSize) {
fields = new Object[initialSize][2];
for(int i = 0; i < initialSize; i++)
fields[i] = new Object[] { null, null };
}
@Override
public String toString() {
StringBuilder result = new StringBuilder();
```

```
for(Object[] obj : fields) {
result.append(obj[0]);
result.append(": ");
result.append(obj[1]);
result.append("\n");
}
return result.toString();
}
private int hasField(String id) {
for(int i = 0; i < fields.length; i++)
if(id.equals(fields[i][0]))
return i;
return -1;
}
private int getFieldNumber(String id)
throws NoSuchFieldException {
int fieldNum = hasField(id);
if(fieldNum == -1)
throw new NoSuchFieldException();
return fieldNum;
```

```
}
private int makeField(String id) {
for(int i = 0; i < fields.length; i++)
if(fields[i][0] == null) {
fields[i][0] = id;
return i;
}
// No empty fields. Add one:
Object[][] tmp = new Object[fields.length + 1][2];
for(int i = 0; i < fields.length; i++)
tmp[i] = fields[i];
for(int i = fields.length; i < tmp.length; i++)
tmp[i] = new Object[] { null, null };
fields = tmp;
// Recursive call with expanded fields:
return makeField(id);
}
public Object
getField(String id) throws NoSuchFieldException {
return fields[getFieldNumber(id)][1];
```

```
}
public Object setField(String id, Object value)
throws DynamicFieldsException {
if(value == null) {
// Most exceptions don't have a "cause"
// constructor. In these cases you must use
// initCause(), available in all
// Throwable subclasses.
DynamicFieldsException dfe =
new DynamicFieldsException();
dfe.initCause(new NullPointerException());
throw dfe;
}
int fieldNumber = hasField(id);
if(fieldNumber == -1)
fieldNumber = makeField(id);
Object result = null;
try {
result = getField(id); // Get old value
} catch(NoSuchFieldException e) {
```

```
// Use constructor that takes "cause":
throw new RuntimeException(e);
}
fields[fieldNumber][1] = value;
return result;
}
public static void main(String[] args) {
DynamicFields df = new DynamicFields(3);
System.out.println(df);
try {
df.setField("d", "A value for d");
df.setField("number", 47);
df.setField("number2", 48);
System.out.println(df);
df.setField("d", "A new value for d");
df.setField("number3", 11);
System.out.println("df: " + df);
System.out.println("df.getField(\"d\") : "
+ df.getField("d"));
Object field =
```

```
df.setField("d", null); // Exception
} catch(NoSuchFieldException |
DynamicFieldsException e) {
e.printStackTrace(System.out);
}
}
}
/* Output:
null: null
null: null
null: null
d: A value for d
number: 47
number2: 48
df: d: A new value for d
number: 47
number2: 48
number3: 11
df.getField("d") : A new value for d
DynamicFieldsException
```

at

DynamicFields.setField(DynamicFields.java:65)

at DynamicFields.main(DynamicFields.java:97)

Caused by: java.lang.NullPointerException

at

DynamicFields.setField(DynamicFields.java:67)

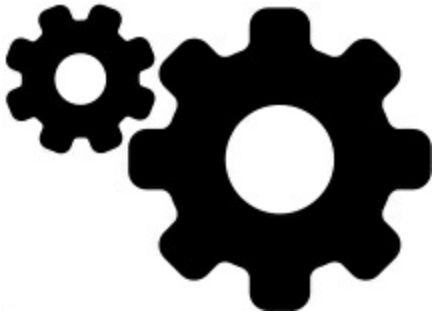
... 1 more

**/*

Each **DynamicFields** object contains an array of **Object-Object** pairs. The first object is the field identifier (a **String**), and the second is the field value, which can be any type except an unwrapped primitive. When you create the object, you make an educated guess about how many fields you need. When you call **setField()**, it either finds the existing field by that name or creates a new one, and puts in your value. If it runs out of space, it adds new space by creating an array of length one longer and copying the old elements in. If you try to put in a **null** value, it throws a **DynamicFieldsException** by creating one and using **initCause()** to insert a **NullPointerException** as the cause.

As a return value, **setField()** also fetches out the old value at that

field location using **getField()**, which could throw a **NoSuchFieldException**. If the client programmer calls **getField()**, they are responsible for handling



NoSuchFieldException, but if this exception is thrown inside **setField()**, it's a programming error, so the **NoSuchFieldException** is converted to a **RuntimeException** using the constructor that takes a *cause* argument.

You'll notice that **toString()** uses a **StringBuilder** to create its result. You'll learn more about **StringBuilder** in the Strings chapter, but in general you'll use it whenever you're writing a **toString()** that involves looping, as is the case here.

The **catch** clause in **main()** looks different—it handles *two* different types of exceptions with the same clause, combined with an "OR" symbol. This Java 7 feature helps reduce code duplication and makes it easier to specify the exact types you are catching, rather than simply catching a base type. You can combine numerous exception

types this way.

Standard Java

Exceptions

The Java class **Throwable** describes anything that can be thrown as an exception. There are two general types of **Throwable** objects ("types of" = "inherited from"). **Error** represents compile-time and system errors you don't worry about catching (except in very special cases). **Exception** is the basic type that can be thrown from any of the standard Java library class methods and from your methods and runtime accidents. So the Java programmer's base type of interest is usually **Exception**.

The best way to get an overview of the exceptions is to browse the JDK

documentation. It's worth doing this once just to get a feel for the various exceptions, but you'll soon see there isn't anything special between one exception and the next except for the name. Also, the number of exceptions in Java keeps expanding; basically, it's pointless to put them in a book. Any new library you get from a third-party

vendor will probably have its own exceptions as well. The important thing to understand is the concept and what to do with the exceptions. The basic idea is that the name of the exception represents the problem that occurred. The exception name should be relatively self-explanatory. The exceptions are not all defined in **java.lang**; some are created to support other libraries such as **util**, **net**, and **io**, which you see from their full class names or their base classes. For example, all I/O exceptions are inherited from **java.io.IOException**.

Special Case: RuntimeException

The first example in this chapter was

```
if(t == null)
throw new NullPointerException();
```

It can be a bit horrifying to think you must check for **null** on every reference that is passed into a method (since you can't know if the caller has passed you a valid reference). Fortunately, you don't—this is part of the standard runtime checking that Java performs for you, and if any call is made to a **null** reference, Java will automatically throw a **NullPointerException**. So the above bit of code is always superfluous, although you might perform other checks to guard

against the appearance of a **NullPointerException**.

There's a whole group of exception types in this category. They're always thrown automatically by Java and you don't include them in your exception specifications. Conveniently enough, they're all grouped together by putting them under a single base class called **RuntimeException**, a perfect example of inheritance: It establishes a family of types that have some characteristics and behaviors in common.

A **RuntimeException** represents a programming error, which is:

1. An error you cannot anticipate. For example, a **null** reference that is outside of your control.
2. An error that you, as a programmer, should have checked for in your code (such as **ArrayIndexOutOfBoundsException** where you should pay attention to the size of the array). An exception that happens from point #1 often becomes an issue for point #2.

Exceptions are a tremendous benefit here, since they help in the debugging process.

You never write an exception specification saying that a method might throw a **RuntimeException** (or any type inherited from

RuntimeException), because they are *unchecked exceptions*. Because they indicate bugs, you don't usually catch a **RuntimeException**—it's dealt with automatically. If you were forced to check for **RuntimeException**s, your code could get too messy. Even though you don't typically catch **RuntimeException**s, in your own packages you might choose to throw some **RuntimeException**s.

What happens when you don't catch such exceptions? Since the compiler doesn't enforce exception specifications for these, it's plausible that a **RuntimeException** could percolate all the way out to your **main()** method without being caught:

```
// exceptions/NeverCaught.java
// Ignoring RuntimeExceptions
// {ThrowsException}
public class NeverCaught {
static void f() {
throw new RuntimeException("From f()");
}
static void g() {
f();
```

```
}
public static void main(String[] args) {
g();
}
}
/* Output:
___[ Error Output ]___
Exception in thread "main" java.lang.RuntimeException:
From f()
at NeverCaught.f(NeverCaught.java:7)
at NeverCaught.g(NeverCaught.java:10)
at NeverCaught.main(NeverCaught.java:13)
*/
```

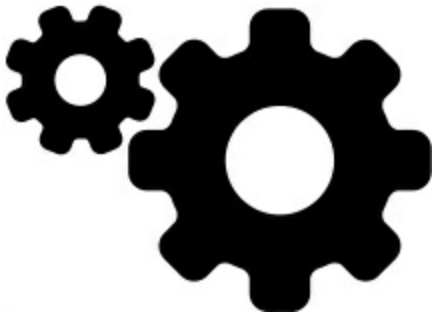
If a **RuntimeException** gets all the way out to **main()** without being caught, **printStackTrace()** is called for that exception as the program exits.

You can see that a **RuntimeException** (or anything inherited from it) is a special case, since the compiler doesn't require an exception specification for these types. The output is reported to **System.err**.

Keep in mind that only exceptions of type **RuntimeException** (and

subclasses) can be ignored in your coding, since the compiler carefully enforces the handling of all checked exceptions.

You cannot classify Java exception handling as a single-purpose tool. Yes, it is designed to handle those pesky runtime errors that occur from forces outside your code's control, but it's also essential for



certain types of programming bugs that the compiler cannot detect.

Performing Cleanup

with finally

There's often a piece of code you must execute whether or not an exception is thrown within a **try** block. This usually pertains to an operation other than memory recovery (since that's taken care of by the garbage collector). To achieve this effect, you use a **finally** clause[4] at the end of all the exception handlers. The full picture of exception-handling is thus:

try {

// The guarded region: Dangerous activities

// that might throw A, B, or C

} **catch**(A a1) {

// Handler for situation A

} **catch**(B b1) {

// Handler for situation B

} **catch**(C c1) {

// Handler for situation C

} **finally** {

// Activities that happen every time

}

This program demonstrate that the **finally** clause always runs:

// exceptions/FinallyWorks.java

// The finally clause is always executed

class ThreeException **extends** Exception {}

public class FinallyWorks {

static int count = 0;

public static void main(String[] args) {

while(**true**) {

```
try {
// Post-increment is zero first time:
if(count++ == 0)
throw new ThreeException();
System.out.println("No exception");
} catch(ThreeException e) {
System.out.println("ThreeException");
} finally {
System.out.println("In finally clause");
if(count == 2) break; // out of "while"
}
}
}
}
/* Output:
ThreeException
In finally clause
```

No exception

In finally clause

*/

From the output you see that the **finally** clause is executed whether or not an exception is thrown. There's also a hint for dealing with the fact that exceptions in Java do not allow you to resume back to where the exception was thrown, as discussed earlier. If you place your **try** block in a loop, you can establish a condition that must be met before you continue the program. You can also add a **static** counter or some other device to allow the loop to try several different approaches before giving up. This way you can build a greater level of robustness into your programs.

What's finally for?

In a language without garbage collection *and* without automatic destructor calls,[5] **finally** is important because it allows the programmer to guarantee the release of memory regardless of what happens in the **try** block. But Java has garbage collection, so releasing memory is virtually never a problem. Also, it has no destructors to call. So when do you use **finally** in Java?

The **finally** clause is necessary to clean up something *other* than memory. Examples include an open file or network connection,

something you’ve drawn on the screen, or even a switch in the outside world:

```
// exceptions/Switch.java
public class Switch {
private boolean state = false;
public boolean read() { return state; }
public void on() {
state = true;
System.out.println(this);
}
public void off() {
state = false;
System.out.println(this);
}
@Override
public String toString() {
return state ? "on" : "off";
}
}
```

```
// exceptions/OnOffException1.java
```

```
public class OnOffException1 extends Exception {}
// exceptions/OnOffException2.java
public class OnOffException2 extends Exception {}
// exceptions/OnOffSwitch.java
// Why use finally?
public class OnOffSwitch {
private static Switch sw = new Switch();
public static void f()
throws OnOffException1, OnOffException2 {}
public static void main(String[] args) {
try {
sw.on();
// Code that can throw exceptions...
f();
sw.off();
} catch(OnOffException1 e) {
System.out.println("OnOffException1");
sw.off();
} catch(OnOffException2 e) {
System.out.println("OnOffException2");
```

```
sw.off();
}
}
}
/* Output:
on
off
*/
```

The goal here is to make sure the switch is off when **main()** completes, so **sw.off()** is placed at the end of the **try** block and at the end of each exception handler. But an exception might be thrown that isn't caught here, so **sw.off()** would be missed. However, with **finally** you can place the cleanup code from a **try** block in just one place:

```
// exceptions/WithFinally.java
// Finally Guarantees cleanup
public class WithFinally {
static Switch sw = new Switch();
public static void main(String[] args) {
try {
```

```
sw.on();
// Code that can throw exceptions...
OnOffSwitch.f();
} catch(OnOffException1 e) {
System.out.println("OnOffException1");
} catch(OnOffException2 e) {
System.out.println("OnOffException2");
} finally {
sw.off();
}
}
}
/* Output:
on
off
*/
```

Here **sw.off()** is guaranteed to run no matter what happens.

Even in cases when the exception is not caught in the current set of **catch** clauses, **finally** is executed before the exception-handling mechanism continues its search for a handler at the next higher level:

```
// exceptions/AlwaysFinally.java
// Finally is always executed
class FourException extends Exception {}
public class AlwaysFinally {
public static void main(String[] args) {
System.out.println("Entering first try block");
try {
System.out.println("Entering second try block");
try {
throw new FourException();
} finally {
System.out.println("finally in 2nd try block");
}
} catch(FourException e) {
System.out.println(
```

```
"Caught FourException in 1st try block");
} finally {
```

```
System.out.println("finally in 1st try block");
}
}
}
/* Output:
Entering first try block
Entering second try block
finally in 2nd try block
Caught FourException in 1st try block
finally in 1st try block
*/
```

The **finally** statement is also executed when **break** and **continue** statements are involved. Together with the labeled **break** and labeled **continue**, **finally** eliminates the need for a **goto** statement in Java.

Using finally During return

Because a **finally** clause is always executed, it’s possible to return from multiple points within a method and still guarantee that important cleanup is performed:

```
// exceptions/MultipleReturns.java
```

```
public class MultipleReturns {
public static void f(int i) {
System.out.println(
"Initialization that requires cleanup");
try {
System.out.println("Point 1");
if(i == 1) return;
System.out.println("Point 2");
if(i == 2) return;
System.out.println("Point 3");
if(i == 3) return;
```

```
System.out.println("End");
return;
} finally {
System.out.println("Performing cleanup");
}
}
```

```
public static void main(String[] args) {
for(int i = 1; i <= 4; i++)
f(i);
}
}
/* Output:
Initialization that requires cleanup
Point 1
Performing cleanup
Initialization that requires cleanup
Point 1
Point 2
Performing cleanup
Initialization that requires cleanup
Point 1
Point 2
Point 3
Performing cleanup
Initialization that requires cleanup
Point 1
```

Point 2

Point 3

End

Performing cleanup

*/

The output shows it doesn’t matter where you return, the **finally** clause always runs.

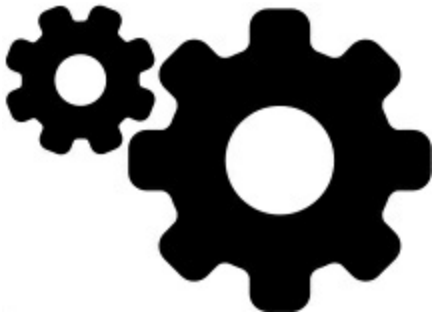
Pitfall: the Lost Exception

Unfortunately, there’s a flaw in Java’s exception implementation. Although exceptions are an indication of a crisis in your program and should never be ignored, it’s possible for an exception to be lost. This happens with a particular configuration using a **finally** clause:

```
// exceptions/LostMessage.java
// How an exception can be lost
class VeryImportantException extends Exception {
@Override
public String toString() {
return "A very important exception!";
}
}
```

```
class HoHumException extends Exception {
@Override
public String toString() {
return "A trivial exception";
}
}
public class LostMessage {
void f() throws VeryImportantException {
throw new VeryImportantException();
}
void dispose() throws HoHumException {
throw new HoHumException();
}
public static void main(String[] args) {
try {
LostMessage lm = new LostMessage();
try {
lm.f();
} finally {
lm.dispose();
```

```
}
} catch(VeryImportantException |
HoHumException e) {
System.out.println(e);
}
}
}
/* Output:
```



A trivial exception

*/

The output shows no evidence of the **VeryImportantException**, which is replaced by the **HoHumException** in the **finally** clause. This is a rather serious pitfall, since it means an exception can be completely lost, and in a far more subtle and difficult-to-detect fashion than the preceding example. In contrast, C++ treats the situation where a second exception is thrown before the first one is handled as a

dire programming error. Perhaps a future version of Java will repair this problem (on the other hand, you typically wrap any method that throws an exception, such as **dispose()** in the example above, inside a **try-catch** clause).

An even simpler way to lose an exception is just to **return** from inside a **finally** clause:

```
// exceptions/ExceptionSilencer.java
public class ExceptionSilencer {
public static void main(String[] args) {
try {
throw new RuntimeException();
} finally {
// Using 'return' inside the finally block
// will silence any thrown exception.
return;
}
}
}
```

If you run this program you'll see it produces no output, even though an exception is thrown.

Exception Restrictions

When you override a method, you can throw only the exceptions specified in the base-class version of the method. This is a useful restriction, since it means code that works with the base class will automatically work with any object derived it (a fundamental OOP concept), including exceptions.

This example demonstrates the kinds of restrictions imposed (at compile time) for exceptions:

```
// exceptions/StormyInning.java
// Overridden methods can throw only the exceptions
// specified in their base-class versions, or exceptions
// derived from the base-class exceptions
class BaseballException extends Exception {}
class Foul extends BaseballException {}
class Strike extends BaseballException {}
abstract class Inning {
Inning() throws BaseballException {}
public void event() throws BaseballException {
// Doesn't actually have to throw anything
}
```

```
public abstract void atBat() throws Strike, Foul;
public void walk() {} // Throws no checked exceptions
}
class StormException extends Exception {}
class RainedOut extends StormException {}
class PopFoul extends Foul {}
interface Storm {
void event() throws RainedOut;
void rainHard() throws RainedOut;
}
public
class StormyInning extends Inning implements Storm {
// OK to add new exceptions for constructors, but you
// must deal with the base constructor exceptions:
public StormyInning()
throws RainedOut, BaseballException {}
public StormyInning(String s)
throws BaseballException {}
// Regular methods must conform to base class:
//- void walk() throws PopFoul {} //Compile error
```

```
// Interface CANNOT add exceptions to existing
// methods from the base class:
//- public void event() throws RainedOut {}
// If the method doesn't already exist in the
// base class, the exception is OK:
@Override
public void rainHard() throws RainedOut {}
// You can choose to not throw any exceptions,
// even if the base version does:
@Override
public void event() {}
// Overridden methods can throw inherited exceptions:
@Override
public void atBat() throws PopFoul {}
public static void main(String[] args) {
try {
StormyInning si = new StormyInning();
si.atBat();
} catch(PopFoul e) {
System.out.println("Pop foul");
```

```
} catch(RainedOut e) {
System.out.println("Rained out");
} catch(BaseballException e) {
System.out.println("Generic baseball exception");
}
// Strike not thrown in derived version.
try {
// What happens if you upcast?
Inning i = new StormyInning();
i.atBat();
// You must catch the exceptions from the
// base-class version of the method:
} catch(Strike e) {
System.out.println("Strike");
} catch(Foul e) {
System.out.println("Foul");
} catch(RainedOut e) {
System.out.println("Rained out");
} catch(BaseballException e) {
System.out.println("Generic baseball exception");
```

}

}

}

In **Inning**, you see that both the constructor and the **event()** method say they will throw an exception, but they never do. This is legal because it forces the user to catch any exceptions that might be added in overridden versions of **event()**. The same idea holds for **abstract** methods, as seen in **atBat()**.

The interface **Storm** contains one method (**event()**) that is defined in **Inning**, and one method that isn't. Both methods throw a new type of exception, **RainedOut**. When **StormyInning extends Inning** and **implements Storm**, the **event()** method in **Storm** *cannot* change the exception interface of **event()** in **Inning**. Again, this makes sense because otherwise you'd never know if you were catching the correct thing when working with the base class. However, if a method described in an interface is not in the base class, such as **rainHard()**, there's no problem if it throws exceptions.

The restriction on exceptions does not apply to constructors. **StormyInning** shows that a constructor can throw anything it

wants, regardless of what the base-class constructor throws. However, since a base-class constructor must always be called one way or another (here, the no-arg constructor is called automatically), the derived-class constructor must declare any base-class constructor exceptions in its exception specification.

A derived-class constructor cannot catch exceptions thrown by its base-class constructor.

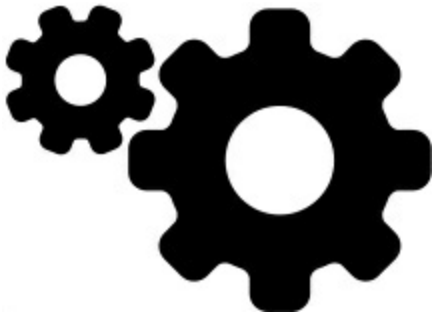
The reason **StormyInning.walk()** will not compile is that it throws an exception, but **Inning.walk()** does not. If this were allowed, you could write code that called **Inning.walk()** without handling any exceptions. However, when you substituted an object of a class derived from **Inning**, exceptions would be thrown so your code would break. By forcing the derived-class methods to conform to the exception specifications of the base-class methods, substitutability of objects is maintained.

The overridden **event()** method shows that a derived-class version of a method can choose not to throw any exceptions, even if the base-class version does. Again, this is fine since it doesn't break code that is written assuming the base-class version throws exceptions. Similar logic applies to **atBat()**, which throws **PopFoul**, an exception that

is derived from **Foul** thrown by the base-class version of **atBat()**. This way, if you write code that works with **Inning** and calls **atBat()**, you must catch the **Foul** exception. Since **PopFoul** is derived from **Foul**, the exception handler will also catch **PopFoul**.

The last point of interest is in **main()**. Notice that if you're dealing with exactly a **StormyInning** object, the compiler forces you to catch only the exceptions specific to that class, but if you upcast to the base type, the compiler (correctly) forces you to catch the exceptions for the base type. All these constraints produce much more robust exception-handling code.6

Although exception specifications are enforced by the compiler during inheritance, the exception specifications are not part of the type of a method, which comprises only the method name and argument types. Therefore, you cannot overload methods based on exception specifications. In addition, just because an exception specification exists in a base-class version of a method doesn't mean it must exist in the derived-class version of the method. This is different from inheritance rules, where a method in the base class must also exist in



the derived class. Put another way, the “exception specification interface” for a particular method can narrow during inheritance and overriding, but it cannot widen—this is precisely the opposite of the rule for the class interface during inheritance.

Constructors

It’s important that you always ask, “If an exception occurs, will everything be properly cleaned up?” Most of the time you’re fairly safe, but with constructors there’s a problem. The constructor puts the object into a safe starting state, but it might perform some operation—such as opening a file—that doesn’t get cleaned up until the user is finished with the object and calls a special cleanup method. If you throw an exception from inside a constructor, these cleanup behaviors might not occur properly. This means you must be especially vigilant when writing a constructor.

You might think **finally** is the solution. But it’s not that simple, because **finally** performs the cleanup code *every time*. If a

constructor fails partway through its execution, it might not have successfully created some part of the object that is cleaned up in the **finally** clause.

In the following example, a class called **InputFile** opens a file and reads it one line at a time. It uses the classes **FileReader** and **BufferedReader** from the Java standard I/O library discussed in the Appendix: I/O Streams. These classes are simple enough you probably won't have any trouble understanding their basic use:

```
// exceptions/InputFile.java
// Paying attention to exceptions in constructors
import java.io.*;
public class InputFile {
private BufferedReader in;
public InputFile(String fname) throws Exception {
try {
in = new BufferedReader(new FileReader(fname));
// Other code that might throw exceptions
} catch(FileNotFoundException e) {
System.out.println("Could not open " + fname);
// Wasn't open, so don't close it
throw e;
```

```
} catch(Exception e) {
// All other exceptions must close it
try {
in.close();
} catch(IOException e2) {
System.out.println("in.close() unsuccessful");
}
throw e; // Rethrow
} finally {
// Don't close it here!!!
}
}
public String getLine() {
String s;
try {
s = in.readLine();
} catch(IOException e) {
throw new RuntimeException("readLine() failed");
}
return s;
```

```
}
public void dispose() {
try {
in.close();
System.out.println("dispose() successful");
} catch(IOException e2) {
throw new RuntimeException("in.close() failed");
}
}
}
```

The constructor for **InputFile** takes a **String** argument: the name of the file to open. Inside a **try** block, it creates a **FileReader** using the file name. A **FileReader** isn't particularly useful until you use it to create a **BufferedReader**. One of the benefits of **InputFile** is that it combines these two actions.

If the **FileReader** constructor is unsuccessful, it throws a **FileNotFoundException**. This is the one case when you don't close the file, because it wasn't successfully opened. Any *other* **catch** clauses must close the file because it *was* opened by the time those **catch** clauses are entered. (This gets trickier if more than one method can throw a **FileNotFoundException**. In that case,

you'll usually break things into several **try** blocks.) The **close()** method might throw an exception so it is tried and caught even though it's within the block of another **catch** clause—it's just another pair of curly braces to the Java compiler. After performing local operations, the exception is rethrown, which is appropriate because this constructor failed, and you don't want the calling method to assume that the object was properly created and is valid.

In this example, the **finally** clause is definitely *not* the place to **close()** the file, since that would close it every time the constructor completed. We want the file to be open for the useful lifetime of the **InputFile** object.

The **getLine()** method returns a **String** containing the next line in the file. It calls **readLine()**, which can throw an exception, but that exception is caught so **getLine()** doesn't throw any exceptions.

One of the design issues with exceptions is whether to handle an exception completely at this level, to handle it partially and pass the same exception (or a different one) on, or whether to simply pass it on. Passing it on, when appropriate, can certainly simplify coding. In this situation, the **getLine()** method *converts* the exception to a **RuntimeException** to indicate a programming error.

The **dispose()** method must be called by the user when the **InputFile** object is no longer needed. This will release the system resources (such as file handles) used by the **BufferedReader** and/or **FileReader** objects. You don't do this until you're finished with the **InputFile** object. You might think of putting such functionality into a **finalize()** method, but as mentioned in the Housekeeping chapter, you can't always be sure that **finalize()** is called (even if you *can* be sure it gets called, you don't know *when*).

This is one of the downsides to Java: All cleanup—other than memory cleanup—doesn't happen automatically, so you must inform the client programmers they are responsible.

The safest way to use a class which might throw an exception during construction and which requires cleanup is to use nested **try** blocks:

```
// exceptions/Cleanup.java
// Guaranteeing proper cleanup of a resource
public class Cleanup {
public static void main(String[] args) {
try {
InputFile in = new InputFile("Cleanup.java");
try {
String s;
```

```
int i = 1;
while((s = in.getLine()) != null)
; // Perform line-by-line processing here...
} catch(Exception e) {
System.out.println("Caught Exception in main");
e.printStackTrace(System.out);
} finally {
in.dispose();
}
} catch(Exception e) {
System.out.println(
"InputFile construction failed");
}
}
}
/* Output:
dispose() successful
*/
```

Look carefully at the logic here: The construction of the **InputFile** object is effectively in its own **try** block. If that construction fails, the

outer **catch** clause is entered and **dispose()** is not called.

However, if construction succeeds then you must ensure the object is cleaned up, so immediately after construction you create a new **try** block. The **finally** that performs cleanup is associated with the *inner* **try** block; this way, the **finally** clause is not executed if construction fails, and it is *always* executed if construction succeeds. This general cleanup idiom should still be used if the constructor throws no exceptions. The basic rule is: Right after you create an object that requires cleanup, begin a **try-finally**:

```
// exceptions/CleanupIdiom.java
// Disposable objects must be followed by a try-finally
class NeedsCleanup { // Construction can't fail
private static long counter = 1;
private final long id = counter++;
public void dispose() {
System.out.println(
"NeedsCleanup " + id + " disposed");
}
}
class ConstructionException extends Exception {}
```

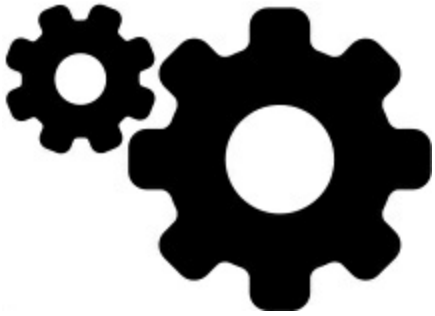
```
class NeedsCleanup2 extends NeedsCleanup {
// Construction can fail:
NeedsCleanup2() throws ConstructionException {}
}
public class CleanupIdiom {
public static void main(String[] args) {
// [1]:
NeedsCleanup nc1 = new NeedsCleanup();
try {
// ...
} finally {
nc1.dispose();
}
// [2]:
// If construction cannot fail,
// you can group objects:
NeedsCleanup nc2 = new NeedsCleanup();
NeedsCleanup nc3 = new NeedsCleanup();
try {
// ...
```

```
} finally {
nc3.dispose(); // Reverse order of construction
nc2.dispose();
}
// [3]:
// If construction can fail you must guard each one:
try {
NeedsCleanup2 nc4 = new NeedsCleanup2();
try {
NeedsCleanup2 nc5 = new NeedsCleanup2();
try {
// ...
} finally {
nc5.dispose();
}
} catch(ConstructionException e) { // nc5 const.
System.out.println(e);
} finally {
nc4.dispose();
}
```

} **catch**(ConstructionException e) { *// nc4 const.*

System.out.println(e);

}



}

}

/ *Output:*

NeedsCleanup 1 disposed

NeedsCleanup 3 disposed

NeedsCleanup 2 disposed

NeedsCleanup 5 disposed

NeedsCleanup 4 disposed

**/*

[1] This is fairly straightforward: You follow a disposable object with a **try-finally**. If the object construction cannot fail, no **catch** is necessary.

[2] Here you see objects with constructors that cannot fail

grouped together for both construction and cleanup.

[3] This shows how to deal with objects whose constructors can fail *and* which need cleanup. To properly handle this situation, things get messy, because you must surround each construction with its own **try-catch**, and each object construction must be followed by a **try-finally** to guarantee cleanup.

The messiness of exception handling here is a strong argument for creating constructors that cannot fail, although this is not always possible.

Note that if **dispose()** can throw an exception you might need additional **try** blocks. Basically, you must think carefully about all the possibilities and guard for each one.

Try-With-Resources

The last section might have made your head spin a bit. Figuring out where to put all the **try-catch-finally** blocks becomes intimidating when considering all the ways something can fail. It seems quite challenging to ensure that none of the failure paths leave your system in an unstable state.

InputFile.java is a particularly thorny case, because the file is opened (with all the possible exceptions from that), then it is *left open*

for the lifetime of the object. Each call to **getLine()** can cause an exception, and so can **dispose()**. This is a good example only because it shows how messy things can be. It also demonstrates that you should try your best *not* to design your code that way (of course, you often get into situations when it's not your choice how the code is designed, so you must still understand it).

A better design for **InputFile.java** is if the constructor reads the file and buffers it internally—that way, the opening, reading, and closing of the file all happen in the constructor. Or, if reading and storing the file is impractical, you can instead produce a **Stream**. Ideally you'd design it more like this:

```
// exceptions/InputFile2.java
import java.io.*;
import java.nio.file.*;
import java.util.stream.*;
public class InputFile2 {
private String fname;
public InputFile2(String fname) {
this.fname = fname;
}
```

```
public
Stream<String> getLines() throws IOException {
return Files.lines(Paths.get(fname));
}
public static void
main(String[] args) throws IOException {
new InputFile2("InputFile2.java").getLines()
.skip(15)
.limit(1)
.forEach(System.out::println);
}
}
/* Output:
main(String[] args) throws IOException {
*/
```

Now **getLines()** is solely responsible for opening the file and creating the **Stream**.

You can’t always sidestep the problem this easily. Sometimes there are objects that:

1. Need cleanup.

2. Need cleanup at a particular moment, when you go out of a scope

(by normal means or via an exception).

A common example is **java.io.FileInputStream** (described in

the Appendix: I/O Streams). To use it properly, you must write some tricky boilerplate code:

```
// exceptions/MessyExceptions.java

import java.io.*;

public class MessyExceptions {

public static void main(String[] args) {

InputStream in = null;

try {

in = new FileInputStream(

new File("MessyExceptions.java"));

int contents = in.read();

// Process contents

} catch(IOException e) {

// Handle the error

} finally {

if(in != null) {

try {

in.close();
```

```
} catch(IOException e) {
// Handle the close() error
}
}
}
}
}
```

When the **finally** clause has its own **try** block, it feels like things have become overcomplicated.

Fortunately Java 7 introduces the *try-with-resources* syntax, which cleans up the above code remarkably well:

```
// exceptions/TryWithResources.java
import java.io.*;
public class TryWithResources {
public static void main(String[] args) {
try(
InputStream in = new FileInputStream(
new File("TryWithResources.java"))
) {
int contents = in.read();
```

```
// Process contents
} catch(IOException e) {
// Handle the error
}
}
}
```

Before Java 7, a **try** was always followed by a **{**, but now it can be followed by a parenthesized definition—here our creation of the **FileInputStream** object. The part within parentheses is called the *resource specification header*. Now **in** is available throughout the rest of the **try** block. More importantly, no matter how you exit the **try** block (normally or via exception), the equivalent of the previous **finally** clause is executed, but without writing that messy and tricky code. This is an important improvement.

How does it work? The objects created in the try-with-resources definition clause (within the parentheses) must implement the **java.lang.AutoCloseable interface**, which has a single method, **close()**. When **AutoCloseable** was introduced in Java 7, many interfaces and classes were modified to implement it; look at the Javadocs for **AutoCloseable** to see a list, which includes

Stream objects:

```
// exceptions/StreamsAreAutoCloseable.java
import java.io.*;
import java.nio.file.*;
import java.util.stream.*;
public class StreamsAreAutoCloseable {
public static void
main(String[] args) throws IOException{
try(
Stream<String> in = Files.lines(
Paths.get("StreamsAreAutoCloseable.java"));
PrintWriter outfile = new PrintWriter(
"Results.txt"); // [1]
) {
in.skip(5)
.limit(1)
.map(String::toLowerCase)
.forEachOrdered(outfile::println);
} // [2]
}
```

}

[1] You can see another feature here: the resource specification header can contain multiple definitions, separated by semicolons (the final semicolon is accepted but optional). Each object defined in the header will have its **close()** called at the end of the **try** block.

[2] The **try** block for try-with-resources can stand alone,

without a **catch** or **finally**. Here, the **IOException** is passed out through **main()** so it doesn't have to be caught at the end of the **try**.

The Java 5 **Closeable** interface was modified to inherit from **AutoCloseable**, so anything that historically supports **Closeable** is also supported by try-with-resources.

Revealing the Details

To investigate the underlying mechanisms of try-with-resources, we'll create our own **AutoCloseable** classes:

// exceptions/AutoCloseableDetails.java

```
class Reporter implements AutoCloseable {
String name = getClass().getSimpleName();
Reporter() {
System.out.println("Creating " + name);
}
public void close() {
System.out.println("Closing " + name);
}
}
class First extends Reporter {}
class Second extends Reporter {}
public class AutoCloseableDetails {
public static void main(String[] args) {
try(
First f = new First();
Second s = new Second()
) {
}
}
}
```

/ *Output:*

Creating First

Creating Second

Closing Second

Closing First

**/*

Exiting the **try** block calls **close()** for both objects *and* it closes them in reverse order of creation. The order is important because in this configuration the **Second** object might depend on the **First** object, so if **First** is already closed by the time **Second** closes, **Second**s **close()** might try to access some feature of **First** which is no longer available.

Suppose we define an object within the resource specification header that is *not* **AutoCloseable**:

// exceptions/TryAnything.java

// {WillNotCompile}

class Anything {}

public class TryAnything {

public static void main(String[] args) {

try(

```
Anything a = new Anything()
) {
}
}
}
```

As we hope and expect, Java won't let us do it and emits a compile-time error.

What if one of the constructors throws an exception?

```
// exceptions/ConstructorException.java
class CE extends Exception {}
class SecondExcept extends Reporter {
SecondExcept() throws CE {
super();
throw new CE();
}
}
public class ConstructorException {
public static void main(String[] args) {
try(
First f = new First();
```

```
SecondExcept s = new SecondExcept();
Second s2 = new Second()
) {
System.out.println("In body");
} catch(CE e) {
System.out.println("Caught: " + e);
}
}
}
/* Output:
Creating First
Creating SecondExcept
Closing First
Caught: CE
*/
```

Now there are three objects defined in the resource specification header, and the middle one throws an exception. Because of this, the compiler forces us to have a **catch** clause to catch the constructor exception. This means the resource specification header is actually enclosed by the **try** block.

As expected, **First** is created without incident, and **SecondExcept**

throws an exception during creation. Notice that **close()** is *not*

called for **SecondExcept**, because if your constructor fails you can't

assume you can do *anything* safely with that object, including close it.

Because of the exception from **SecondExcept**, the **Second** object **s2** is never created, so it is not cleaned up.

If no constructors throw exceptions but you might get them in the

body of the **try**, you are again forced to provide a **catch** clause:

```
// exceptions/BodyException.java
class Third extends Reporter {}
public class BodyException {
public static void main(String[] args) {
try(
First f = new First();
Second s2 = new Second()
) {
System.out.println("In body");
Third t = new Third();
new SecondExcept();
System.out.println("End of body");
} catch(CE e) {
```

```
System.out.println("Caught: " + e);
}
}
}
/* Output:
Creating First
Creating Second
In body
Creating Third
Creating SecondExcept
Closing Second
Closing First
Caught: CE
*/
```

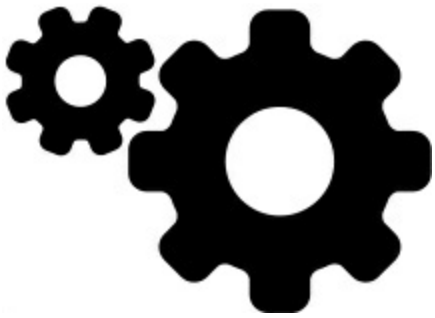
Notice that the **Third** object never gets cleaned up. That’s because it was not created inside the resource specification header, so it is not guarded. This is important, because Java provides no guidance here in the form of warnings or errors, so a mistake like this can easily slip through. Indeed, if you rely on some of the integrated development environments to automatically rewrite code to use try-with-resources,

they will (at the time of this writing) typically only guard the first object they come across, and miss the rest.

Finally, let's look at **close()** methods that throw exceptions:

```
// exceptions/CloseExceptions.java
class CloseException extends Exception {}
class Reporter2 implements AutoCloseable {
String name = getClass().getSimpleName();
Reporter2() {
System.out.println("Creating " + name);
}
public void close() throws CloseException {
System.out.println("Closing " + name);
}
}
class Closer extends Reporter2 {
@Override
public void close() throws CloseException {
super.close();
throw new CloseException();
}
```

```
}
public class CloseExceptions {
public static void main(String[] args) {
try(
First f = new First();
Closer c = new Closer();
Second s = new Second()
) {
System.out.println("In body");
} catch(CloseException e) {
System.out.println("Caught: " + e);
}
}
}
```



```
/* Output:
Creating First
```

Creating Closer

Creating Second

In body

Closing Second

Closing Closer

Closing First

Caught: CloseException

*/

Technically we're not forced to provide a **catch** clause here; you can instead report that **main() throws CloseException**. But the **catch** clause is the typical place to put the error-handling code.

Notice that, because all three objects were created, they are all closed—in reverse order—even though **Closer.close()** throws an exception. When you think about it, this is what you want to happen, but if you must code all that logic yourself, you might miss something and get it wrong. Imagine all the code that's out there where the programmers didn't think through all the implications of cleanup, and did it wrong. For that reason you should always use try-with-resources whenever you can. It helps a lot that the feature also makes the resulting code much cleaner and easier to understand.

Exception Matching

When an exception is thrown, the exception-handling system looks through the “nearest” handlers in the order they are written. When it finds a match, the exception is considered handled, and no further searching occurs.

Matching an exception doesn’t require a perfect match between the exception and its handler. A derived-class object will match a handler for the base class:

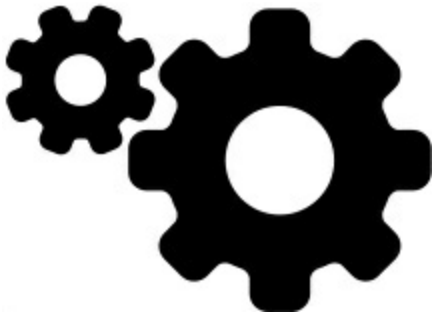
```
// exceptions/Human.java
// Catching exception hierarchies
class Annoyance extends Exception {}
class Sneeze extends Annoyance {}
public class Human {
public static void main(String[] args) {
// Catch the exact type:
try {
throw new Sneeze();
} catch(Sneeze s) {
System.out.println("Caught Sneeze");
} catch(Annoyance a) {
```

```
System.out.println("Caught Annoyance");
}
// Catch the base type:
try {
throw new Sneeze();
} catch(Annoyance a) {
System.out.println("Caught Annoyance");
}
}
}
/* Output:
Caught Sneeze
Caught Annoyance
*/
```

The **Sneeze** exception is caught by the first **catch** clause it matches, which is the first one in the sequence. However, if you remove the first **catch** clause, leaving only the **catch** clause for **Annoyance**, the code still works because it's catching the base class of **Sneeze**. Put another way, **catch(Annoyance a)** will catch an **Annoyance** *or any class derived from it*. This is useful because if you decide to add

more derived exceptions to a method, the client programmer's code won't need changing as long as the client catches the base-class exceptions.

If you try to "mask" the derived-class exceptions by putting the base-



class **catch** clause first, like this:

```
try {
throw new Sneeze();
} catch(Annoyance a) {
// ...
} catch(Sneeze s) {
// ...
}
```

the compiler will give you an error message, since it sees that the **Sneeze catch** clause can never be reached.

Alternative Approaches

An exception-handling system is a trapdoor that allows your program to abandon execution of the normal sequence of statements. The trapdoor is used when an “exceptional condition” occurs, such that normal execution is no longer possible or desirable. Exceptions represent conditions that the current method is unable to handle. The reason exception-handling systems were developed is because the approach of dealing with each possible error condition produced by each function call was too onerous, and programmers simply weren’t doing it. As a result, they were ignoring the errors. It’s worth observing that the issue of programmer convenience in handling errors was a prime motivation for exceptions in the first place.

One of the important guidelines in exception handling is “Don’t catch an exception unless you know what to do with it.” In fact, one of the important goals of exception handling is to move the error-handling code away from the point where the errors occur. This focuses on your objective in one section of your code, and how you’re going to deal with problems in a distinct separate section of your code. As a result, your mainline code is not cluttered with error-handling logic, and it’s (hypothetically) much easier to understand and maintain. Exception handling also tends to reduce the amount of error-handling code, by

allowing one handler to deal with many error sites.

Checked exceptions complicate this scenario a bit, because they force you to add **catch** clauses in places where you might not be ready to handle an error. This results in the “harmful if swallowed” problem:

```
try {
// ... to do something useful
} catch(ObligatoryException e) {} // Gulp!
```

Programmers (myself included, in the 1st edition of *Thinking in Java*) would just do the simplest thing, and “swallow” the exception—often unintentionally, but once you do it, the compiler is satisfied, so unless you remember to revisit and correct the code, the exception is lost. The exception happens, but it vanishes completely when swallowed.

Because the compiler forces you to write code right away to handle the exception, this seems like the easiest solution even though it’s probably the worst thing you can do.

Horrified upon realizing I had done this, in the 2nd edition of *Thinking in Java*, I “fixed” the problem by printing the stack trace inside the handler (as seen—appropriately—in a number of examples in this chapter). While this is useful to trace the behavior of exceptions, it still indicates you don’t really know what to do with the

exception at that point in your code. In this section you'll learn about some of the issues and complications arising from checked exceptions, and options you have when dealing with them.

This topic seems simple. But it is not only complicated, it is also an issue of some volatility. There are people who are staunchly rooted on either side of the fence and who feel that the correct answer (theirs) is blatantly obvious. I believe the reason for one of these positions is the distinct benefit seen in going from a poorly typed language like pre-ANSI C to a strong, statically typed language (that is, checked at compile time) like C++ or Java. When you make that transition (as I did), the benefits are so dramatic it can seem like static type checking

is always the best answer to most problems. My hope is to relate a little bit of my own evolution that has brought the *absolute* value of static type checking into question; clearly, it's very helpful much of the time, but there's a fuzzy line we cross when it begins to get in the way and become a hindrance (one of my favorite quotes is "All models are wrong. Some are useful.").

History

Exception handling originated in systems like PL/1 and Mesa, and later appeared in CLU, SmallTalk, Modula-3, Ada, Eiffel, C++, Python, Java, and the post-Java languages Ruby and C#. The Java design is similar to C++, except in places where the Java designers felt that the C++ approach caused problems.

To provide programmers with a framework they were more likely to use for error handling and recovery, exception handling was added to C++ rather late in the standardization process, promoted by Bjarne Stroustrup, the language's original author. The model for C++ exceptions came primarily from CLU. However, other languages existed at that time that also supported exception handling: Ada, SmallTalk (both of these had exceptions but no exception specifications) and Modula-3 (which included both exceptions and specifications).

In their seminal paper[7] on the subject, Liskov and Snyder observe that a major defect of languages like C, which report errors in a transient fashion, is that:

"…every invocation must be followed by a conditional test to determine what the outcome was. This requirement leads to

programs that are difficult to read, and
probably inefficient as well, thus
discouraging programmers from signaling
and handling exceptions."

Thus, one of the original motivations of exception handling was to prevent this requirement, but with checked exceptions in Java we commonly see exactly this kind of code. They go on to say:

"…requiring that the text of a handler be
attached to the invocation that raises the
exception would lead to unreadable
programs in which expressions were
broken up with handlers."

Following the CLU approach when designing C++ exceptions, Stroustrup stated that the goal was to reduce the amount of code required to recover from errors. I believe that he was observing that programmers were typically not writing error-handling code in C because the amount and placement of such code was daunting and distracting. As a result, they were used to doing it the C way, ignoring errors in code and using debuggers to track down problems. To use exceptions, these C programmers had to be convinced to write

“additional” code they weren’t normally writing. Thus, to draw them into a better way of handling errors, the amount of code they must “add” cannot be onerous. I think it’s important to keep this goal in mind when looking at the effects of checked exceptions in Java.

C++ brought an additional idea over from CLU: the exception specification, to programmatically state in the method signature the exceptions that could result from calling that method. The exception specification really has two purposes. It can say, “I’m originating this exception in my code; you handle it.” But it can also mean, “I’m ignoring this exception that can occur as a result of my code; you handle it.” We’ve been focusing on the “you handle it” part when looking at the mechanics and syntax of exceptions, but here I’m particularly interested in the fact that we often ignore exceptions and

that’s what the exception specification can state.

In C++ the exception specification is not part of the type information of a function. The only compile-time checking is to ensure that exception specifications are used consistently; for example, if a

function or method throws exceptions, the overloaded or derived versions must also throw those exceptions. Unlike Java, however, no compile-time checking occurs to determine whether or not the function or method will actually throw that exception, or whether the exception specification is complete (that is, whether it accurately describes all exceptions that might be thrown). That validation does happen, but only at run time. If an exception is thrown that violates the exception specification, the C++ program will call the standard library function **unexpected()**.

Because of templates, exception specifications are not used at all in the Standard C++ Library. In Java, there are restrictions on the way that Java generics can be used with exception specifications.

Perspectives

First, it's worth noting that Java effectively invented the checked exception (clearly inspired by C++ exception specifications and the fact that C++ programmers typically don't bother with them). However, it was an experiment which no subsequent language has chosen to duplicate.

Secondly, checked exceptions appear to be an "obvious good thing" when seen in introductory examples and in small programs. It is

suggested that the subtle difficulties appear when programs begin getting large. This largeness usually doesn't happen overnight; it creeps. Languages that might not be suited for large-scale projects are used for small projects. These projects grow, and at some point we realize that things have gone from "manageable" to "difficult." This, I'm suggesting, might be the case with too much type checking; in particular, with checked exceptions.

The scale of the program seems to be a significant issue. This is a problem because most discussions tend to use small programs as demonstrations. One of the C# designers observed that:

"Examination of small programs leads to
the conclusion that requiring exception
specifications could both enhance
developer productivity and enhance code
quality, but experience with large
software projects suggests a different
result—decreased productivity and little
or no increase in code quality. "8

In reference to uncaught exceptions, the CLU creators stated:

"We felt it was unrealistic to require the

programmer to provide handlers in
situations where no meaningful action can
be taken.” 9

When explaining why a function declaration with no specification means it can throw *any* exception, rather than *no* exceptions, Stroustrup states:

“However, that would require exception
specifications for essentially every
function, would be a significant cause for
recompilation, and would inhibit
cooperation with software written in other
languages. This would encourage
programmers to subvert the exception-
handling mechanisms and to write
spurious code to suppress exceptions. It
would provide a false sense of security to
people who failed to notice the
exception.” 10

We see this very behavior—subverting the exceptions—happening with checked exceptions in Java.

Martin Fowler (author of *UML Distilled*, *Refactoring*, and *Analysis Patterns*) wrote the following to me:

"…on the whole I think that exceptions
are good, but Java checked exceptions
are more trouble than they are worth."

I now think Java's important step was to unify the error-reporting model, so all errors are *reported* using exceptions. This wasn't happening with C++, because, for backward compatibility with C, the old model of just ignoring errors was still available. With consistent reporting via exceptions, exceptions can be used if desired, and if not, they will propagate out to the highest level (such as the console). When Java modified the C++ model so exceptions were the only way to report errors, the extra enforcement of checked exceptions might have become less necessary.

In the past, I have believed strongly that both checked exceptions and static type checking were essential to robust program development. However, both anecdotal and direct experience[11] with languages that are more dynamic than static led me to think the great benefits actually come from:

1. A unified error-reporting model via exceptions, regardless of whether the programmer is forced by the compiler to handle

them.

2. Type checking, regardless of *when* it takes place. That is, as long as proper use of a type is enforced, it often doesn't matter if it

happens at compile time or run time.

On top of this, there are significant productivity benefits to reducing

the compile-time constraints upon the programmer. Indeed, *reflection*

and *generics* are required to compensate for the overconstraining

nature of static typing, as you shall see in a number of examples

throughout the book.

I've been told by some that what I say here constitutes blasphemy, and

by uttering these words my reputation will be destroyed, civilizations

will fall, and a higher percentage of programming projects will fail.

The belief that the compiler can save your project by pointing out

errors at compile time runs strong, but it's even more important to

realize the limitation of what the compiler is able to do. I emphasize

the value of an automated build process and unit testing, which give

you far more leverage than you get by trying to turn everything into a

syntax error. It's worth keeping in mind that:

"A good programming language is one

that helps programmers write good

programs. No programming language will

prevent its users from writing bad

programs.” 12

In any event, the likelihood of checked exceptions ever being removed from Java seems dim. It’s too radical of a language change, and proponents appear to be quite strong. Java has a history and policy of absolute backward compatibility—to give you a sense of this, virtually all Sun software ran on all Sun hardware, no matter how old.

However, if you find that some checked exceptions are getting in your way, or especially if you find yourself forced to catch exceptions but you don’t know what to do with them, there are some alternatives.

Passing Exceptions to the

Console

In simple programs, the easiest way to preserve exceptions without writing a lot of code is to pass them out of **main()** to the console. For example, to open a file for reading (something you’ll learn about in detail in the Files chapter), you must open and close a **FileInputStream**, which throws exceptions. For a simple

program, you can do this (you'll see this approach used in numerous places throughout this book):

```
// exceptions/MainException.java
import java.util.*;
import java.nio.file.*;
public class MainException {
// Pass exceptions to the console:
public static void
main(String[] args) throws Exception {
// Open the file:
List<String> lines = Files.readAllLines(
Paths.get("MainException.java"));
// Use the file ...
}
}
```

main() is like any method, which means it can also have an exception specification. Here the type of exception is **Exception**, the root class of all checked exceptions. By passing it out to the console, you are relieved from writing **try-catch** clauses within the body of **main()**. (Unfortunately, some file I/O can be significantly more

complex than it would appear from this example. You'll learn more in the Files chapter and the Appendix: I/O Streams).

Converting Checked to Unchecked Exceptions

Throwing an exception from **main()** is convenient when you're writing simple programs for your own consumption, but is not generally useful. The real problem is when you are writing an ordinary method body, and you call another method and realize, "I have no idea what to do with this exception here, but I can't swallow it or print some banal message." With chained exceptions, a simple solution presents itself. You "wrap" a checked exception inside a **RuntimeException** by passing it to the **RuntimeException** constructor, like this:

```
try {
// ... to do something useful
} catch(IDontKnowWhatToDoWithThisCheckedException e) {
throw new RuntimeException(e);
```

}

This seems an ideal way to “turn off” the checked exception—you don’t swallow it, and you don’t put it in your method’s exception specification, but because of exception chaining you don’t lose any information from the original exception.

This technique provides the option to ignore the exception and let it bubble up the call stack without being required to write **try-catch** clauses and/or exception specifications. However, you can still catch and handle the specific exception by using **getCause()**, as seen here:

```
// exceptions/TurnOffChecking.java
// "Turning off" Checked exceptions
import java.io.*;
class WrapCheckedException {
void throwRuntimeException(int type) {
try {
switch(type) {
case 0: throw new FileNotFoundException();
case 1: throw new IOException();
case 2: throw new
```

```
RuntimeException("Where am I?");
default: return;
}
} catch(IOException | RuntimeException e) {
// Adapt to unchecked:
throw new RuntimeException(e);
}
}
}
class SomeOtherException extends Exception {}
public class TurnOffChecking {
public static void main(String[] args) {
WrapCheckedException wce =
new WrapCheckedException();
// You can call throwRuntimeException() without
// a try block, and let RuntimeExceptions
// leave the method:
wce.throwRuntimeException(3);
// Or you can choose to catch exceptions:
for(int i = 0; i < 4; i++)
```

```
try {
if(i < 3)
wce.throwRuntimeException(i);
else
throw new SomeOtherException();
} catch(SomeOtherException e) {
System.out.println(
"SomeOtherException: " + e);
} catch(RuntimeException re) {
try {
throw re.getCause();
} catch(FileNotFoundException e) {
System.out.println(
"FileNotFoundException: " + e);
} catch(IOException e) {
System.out.println("IOException: " + e);
} catch(Throwable e) {
System.out.println("Throwable: " + e);
}
}
```

}

}

/ *Output:*

FileNotFoundException: java.io.FileNotFoundException

IOException: java.io.IOException

Throwable: java.lang.RuntimeException: Where am I?

SomeOtherException: SomeOtherException

**/*

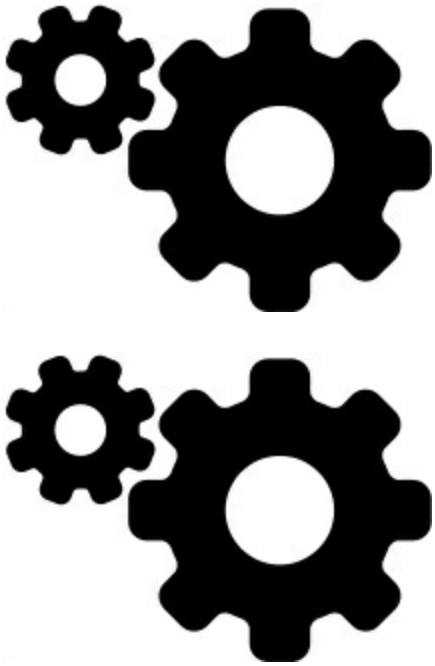
WrapCheckedException.throwRuntimeException()

contains code that generates different types of exceptions. These are caught and wrapped inside **RuntimeException** objects, so they become the “cause” of those exceptions.

In **TurnOffChecking**, you see it’s possible to call **throwRuntimeException()** with no **try** block because the method does not throw any checked exceptions. However, when you’re ready to catch exceptions, you still have the ability to catch any exception you want by putting your code inside a **try** block. You start by catching all the exceptions you explicitly know might emerge from the code in your **try** block—here, **SomeOtherException** is caught first. Lastly, you catch **RuntimeException** and **throw** the result

of **getCause()** (the wrapped exception). This extracts the originating exceptions, which can then be handled in their own **catch** clauses.

The technique of wrapping a checked exception in a **RuntimeException** is used when appropriate throughout the rest of this book. Another solution is to create your own subclass of **RuntimeException**. This way, it doesn't have to be caught, but someone can catch it if they want.



Exception Guidelines

Use exceptions to:

1. Use try-with-resources whenever possible.

2. Handle problems at the appropriate level. (Avoid catching

exceptions unless you know what to do with them.)

3. Fix the problem and re-call the method that caused the exception.

4. Patch things up and continue without retrying the method.

5. Calculate some alternative result instead of what the method was supposed to produce.

6. Do whatever you can in the current context and rethrow the *same* exception to a higher context.

7. Do whatever you can in the current context and throw a *different* exception to a higher context.

8. Terminate the program.

9. Simplify. (If your exception scheme makes things more complicated, it is painful and annoying to use.)

10. Make your library and program safer. (This is a short-term investment for debugging, and a long-term investment for application robustness.)

Summary

Exceptions are integral to programming with Java; you can accomplish only so much without knowing how to work with them.

Exceptions are introduced now for that reason—there are many libraries you can't use without handling exceptions.

One of the advantages of exception handling is that it concentrates on the problem you're trying to solve in one place, then deals with the errors from that code in another place. And although exceptions are generally explained as tools that allow you to *report* and *recover from* errors at run time, I have come to wonder how often the "recovery" aspect is implemented, or even possible. My perception is it is less than 10 percent of the time, and even then it probably amounts to unwinding the stack to a known stable state rather than actually performing any kind of resumptive behavior. Whether or not this is true, I have come to believe that the "reporting" function is where the essential value of exceptions lie. The fact that Java effectively insists that all errors be reported in the form of exceptions gives it a great advantage over languages like C++, which allow you to report errors in a number of different ways, or not at all. A consistent error-reporting system means you no longer ask the question "Are errors slipping

through the cracks?" with each piece of code you write (as long as you don't "swallow" the exceptions, that is!).

As you will see in future chapters, by laying this question to rest—even if you do so by throwing a **RuntimeException**—your design and implementation efforts can be focused on more interesting and challenging issues.

Postscript: Exception Bizarro World

(From a blog post in 2011)

My friend James Ward was trying to create some very straightforward teaching examples using JDBC, and kept getting foiled by checked exceptions. He pointed me to Howard Lewis Ship's post The Tragedy of Checked Exceptions. In particular, James was frustrated by the all the hoops he had to jump through to do something that ought to be simple. Even in the **finally** block he's forced to put in more **try-catch** clauses because closing the connection can also cause exceptions. Where does it end? To do something simple you're forced to jump through hoop after hoop (Note that the try-with-resources statement improves this situation significantly).

We started talking about the Go programming language, which I've

been fascinated with because Rob Pike et. al. have clearly asked many very incisive and fundamental questions about language design. Basically, they've taken everything we've started to accept about languages and asked, "Why?" about each one. Learning this language really makes you think and wonder.

My impression is that the Go team decided not to make any assumptions and to evolve the language only when it is clear that a feature is necessary. They don't seem to worry about making changes that break old code—they created a rewriting tool so if they make such changes it will rewrite the code for you. This frees them to make the language an ongoing experiment to discover what's really necessary rather than doing *Big Upfront Design*.

One of the most interesting decisions they made is to leave out exceptions altogether. You read that right—they aren't just leaving out checked exceptions. They're leaving out *all* exceptions.

The alternative is very simple, and at first it almost seems C-like. Because Go incorporated tuples from the beginning, you can easily return two objects from a function call:

```
result, err := functionCall()
```

(The **:=** tells Go to define **result** and **err** at this point, and to infer their types).

That’s it: for each call you get back the result object and an error object. You can check the error right away (which is typical, because if something fails it’s unlikely you’ll blithely go on to the next step), or check it later if that works.

At first this seems primitive, a regression to ancient times. But so far I’ve found that the decisions in Go are very well considered, and worth pondering. Am I simply reacting because my brain is exception-addled? How would this affect James’s problem?

It occurs to me I’ve always seen exception handling as kind of a parallel execution path. If you hit an exception, you jump out of the normal path into this parallel execution path, a kind of “bizarro world” where you are no longer doing the things you wrote, and instead jumping around into catch and finally clauses. It’s this alternate-execution-path world that causes the problems James is complaining about.

James creates an object. Ideally, object creation does not cause potential exceptions, but if it does you have to catch those. You have to follow creation with a try-finally to make sure cleanup happens (the Python team realized that cleanup is not really an exceptional condition, but a separate problem, so they created a different language

construct—**with**—so as to stop conflating the two). Any call that causes an exception stops the normal execution path and jumps (via parallel bizarro-world) to the catch clause.

One of the fundamental assumptions about exceptions are that we somehow benefit by collecting all the error handling code at the end of the block rather than handling errors when they occur. In both cases we stop normal execution, but exception handling has an automatic mechanism that throws you out of the normal execution path, jumps you into bizarro-parallel-exception world, then pops you back out again in the right handler.

Jumping into bizarro world causes the problems for James, and it adds more work for all programmers: because you can't know when something will happen (you can slip into bizarro world at any moment), you have to add layers of **try** blocks to ensure that nothing slips through the cracks. You end up having to do extra programming to compensate for the exception mechanism (It seems similar to the extra work required to compensate for shared-memory concurrency).

The Go team made the bold move of questioning all this, and saying, "Let's try it without exceptions and see what happens." Yes, this means you're typically going to handle errors where they occur rather than

clumping them all at the end of a try block. But that also means code that is about one thing is localized, and maybe that's not so bad. It might also mean you can't easily combine common error-handling code (unless you identified that common code and put it into a function, also not so bad). But it definitely means you don't have to worry about having more than one possible execution path and all that entails.

1. The C programmer can look up the return value of **printf()** for an example of this.↩

2. Jim Gray, Turing Award winner for his team's contributions on transactions, in an interview on *www.acmqueue.org*. ↩

3. As do most languages, including C++, C#, Python, D, etc. ↩

4. C++ exception handling does not have the **finally** clause because it relies on destructors to accomplish this sort of cleanup. ↩

5. A destructor is a function that's always called when an object becomes unused. You always know exactly where and when the destructor gets called. C++ has automatic destructor calls, and C# (which is much more like Java) has a way that automatic destruction can occur. ↩

6. ISO C++ added similar constraints that require derived-method exceptions to be the same as, or derived from, the exceptions thrown by the base-class method. This is one case where C++ is actually able to check exception specifications at compile time. ↩

7. Barbara Liskov and Alan Snyder, *Exception Handling in CLU*, IEEE Transactions on Software Engineering, Vol. SE-5, No. 6, November 1979. Available from IEEE or ACM. ↩

8. http://discuss.develop.com/archives/wa.e?

A2=ind0011A&L=DOTNET&P=R32820↩

9. *Exception Handling in CLU*, Liskov & Snyder.↩

10. Bjarne Stroustrup, *The C++ Programming Language, 3rd*

Edition (Addison-Wesley, 1997), page 376.↩

11. Indirectly with SmallTalk via conversations with many

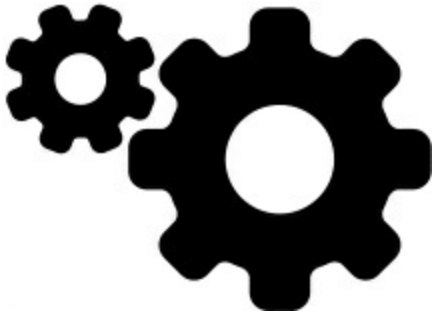
experienced programmers in that language; directly with Python

(*www.Python.org*). ↩

12. Kees Koster, designer of the CDL language, as quoted by Bertrand

Meyer, designer of the Eiffel language,

www.elj.com/elj/v1/n1/bm/right/.↩



Validating Your Code

You can never guarantee your code is

correct. You can only prove it’s wrong.

Let’s pause our learning of language features and look at some programming fundamentals. Specifically, the problem of making sure your code works properly.

Testing

If it’s not tested, it’s broken.

Because Java is a (mostly1) statically-typed language, programmers often become too comfortable with the apparent safety of the language, thinking “if the compiler accepts it, it’s OK.” But static type checking is a very limited form of testing. It only means the compiler accepts the syntax and basic type rules of your code. It doesn’t mean the code satisfies the goals of your program. As you gain more programming experience, you’ll come to understand that your code almost never satisfies those goals. The first step towards code validation is creating tests that check the code behavior against your goals.

Unit Testing

This is the process of building integrated tests into all code you create,

and running those tests every time you build your system. That way, the build process checks for more than just syntax errors. You teach it to check for semantic errors as well.

“Unit” refers to the idea of testing small pieces of your code. Typically, each class has tests checking the behavior of all its methods. “System” testing is different, and checks that the finished program satisfies its requirements.

C-style programming languages, and C++ in particular, traditionally valued performance over programming safety. The reason that developing programs in Java is so much faster than in C++ (roughly twice as fast, by most accounts) is because of Java’s safety net: features like garbage collection and improved type checking. By integrating unit testing into your build process, you extend this safety net, resulting in faster development. You can also more easily and boldly refactor your code when you discover design or implementation flaws, and in general produce a better product, more quickly.

My own experience with testing began when I realized that, to guarantee the correctness of code in a book, every program in that book must be automatically extracted, then compiled using an appropriate build system. The build system used in this book is

Gradle, and after you install the JDK, you can just type **gradlew compileJava** to compile all the code for the book. The effect of automatic extraction and compilation on the code quality of the book was so immediate and dramatic it soon became (in my mind) a requisite for any programming book—how can you trust code you didn't compile? I also discovered that I can make sweeping changes using search-and-replace throughout the book. I know that if I introduce a flaw, the code extractor and the build system flushes it out. As programs became more complex, I found a serious hole in my system. Compiling programs is clearly an important first step, and for a published book it seems a fairly revolutionary one (because of publishing pressures, you can often open a programming book and discover a coding flaw). However, I received messages from readers reporting semantic problems in my code. Of course, these problems could be discovered only by running the code. I took some early faltering steps toward implementing a system to perform automatic execution tests, but succumbed to publishing schedules, all the while knowing there was definitely something wrong with my process that would come back to bite me in the form of embarrassing bug reports. I had also gotten regular complaints that I didn't show enough program output. I needed to validate the output of a program while

showing the validated output in the book. My previous attitude was that the reader should be running the programs while reading the book, and many readers did just that and benefited from it. A hidden reason for that attitude, however, was I didn't have a way to prove the output shown in the book was correct. From experience, I knew that over time, something would happen so the output was no longer correct (or, I wouldn't get it right in the first place). To solve this problem, I created a tool in the Python language (you will find this tool in the downloaded examples). Most programs in this book produce console output, and this tool compares that output to the expected output shown in the comment at the end of the source-code listing, so readers can see the expected output, and know this output is verified by the build process.

JUnit

The original JUnit, published in 2000, was presumably based on Java 1.0 and thus could not make use of Java's reflection facilities. As a result, writing unit tests with the old JUnit was a rather busy and wordy activity. I found the design unpleasant, and wrote my own unit testing framework as an example for the Annotations chapter. This framework went to the other extreme, "trying the simplest thing that could possibly work" (A key phrase from *Extreme Programming*

(XP)). Since then, JUnit has been vastly improved using reflection and annotations, which greatly simplifies the process of writing unit test code. For Java 8, they even added support for lambdas. This book uses *JUnit5*, the latest version at the time.

In the simplest use of JUnit, you tag each method that represents a test with the **@Test** annotation. JUnit identifies these methods as individual tests and sets up and runs them one at a time, taking measures to avoid side effects between tests.

Let's try a simple example. **CountedList** inherits **ArrayList**, with added information to keep track of how many **CountedList**s are created:

```
// validating/CountedList.java
// Keeps track of how many of itself are created.
package validating;
import java.util.*;
public class CountedList extends ArrayList<String> {
private static int counter = 0;
private int id = counter++;
public CountedList() {
System.out.println("CountedList #" + id);
```

```
}
public int getId() { return id; }
}
```

Standard practice is to put tests in their own subdirectory. Tests must also be in packages so JUnit can discover them:

```
// validating/tests/CountedListTest.java
// Simple use of JUnit to test CountedList.
package validating;
import java.util.*;
import org.junit.jupiter.api.*;
import static org.junit.jupiter.api.Assertions.*;
public class CountedListTest {
private CountedList list;
@BeforeAll
static void beforeAllMsg() {
System.out.println(">>> Starting CountedListTest");
}
@AfterAll
static void afterAllMsg() {
System.out.println(">>> Finished CountedListTest");
```

```
}
@BeforeEach
public void initialize() {
list = new CountedList();
System.out.println("Set up for " + list.getId());
for(int i = 0; i < 3; i++)
list.add(Integer.toString(i));
}
@AfterEach
public void cleanup() {
System.out.println("Cleaning up " + list.getId());
}
@Test
public void insert() {
System.out.println("Running testInsert()");
assertEquals(list.size(), 3);
list.add(1, "Insert");
assertEquals(list.size(), 4);
assertEquals(list.get(1), "Insert");
}
```

```
@Test
public void replace() {
System.out.println("Running testReplace()");
assertEquals(list.size(), 3);
list.set(1, "Replace");
assertEquals(list.size(), 3);
assertEquals(list.get(1), "Replace");
}
// A helper method to simplify the code. As
// long as it's not annotated with @Test, it will
// not be automatically executed by JUnit.
private
void compare(List<String> lst, String[] strs) {
assertArrayEquals(lst.toArray(new String[0]), strs);
}
@Test
public void order() {
System.out.println("Running testOrder()");
compare(list, new String[] { "0", "1", "2" });
}
```

```
@Test
public void remove() {
System.out.println("Running testRemove()");
assertEquals(list.size(), 3);
list.remove(1);
assertEquals(list.size(), 2);
compare(list, new String[] { "0", "2" });
}
@Test
public void addAll() {
System.out.println("Running testAddAll()");
list.addAll(Arrays.asList(new String[] {
"An", "African", "Swallow"}));
assertEquals(list.size(), 6);
compare(list, new String[] { "0", "1", "2",
"An", "African", "Swallow" });
}
}
/* Output:
>>> Starting CountedListTest
```

CountedList #0

Set up for 0

Running testRemove()

Cleaning up 0

CountedList #1

Set up for 1

Running testReplace()

Cleaning up 1

CountedList #2

Set up for 2

Running testAddAll()

Cleaning up 2

CountedList #3

Set up for 3

Running testInsert()

Cleaning up 3

CountedList #4

Set up for 4

Running testOrder()

Cleaning up 4

>>> Finished CountedListTest

*/

@BeforeAll annotates a method that runs once before any other test operations. **@AfterAll** is for a method that runs once after all other test operations. Both methods must be **static**.

@BeforeEach annotates a method typically used to create and initialize a common set of objects and runs before each test. Alternatively, you can put all such initialization in the constructor for the test class, although I think **@BeforeEach** makes it clearer. JUnit creates an object for each test to ensure there are no side effects between test runs. However, all objects for all tests are created at once (rather than creating the object right before the test), so the only difference between using **@BeforeEach** and the constructor is **@BeforeEach** is called directly before the test. In most situations this is not an issue, and you can use the constructor approach if you prefer.

If you must perform cleanup after each test (if you modify any **static**s that need restoring, open files that need closing, open databases or network connections, etc.), annotate a method with **@AfterEach**.

Each test creates a new **CountedListTest** object, thus any non-**static** members are also created at that time. **initialize()** is then called for that test, so **list** is assigned a new **CountedList** object which is then initialized with the **String**s **"0"** , **"1"** , and **"2"** .

To observe the behavior of **@BeforeEach** and **@AfterEach**, those methods display information about the test as it is initialized and cleaned up.

insert() and **replace()** demonstrate typical test methods. JUnit discovers these methods using the **@Test** annotation and runs each one as a test. Inside the methods, you perform any desired operations and use JUnit assertion methods (which all start with the name "assert") to verify the correctness of your tests (the full range of "assert" statements is found in the JUnit docs). If the assertion fails, the expression and values that caused the failure are displayed. This is often enough, but you can also use the overloaded version of each JUnit assertion statement and include a **String** for display when the assertion fails.

The assertion statements are not required; you can also run the test without assertions and consider it a success if there are no exceptions.

compare() is an example of a "helper method" that is not executed by JUnit but instead is used by other tests in the class. As long as

there's no **@Test** annotation, JUnit doesn't run it or expect a particular signature. Here, **compare()** is **private**, emphasizing it is used only within the test class, but it can also be **public**. The remaining test methods eliminate duplicate code by refactoring it into the **compare()** method.

The **build.gradle** file for this book controls testing. To run the tests for this chapter, the command is:

gradlew validating:test

Gradle doesn't run tests that have already run for that build, so if you get no test results, first run:

gradlew validating:clean

You can run all tests in the book with the command:

gradlew test

Although you can probably survive with the simplest approach to JUnit as shown in **CountedListTest.java**, JUnit contains numerous additional testing structures you can learn about at junit.org.

JUnit is the most popular unit testing framework for Java, but there are alternatives. You can explore others via the Internet in case one of those better suits your needs.

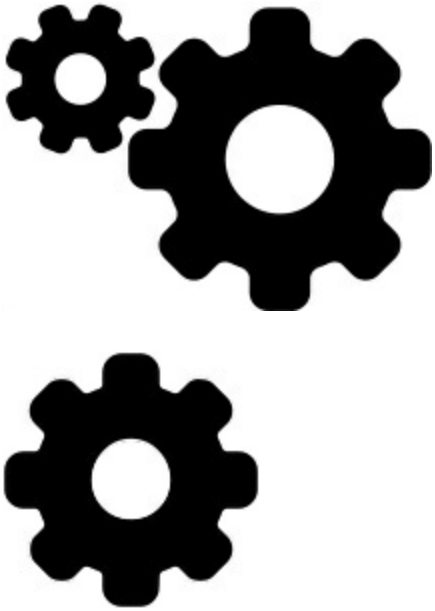
The Illusion of Test Coverage

Test coverage, also called *code coverage*, measures the test percentage for your code base. The higher the percentage, the greater the test coverage. There are a number of approaches for calculating coverage, and a helpful article describing Java Code Coverage Tools.

It is far too easy for persons without knowledge but in positions of control to decide that 100% coverage is the only acceptable value. This is a problem because the number is not really a good measure of testing effectiveness. You might test everything that needs it, but only measure 65% test coverage. If someone demands 100% coverage, you waste a lot of time generating the rest, and more as you add code to the project.

Test coverage as a rough measure is useful when you're analyzing an unknown code base. If a coverage tool reports an especially low value (say, less than 40%), that tells you the coverage is probably insufficient. However, a very high value is equally suspicious, suggesting that someone with inadequate knowledge of the programming field has forced an arbitrary decision on the team. The

best use of coverage tools is to discover untested parts of your codebase. However, don’t rely on coverage to tell you anything about the quality of your tests.



Preconditions

The concept of the *precondition* comes from *Design By Contract* (DbC) and is implemented using the basic *assertion* mechanism. We’ll start by looking at assertions in Java, then cover DbC, and finally use the Google Guava library for preconditions.

Assertions

Assertions increase program robustness by verifying that certain conditions are satisfied during the execution of your program.
For example, suppose you have a numerical field in an object that represents the month on the Julian calendar. You know this value

must always be in the range 1-12. An assertion can check this and report an error if it somehow falls outside that range. If you're inside a method, you can check the validity of an argument with an assertion. These are important tests to make sure your program is correct, but they cannot be checked at compile-time, and they do not fall under the purview of unit testing.

Java Assertion Syntax

You can simulate the effect of assertions using other programming constructs, so the point of including assertions in Java is that they are easy to write. Assertion statements come in two forms:

assert boolean-expression;

assert boolean-expression: information-expression;

Both say "I assert this boolean-expression produces a **true** value." If this is not the case, the assertion produces an **AssertionError** exception. This is a **Throwable** subclass, and as such doesn't require an exception specification.

Unfortunately, an exception from the first form of assertion does *not* produce any information containing the boolean-expression (in contrast with most other languages' assertion mechanisms). Here's an example showing the use of the first form:

// validating/Assert1.java

```
// Non-informative style of assert
// Must run using -ea flag:
// {java -ea Assert1}
// {ThrowsException}
public class Assert1 {
public static void main(String[] args) {
assert false;
}
}
/* Output:
___[ Error Output ]___
Exception in thread "main" java.lang.AssertionError
at Assert1.main(Assert1.java:9)
*/
```

If you run the program normally, without any special assertion flags, nothing happens. You must explicitly enable assertions when you run the program. The easiest way to do this is with the **-ea** flag, which can also be spelled out: **-enableassertions**. This runs the program and executes any assertion statements.

The output doesn’t contain much in the way of useful information. On

the other hand, if you use the *information-expression*, you'll produce a helpful message as part of the exception stack trace. The most useful *information-expression* is typically a **String** of text directed at the programmer:

```
// validating/Assert2.java
// Assert with an information-expression
// {java Assert2 -ea}
// {ThrowsException}
public class Assert2 {
public static void main(String[] args) {
assert false:
"Here's a message saying what happened";
}
}
/* Output:
___[ Error Output ]___
Exception in thread "main" java.lang.AssertionError:
Here's a message saying what happened
at Assert2.main(Assert2.java:8)
*/
```

The *information-expression* can produce any kind of object, so you typically construct a more complex **String** containing the value(s) of objects that were involved with the failed assertion.

You can also turn assertions on and off based on the class name or package name; that is, you can enable or disable assertions for an entire package. Details for doing this are in the JDK documentation on assertions. This feature is useful for a large project instrumented with assertions when you want to turn some of them on or off. However, Logging or Debugging, described in their respective sections, are probably better tools for capturing that kind of information.

There's one other way you can control assertions: programmatically, by hooking into the **ClassLoader** object. There are several methods in **ClassLoader** that allow the dynamic enabling and disabling of assertions, including **setDefaultAssertionStatus()**, which sets the assertion status for all the classes loaded afterward. So you might think you can silently turn on assertions like this:

```
// validating/LoaderAssertions.java
// Using the class loader to enable assertions
// {ThrowsException}
public class LoaderAssertions {
public static void main(String[] args) {
```

```
ClassLoader.getSystemClassLoader()
.setDefaultAssertionStatus(true);
new Loaded().go();
}
}
class Loaded {
public void go() {
assert false: "Loaded.go()";
}
}
/* Output:
___[ Error Output ]___
Exception in thread "main" java.lang.AssertionError:
Loaded.go()
at Loaded.go(LoaderAssertions.java:15)
at
LoaderAssertions.main(LoaderAssertions.java:9)
*/
```

This eliminates the need for the **-ea** flag on the command line when running the program. It may be just as straightforward to enable

assertions using the **-ea** flag. When delivering a standalone product, you probably have to set up an execution script enabling the user to start the program anyway, to configure other startup parameters.

It does make sense, however, to decide to *require* assertions enabled when the program runs. You can accomplish this with the following **static** clause, placed in the main class of your system:

```
static {
boolean assertionsEnabled = false;
// Note intentional side effect of assignment:
assert assertionsEnabled = true;
if(!assertionsEnabled)
throw new RuntimeException("Assertions disabled");
}
```

If assertions are enabled, then the **assert** statement executes and **assertionsEnabled** becomes **true**. The assertion never fails because the return value of the assignment is the assigned value. If assertions are not enabled, the **assert** statement doesn’t execute and **assertionsEnabled** remains **false**, resulting in the exception.

Guava Assertions

Because turning on native Java assertions is a bother, the Guava team

added a **Verify** class with replacement assertions always enabled.

The team recommends importing the **Verify** methods statically:

```
// validating/GuavaAssertions.java
// Assertions that are always enabled.
import com.google.common.base.*;
import static com.google.common.base.Verify.*;
public class GuavaAssertions {
public static void main(String[] args) {
verify(2 + 2 == 4);
try {
verify(1 + 2 == 4);
} catch(VerifyException e) {
System.out.println(e);
}
try {
verify(1 + 2 == 4, "Bad math");
} catch(VerifyException e) {
System.out.println(e.getMessage());
}
try {
```

```
verify(1 + 2 == 4, "Bad math: %s", "not 4");
} catch(VerifyException e) {
System.out.println(e.getMessage());
}
String s = "";
s = verifyNotNull(s);
s = null;
try {
verifyNotNull(s);
} catch(VerifyException e) {
System.out.println(e.getMessage());
}
try {
verifyNotNull(
s, "Shouldn't be null: %s", "arg s");
} catch(VerifyException e) {
System.out.println(e.getMessage());
}
}
}
```

/ *Output:*

com.google.common.base.VerifyException

Bad math

Bad math: not 4

expected a non-null reference

Shouldn't be null: arg s

**/*

There are two methods, **verify()** and **verifyNotNull()** with

variations to support useful error messages. Note that

verifyNotNull()'s built-in error message is typically enough,

while **verify()** is too general to have a useful default error message.

Using Assertions for *Design By Contract*

Design by Contract (DbC) is a concept developed by Bertrand Meyer,

inventor of the Eiffel programming language, to help create robust

programs by guaranteeing that objects follow certain rules. 2 These rules are determined by the nature of the problem being solved, which

is outside the scope that the compiler can validate.

Although assertions do not directly implement DBC (as does the Eiffel

language), they create an informal style of DbC programming.

DbC presumes a clearly-specified contract between the supplier of a

service and the consumer or client of that service. In object-oriented

programming, services are usually supplied by objects, and the boundary of the object—the division between the supplier and consumer—is the interface of an object's class. When clients call a particular public method, they expect certain behavior from that call: a state change in the object, and a predictable return value. Meyer's thesis is that:

1. This behavior can be clearly specified, as if it were a contract.
2. This behavior can be guaranteed by implementing certain run-time checks, which he calls *preconditions*, *postconditions* and *invariants*.

Whether or not you agree that point 1 is always true, it does appear true for enough situations to make DbC a useful approach. (I believe that, like any solution, there are boundaries to its usefulness. But if you know these boundaries, you know when to try it.) In particular, a valuable part of the design process is the expression of DbC constraints for a particular class; if you are unable to specify the constraints, you probably don't know enough about what you're trying to build.

Check Instructions

Before looking at DbC in detail, consider the simplest use for

assertions, which Meyer calls the *check instruction*. A check instruction states your conviction that a particular property is satisfied at this point in the code. The idea of the check instruction is to express non-obvious conclusions in code, not only to verify the test, but also as documentation for future readers of the code.

In chemistry, you might titrate one clear liquid into another, and when you reach a certain point, everything turns blue. This is not obvious from the color of the two liquids; it is part of a complex reaction. A useful check instruction at the completion of the titration process would assert that the resulting liquid is blue.

Check instructions are a valuable addition to your code, and should be used whenever you can test and illuminate the state of your object or program.

Preconditions

Preconditions ensure the client (the code calling this method) fulfills its part of the contract. This almost always means checking the arguments at the very beginning of a method call (before you do anything else in that method) to guarantee they are appropriate for use in the method. Since you never know what a client will hand you, precondition checks are always a good idea.

Postconditions

Postconditions test the results of what you did in the method. This code is placed at the end of the method call, before the **return** statement (if there is one). For long, complex methods where calculation results should be verified before returning them (that is, in situations where for some reason you cannot always trust the results), postcondition checks are essential, but any time you can describe constraints on the result of the method, it's wise to express those constraints in code as a postcondition.

Invariants

An invariant gives guarantees about the state of the object that must be maintained between method calls. However, it doesn't restrain a method from temporarily diverging from those guarantees during the execution of the method. It just says that the state information of the object will always obey the stated rules:

1. Upon entry to the method.
2. Before leaving the method.

In addition, the invariant is a guarantee about the state of the object after construction.

According to this description, an effective invariant is defined as a

method, probably named **invariant()**, which is invoked after construction, and at the beginning and end of each method. The method could be invoked as:

assert invariant();

This way, if you disable assertions for performance reasons, there's no overhead.

Relaxing DbC

Although he emphasizes the value of expressing preconditions, postconditions, and invariants, and the importance of using these during development, Meyer admits it is not always practical to include all DbC code in a shipping product. You can relax DbC checking based on the amount of trust you can place in the code at a particular point. Here is the order of relaxation, from safest to least safe:

1. The invariant check at the beginning of each method is disabled first, since the invariant check at the end of each method guarantees that the object's state is valid at the beginning of every method call. That is, you can generally trust that the state of the object will not change in between method calls. This one is such a safe assumption that you might choose to write code with invariant checks only at the end.

2. The postcondition check is disabled next, when you have

reasonable unit testing to verify that your methods are returning appropriate values. Since the invariant check is watching the state of the object, the postcondition check is only validating the results of the calculation during the method, and therefore may be discarded in favor of unit testing. The unit testing will not be as safe as a run-time postcondition check, but it may be enough, especially if you have confidence in the code.

3. The invariant check at the end of a method call can be disabled if you are confident the method body does not put the object into an invalid state. It might be possible to verify this with *white-box* unit testing (that is, unit tests that have access to private fields, to validate the object state). Thus, although it may not be as robust as calls to **invariant()**, it is possible to "migrate" the invariant checking from run-time tests to build-time tests (via unit testing), just as with postconditions.

4. Finally, as a last resort, disable precondition checks. This is the

least safe and least advisable option, because although you know and have control over your own code, you have no control over what arguments the client may pass to a method. However, in a situation where (A) performance is desperately needed and profiling has pointed at precondition checks as a bottleneck and (B) you have some kind of reasonable assurance that the client will not violate preconditions (as in the case where you've written the client code yourself) it may be acceptable to disable precondition checks.

You shouldn't remove the code that performs the checks described here as you disable the checks (just comment it out). If a bug is discovered, you can easily recover the checks to rapidly discover the problem.

DbC + Unit Testing

The following example demonstrates the potency of combining concepts from Design by Contract with unit testing. It shows a small first-in, first-out (FIFO) queue implemented as a "circular" array—that is, an array used in a circular fashion. When the end of the array is reached, the class wraps back around to the beginning.

We can make a number of contractual definitions for this queue:

1. **Precondition (for a put())**: Null elements are not allowed to be added to the queue.

2. **Precondition (for a put())**: It is illegal to put elements into a full queue.

3. **Precondition (for a get())**: It is illegal to try to get elements from an empty queue.

4. **Postcondition (for a get())**: Null elements cannot be produced from the array.

5. **Invariant**: The region that contains objects cannot contain any null elements.

6. **Invariant**: The region that doesn't contain objects must have only null values.

Here is one way to implement these rules, using explicit method calls for each type of DbC element. First, we create a dedicated **Exception**:

```
// validating/CircularQueueException.java
package validating;
public class
CircularQueueException extends RuntimeException {
public CircularQueueException(String why) {
```

```
super(why);
}
}
```

This is used to report errors with the **CircularQueue** class:

```
// validating/CircularQueue.java
// Demonstration of Design by Contract (DbC)
package validating;
import java.util.*;
public class CircularQueue {
private Object[] data;
private int
in = 0, // Next available storage space
out = 0; // Next gettable object
// Has it wrapped around the circular queue?
private boolean wrapped = false;
public CircularQueue(int size) {
data = new Object[size];
// Must be true after construction:
assert invariant();
}
```

```
public boolean empty() {
return !wrapped && in == out;
}
public boolean full() {
return wrapped && in == out;
}
public boolean isWrapped() { return wrapped; }
public void put(Object item) {
precondition(item != null, "put() null item");
precondition(!full(),
"put() into full CircularQueue");
assert invariant();
data[in++] = item;
if(in >= data.length) {
in = 0;
wrapped = true;
}
assert invariant();
}
public Object get() {
```

```
precondition(!empty(),
"get() from empty CircularQueue");
assert invariant();
Object returnVal = data[out];
data[out] = null;
out++;
if(out >= data.length) {
out = 0;
wrapped = false;
}
assert postcondition(
returnVal != null,
"Null item in CircularQueue");
assert invariant();
return returnVal;
}
// Design-by-contract support methods:
private static void
precondition(boolean cond, String msg) {
if(!cond) throw new CircularQueueException(msg);
```

```
}
private static boolean
postcondition(boolean cond, String msg) {
if(!cond) throw new CircularQueueException(msg);
return true;
}
private boolean invariant() {
// Guarantee that no null values are in the
// region of 'data' that holds objects:
for(int i = out; i != in; i = (i + 1) % data.length)
if(data[i] == null)
throw new CircularQueueException(
"null in CircularQueue");
// Guarantee that only null values are outside the
// region of 'data' that holds objects:
if(full()) return true;
for(int i = in; i != out; i = (i + 1) % data.length)
if(data[i] != null)
throw new CircularQueueException(
"non-null outside of CircularQueue range: "
```

```
+ dump());
return true;
}
public String dump() {
return "in = " + in +
", out = " + out +
", full() = " + full() +
", empty() = " + empty() +
", CircularQueue = " + Arrays.asList(data);
}
}
```

The **in** counter indicates the place in the array where the next object goes. The **out** counter indicates where the next object comes from. The **wrapped** flag means **in** has gone “around the circle” and is now coming up from behind **out**. When **in** and **out** coincide, the queue is empty (if **wrapped** is false) or full (if **wrapped** is true).

The **put()** and **get()** methods call **precondition()**, **postcondition()**, and **invariant()**, which are **private** methods defined further down in the class. **precondition()** and **postcondition()** are helper methods designed to clarify the code.

Note that **precondition()** returns **void**, because it is not used with **assert**. As previously noted, you'll generally keep preconditions in your code. By wrapping them in a **precondition()** method call, you have better options if you are reduced to the dire move of turning them off.

postcondition() and **invariant()** both return a Boolean value so they can be used in **assert** statements. Then, if you disable assertions for performance reasons, there are no method calls at all.

invariant() performs internal validity checks on the object. This is an expensive operation if you do it at both the start and end of every method call, as Meyer suggests. However, it's valuable to clearly represent in code, and it helped me debug the implementation. In addition, if you make any changes to the implementation, the **invariant()** ensures you haven't broken the code. But it's fairly trivial to move the invariant tests from the method calls into the unit test code. If your unit tests are thorough, you have a reasonable level of confidence that invariants are respected.

The **dump()** helper method returns a **String** with all the data, rather than printing the data directly. This allows more options for using the information.

Now we can create JUnit tests for the class:

```
// validating/tests/CircularQueueTest.java
package validating;
import org.junit.jupiter.api.*;
import static org.junit.jupiter.api.Assertions.*;
public class CircularQueueTest {
private CircularQueue queue = new CircularQueue(10);
private int i = 0;
@BeforeEach
public void initialize() {
while(i < 5) // Pre-load with some data
queue.put(Integer.toString(i++));
}
// Support methods:
private void showFullness() {
assertTrue(queue.full());
assertFalse(queue.empty());
System.out.println(queue.dump());
}
private void showEmptiness() {
```

```
assertFalse(queue.full());
assertTrue(queue.empty());
System.out.println(queue.dump());
}
@Test
public void full() {
System.out.println("testFull");
System.out.println(queue.dump());
System.out.println(queue.get());
System.out.println(queue.get());
while(!queue.full())
queue.put(Integer.toString(i++));
String msg = "";
try {
queue.put("");
} catch(CircularQueueException e) {
msg = e.getMessage();
System.out.println(msg);
}
assertEquals(msg, "put() into full CircularQueue");
```

```
showFullness();
}
@Test
public void empty() {
System.out.println("testEmpty");
while(!queue.empty())
System.out.println(queue.get());
String msg = "";
try {
queue.get();
} catch(CircularQueueException e) {
msg = e.getMessage();
System.out.println(msg);
}
assertEquals(msg, "get() from empty CircularQueue");
showEmptiness();
}
@Test
public void nullPut() {
System.out.println("testNullPut");
```

```
String msg = "";
try {
queue.put(null);
} catch(CircularQueueException e) {
msg = e.getMessage();
System.out.println(msg);
}
assertEquals(msg, "put() null item");
}
@Test
public void circularity() {
System.out.println("testCircularity");
while(!queue.full())
queue.put(Integer.toString(i++));
showFullness();
assertTrue(queue.isWrapped());
while(!queue.empty())
System.out.println(queue.get());
showEmptiness();
while(!queue.full())
```

```
queue.put(Integer.toString(i++));
showFullness();
while(!queue.empty())
System.out.println(queue.get());
showEmptiness();
}
}
/* Output:
testNullPut
put() null item
testCircularity
in = 0, out = 0, full() = true, empty() = false,
CircularQueue =
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
0
1
2
3
4
5
```

6

7

8

9

in = 0, out = 0, full() = false, empty() = true,

CircularQueue =

[null, null, null, null, null, null, null, null, null,

null]

in = 0, out = 0, full() = true, empty() = false,

CircularQueue =

[10, 11, 12, 13, 14, 15, 16, 17, 18, 19]

10

11

12

13

14

15

16

17

18

19

in = 0, out = 0, full() = false, empty() = true,

CircularQueue =

[null, null, null, null, null, null, null, null, null,

null]

testFull

in = 5, out = 0, full() = false, empty() = false,

CircularQueue =

[0, 1, 2, 3, 4, null, null, null, null, null]

0

1

put() into full CircularQueue

in = 2, out = 2, full() = true, empty() = false,

CircularQueue =

[10, 11, 2, 3, 4, 5, 6, 7, 8, 9]

testEmpty

0

1

2

3

4

get() from empty CircularQueue

in = 5, out = 5, full() = false, empty() = true,

CircularQueue =

[null, null, null, null, null, null, null, null, null,

null]

**/*

The **initialize()** method adds some data so the **CircularQueue** is partially full for each test. The support methods **showFullness()** and **showEmptiness()** indicate that the **CircularQueue** is full or empty, respectively. Each of the four test methods ensures that a different aspect of the **CircularQueue** functions correctly.

Note that by combining DbC with unit testing, you not only get the best of both worlds, but you also have a migration path—you can move

some DbC tests to unit tests rather than simply disabling them, so you still have some level of testing.

Using Guava Preconditions

In Relaxing DbC, I pointed out that the precondition is the one part of DbC you don't want to remove, as it checks the validity of method arguments. That's something you have no control over, so you do want to check them. Because Java disables assertions by default, it's usually better to use a different library that's always validating method arguments.

Google's *Guava* library incorporates a nice set of precondition tests that are not only easy to use, but also descriptively well-named. Here you see simple usages of all of them. The library designers recommend you import the preconditions statically:

```
// validating/GuavaPreconditions.java
// Demonstrating Guava Preconditions
import java.util.function.*;
import static com.google.common.base.Preconditions.*;
public class GuavaPreconditions {
static void test(Consumer<String> c, String s) {
try {
System.out.println(s);
c.accept(s);
System.out.println("Success");
```

```
} catch(Exception e) {
String type = e.getClass().getSimpleName();
String msg = e.getMessage();
System.out.println(type +
(msg == null ? "" : ": " + msg));
}
}
public static void main(String[] args) {
test(s -> s = checkNotNull(s), "X");
test(s -> s = checkNotNull(s), null);
test(s -> s = checkNotNull(s, "s was null"), null);
test(s -> s = checkNotNull(
s, "s was null, %s %s", "arg2", "arg3"), null);
test(s -> checkArgument(s == "Fozzie"), "Fozzie");
test(s -> checkArgument(s == "Fozzie"), "X");
test(s -> checkArgument(s == "Fozzie"), null);
test(s -> checkArgument(
s == "Fozzie", "Bear Left!"), null);
test(s -> checkArgument(
s == "Fozzie", "Bear Left! %s Right!", "Frog"),
```

```
null);
test(s -> checkState(s.length() > 6), "Mortimer");
test(s -> checkState(s.length() > 6), "Mort");
test(s -> checkState(s.length() > 6), null);
test(s ->
checkElementIndex(6, s.length()), "Robert");
test(s ->
checkElementIndex(6, s.length()), "Bob");
test(s ->
checkElementIndex(6, s.length()), null);
test(s ->
checkPositionIndex(6, s.length()), "Robert");
test(s ->
checkPositionIndex(6, s.length()), "Bob");
test(s ->
checkPositionIndex(6, s.length()), null);
test(s -> checkPositionIndexes(
0, 6, s.length()), "Hieronymus");
test(s -> checkPositionIndexes(
0, 10, s.length()), "Hieronymus");
```

```
test(s -> checkPositionIndexes(
0, 11, s.length()), "Hieronymus");
test(s -> checkPositionIndexes(
-1, 6, s.length()), "Hieronymus");
test(s -> checkPositionIndexes(
7, 6, s.length()), "Hieronymus");
test(s -> checkPositionIndexes(
0, 6, s.length()), null);
}
}
/* Output:
X
Success
null
NullPointerException
null
NullPointerException: s was null
null
NullPointerException: s was null, arg2 arg3
Fozzie
```

Success

X

IllegalArgumentException

null

IllegalArgumentException

null

IllegalArgumentException: Bear Left!

null

IllegalArgumentException: Bear Left! Frog Right!

Mortimer

Success

Mort

IllegalStateException

null

NullPointerException

Robert

IndexOutOfBoundsException: index (6) must be less than

size (6)

Bob

IndexOutOfBoundsException: index (6) must be less than

size (3)

null

NullPointerException

Robert

Success

Bob

IndexOutOfBoundsException: index (6) must not be

greater than size (3)

null

NullPointerException

Hieronymus

Success

Hieronymus

Success

Hieronymus

IndexOutOfBoundsException: end index (11) must not be

greater than size (10)

Hieronymus

IndexOutOfBoundsException: start index (-1) must not be

negative

Hieronymus

IndexOutOfBoundsException: end index (6) must not be

less than start index (7)

null

NullPointerException

*/

Although Guava preconditions work with all types, I only demonstrate **String**s here. The **test()** method expects a **Consumer<String>** so we can pass a lambda expression as the first argument, and the **String** to pass to the lambda as the second argument. It displays the **String** in order to orient you when looking at the output, then passes the **String** to the lambda expression. The second **println()** in the **try** block is only displayed if the lambda expression succeeds; otherwise the **catch** clause displays the error information. Notice how much duplicate code the **test()** method eliminates.

Each precondition has three different overloaded forms: a test with no message, a test with a simple **String** message, and a test with a **String** and a variable argument list of replacement values. For efficiency, only **%s** (**String** type) replacement tags are allowed. In

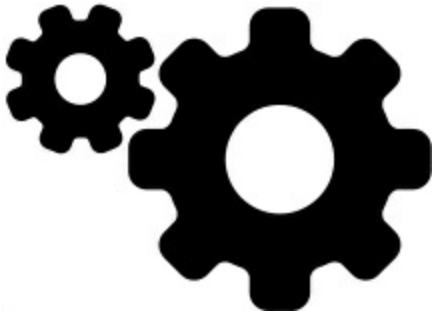
the above example, the two forms of **String** message are only demonstrated for **checkNotNull()** and **checkArgument()**, but they are the same for all the rest of the precondition methods.

Note that **checkNotNull()** returns its argument, so you can use it inline in an expression. Here's how to use it in a constructor to prevent object construction containing **null** values:

```
// validating/NonNullConstruction.java
import static com.google.common.base.Preconditions.*;
public class NonNullConstruction {
private Integer n;
private String s;
NonNullConstruction(Integer n, String s) {
this.n = checkNotNull(n);
this.s = checkNotNull(s);
}
public static void main(String[] args) {
NonNullConstruction nnc =
new NonNullConstruction(3, "Trousers");
}
}
```

checkArgument() takes a **boolean** expression for a more specific test of an argument, and throws **IllegalArgumentException** upon failure. **checkState()** is for testing the state of the object (for example, an invariant check), rather than checking the arguments, and throws **IllegalStateException** upon failure.

The last three methods throw **IndexOutOfBoundsException** upon failure. **checkElementIndex()** ensures that its first argument is a valid element index into a list, string, or array with a size specified by its second argument. **checkPositionIndex()** ensures that its first argument is in the range from zero to its second argument, inclusive. **checkPositionIndexes()** checks that **[first_arg, second_arg)** is a valid subrange of a **List**, **String**, or array with the size specified by the third argument.



All Guava precondition methods have the necessary overloads for primitive types as well as **Object**s.

Test-Driven

Development

The premise of *Test-Driven Development* (TDD) is that if you design and write your code with testing in mind, you not only create testable code, it will also be better-designed. In general, this seems to hold true. If I'm thinking "how will I test this?" it makes my code different, and oftentimes "testable" translates to "usable."

TDD purists write tests for a new feature before implementing that feature; this is called *Test-First Development*. To demonstrate, consider a toy example utility that inverts the case of characters in a **String**. Let's add some arbitrary constraints: the **String** must be less than or equal to 30 characters, and must contain only letters, spaces, commas and periods.

This example is different from standard TDD because it's designed to accept different implementations of the **StringInverter**, in order to show the evolution of the class as we satisfy the tests step-by-step. To enable this, the **StringInverter** is represented as an **interface**:

```
// validating/StringInverter.java
package validating;
interface StringInverter {
```

String invert(String str);

}

Now we can write tests to express our requirements. The following is not typically the way you'd write your tests, but we have a special constraint here: we want to test multiple versions of the **StringInverter** implementation. To achieve this, we exploit one of the most sophisticated new features in JUnit5: *dynamic test generation*. This is exactly what it sounds like—instead of each test being coded explicitly, you can write code that generates tests at runtime. This opens many new possibilities, especially in situations where writing a full set of tests explicitly might otherwise be prohibitive.

JUnit5 provides several ways to dynamically generate tests, but the one used here might be the most complex. The **DynamicTest.stream()** method takes:

An iterator over the set of objects that vary from one set of tests to another. The object produced by that iterator can be of any type, but there's only a single object produced so for multiple items that vary, you must artificially package them into a single type.

A **Function** that takes the object from the iterator and produces

a **String** describing the test.

A **Consumer** that accepts the object from the iterator and

contains the test code based on that object.

In this example, all code that would otherwise be duplicated is

combined in **testVersions()**. The objects that represent change

and are produced by the iterator are different implementations of

DynamicTest:

```
// validating/tests/DynamicStringInverterTests.java
package validating;
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
import org.junit.jupiter.api.*;
import static org.junit.jupiter.api.Assertions.*;
import static org.junit.jupiter.api.DynamicTest.*;
class DynamicStringInverterTests {
// Combine operations to prevent code duplication:
Stream<DynamicTest> testVersions(String id,
Function<StringInverter, String> test) {
List<StringInverter> versions = Arrays.asList(
```

```
new Inverter1(), new Inverter2(),
new Inverter3(), new Inverter4());
return DynamicTest.stream(
versions.iterator(),
inverter -> inverter.getClass().getSimpleName(),
inverter -> {
System.out.println(
inverter.getClass().getSimpleName() +
": " + id);
try {
if(test.apply(inverter) != "fail")
System.out.println("Success");
} catch(Exception | Error e) {
System.out.println(
"Exception: " + e.getMessage());
}
}
);
}
String isEqual(String lval, String rval) {
```

```
if(lval.equals(rval))
return "success";
System.out.println("FAIL: " + lval + " != " + rval);
return "fail";
}
@BeforeAll
static void startMsg() {
System.out.println(
">>> Starting DynamicStringInverterTests <<<");
}
@AfterAll
static void endMsg() {
System.out.println(
">>> Finished DynamicStringInverterTests <<<");
}
@TestFactory
Stream<DynamicTest> basicInversion1() {
String in = "Exit, Pursued by a Bear.";
String out = "eXIT, pURSUED BY A bEAR.";
return testVersions(
```

```
"Basic inversion (should succeed)",
inverter -> isEqual(inverter.invert(in), out)
);
}
@TestFactory
Stream<DynamicTest> basicInversion2() {
return testVersions(
"Basic inversion (should fail)",
inverter -> isEqual(inverter.invert("X"), "X"));
}
@TestFactory
Stream<DynamicTest> disallowedCharacters() {
String disallowed = ";-_()*&^%$#@!~`0123456789";
return testVersions(
"Disallowed characters",
inverter -> {
String result = disallowed.chars()
.mapToObj(c -> {
String cc = Character.toString((char)c);
try {
```

```
inverter.invert(cc);
return "";
} catch(RuntimeException e) {
return cc;
}
}).collect(Collectors.joining(""));
if(result.length() == 0)
return "success";
System.out.println("Bad characters: " + result);
return "fail";
}
);
}
@TestFactory
Stream<DynamicTest> allowedCharacters() {
String lowcase = "abcdefghijklmnopqrstuvwxyz ,.";
String upcase = "ABCDEFGHIJKLMNOPQRSTUVWXYZ ,.";
return testVersions(
"Allowed characters (should succeed)",
inverter -> {
```

```
assertEquals(inverter.invert(lowcase), upcase);
assertEquals(inverter.invert(upcase), lowcase);
return "success";
}
);
}
@TestFactory
Stream<DynamicTest> lengthNoGreaterThan30() {
String str = "xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx";
assertTrue(str.length() > 30);
return testVersions(
"Length must be less than 31 (throws exception)",
inverter -> inverter.invert(str)
);
}
@TestFactory
Stream<DynamicTest> lengthLessThan31() {
String str = "xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx";
assertTrue(str.length() < 31);
return testVersions(
```

"Length must be less than 31 (should succeed)",

inverter -> inverter.invert(str)

);

}

}

In ordinary testing, you'd want a failed test to stop the build. Here, however, we only want the system to report the issue, but then still continue so you can see the effects of the different versions of **StringInverter**.

Each method annotated with **@TestFactory** produces a **Stream** of **DynamicTest** objects (via **testVersions()**), each of which JUnit executes just like regular **@Test** methods.

Now that the tests are in place, we can begin implementing the **StringInverter**. We start with a dummy class that returns its argument:

```
// validating/Inverter1.java
package validating;
public class Inverter1 implements StringInverter {
public String invert(String str) { return str; }
}
```

Next we implement the inversion operation:

```
// validating/Inverter2.java
package validating;
import static java.lang.Character.*;
public class Inverter2 implements StringInverter {
public String invert(String str) {
String result = "";
for(int i = 0; i < str.length(); i++) {
char c = str.charAt(i);
result += isUpperCase(c) ?
toLowerCase(c) :
toUpperCase(c);
}
return result;
}
}
```

Now add code to ensure there are no more than 30 characters:

```
// validating/Inverter3.java
package validating;
import static java.lang.Character.*;
```

```
public class Inverter3 implements StringInverter {
public String invert(String str) {
if(str.length() > 30)
throw new RuntimeException("argument too long!");
String result = "";
for(int i = 0; i < str.length(); i++) {
char c = str.charAt(i);
result += isUpperCase(c) ?
toLowerCase(c) :
toUpperCase(c);
}
return result;
}
}
```

Finally, we exclude disallowed characters:

```
// validating/Inverter4.java
package validating;
import static java.lang.Character.*;
public class Inverter4 implements StringInverter {
static final String ALLOWED =
```

```
"abcdefghijklmnopqrstuvwxyz ,." +
"ABCDEFGHIJKLMNOPQRSTUVWXYZ";
public String invert(String str) {
if(str.length() > 30)
throw new RuntimeException("argument too long!");
String result = "";
for(int i = 0; i < str.length(); i++) {
char c = str.charAt(i);
if(ALLOWED.indexOf(c) == -1)
throw new RuntimeException(c + " Not allowed");
result += isUpperCase(c) ?
toLowerCase(c) :
toUpperCase(c);
}
return result;
}
}
```

You'll see from the test output that each version of **Inverter** is closer to passing all the tests. This duplicates your experience while performing test-first development.

DynamicStringInverterTests.java was only used to show the development of the different **StringInverter** implementations during the TDD process. Ordinarily, you just write a set of tests like the following, and modify a single **StringInverter** class until it satisfies all tests:

```
// validating/tests/StringInverterTests.java
package validating;
import java.util.*;
import java.util.stream.*;
import org.junit.jupiter.api.*;
import static org.junit.jupiter.api.Assertions.*;
public class StringInverterTests {
StringInverter inverter = new Inverter4();
@BeforeAll
static void startMsg() {
System.out.println(">>> StringInverterTests <<<");
}
@Test
void basicInversion1() {
String in = "Exit, Pursued by a Bear.";
```

```
String out = "eXIT, pURSUED BY A bEAR.";
assertEquals(inverter.invert(in), out);
}
@Test
void basicInversion2() {
expectThrows(Error.class, () -> {
assertEquals(inverter.invert("X"), "X");
});
}
@Test
void disallowedCharacters() {
String disallowed = ";-_()*&^%$#@!~`0123456789";
String result = disallowed.chars()
.mapToObj(c -> {
String cc = Character.toString((char)c);
try {
inverter.invert(cc);
return "";
} catch(RuntimeException e) {
return cc;
```

```
}
}).collect(Collectors.joining(""));
assertEquals(result, disallowed);
}
@Test
void allowedCharacters() {
String lowcase = "abcdefghijklmnopqrstuvwxyz ,.";
```

```
String upcase = "ABCDEFGHIJKLMNOPQRSTUVWXYZ ,.";
assertEquals(inverter.invert(lowcase), upcase);
assertEquals(inverter.invert(upcase), lowcase);
}
@Test
void lengthNoGreaterThan30() {
String str = "xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx";
assertTrue(str.length() > 30);
expectThrows(RuntimeException.class, () -> {
inverter.invert(str);
```

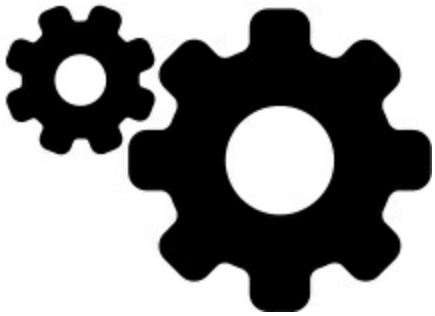
```
});
}
@Test
void lengthLessThan31() {
String str = "xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx";
assertTrue(str.length() < 31);
inverter.invert(str);
}
}
```

By establishing all the desired characteristics within tests as a starting point, you can add functionality until all the tests pass. Once you're finished, you also have the tests to tell you (or anyone else) when you've broken the code in the future, while fixing bugs or adding features. TDD tends to produce better, more thoughtful tests, whereas attempting to achieve full test coverage after the fact often produces hurried or meaningless tests.

Test-Driven vs. Test-First

Although I myself have not achieved the Test-First level of consciousness, I am most intrigued by the concept of "failing test as bookmark" that comes from Test-First. When you walk away from

your work for awhile, it can sometimes be challenging to get back into the groove, or even find where you left off. A failing test, however, brings you right back to where you stopped. This seems like it makes it easier to step away without worrying about losing your place.



The main problem with pure test-first programming is it assumes you know everything about the problem you're solving, up front. In my own experience, I usually start by experimenting, and only when I've worked with the problem for awhile do I understand it well enough to write tests. Certainly, there are occasional problems that are perfectly defined before you start, but I personally don't run across such problems very often. Indeed, it might be worth coining the phrase *Test-Oriented Development* to describe the practice of writing code that tests well.

Logging

Logging reports information about a running program.

In a debugged program, this can be ordinary status data showing the progress of the program (for example, an installation program may log the steps taken during installation, the directories where you stored files, startup values for the program, etc.).

Logging is also helpful during debugging. Without logging, you might try to decipher the behavior of a program by inserting **println()** statements. Some examples in this book use that very technique, and in the absence of a debugger (a topic introduced shortly), it's about all you have. However, once you decide the program is working properly, you'll probably take the **println()** statements out. Then if you run into more bugs, you may need to put them back in. It's much nicer if you include output statements that are only used when necessary.

Prior to the availability of logging packages, programmers relied on the fact that the Java compiler optimizes away code that is never called. If **debug** is a **static final boolean**, you can say:

```
if(debug) {
System.out.println("Debug info");
}
```

Then, when **debug** is **false**, the compiler removes the code within the braces. Thus, the code has no run-time impact when it isn't used.

With this approach, you can place trace code throughout your program and easily turn it on and off. One drawback to the technique, however, is you must recompile your code to turn your trace statements on and off. It's more convenient to turn on the trace without recompiling the program, via a configuration file you change to modify the logging properties.

The logging package from the standard Java distribution (**java.util.logging**) is almost universally considered a poor design. Most people choose an alternative logging package instead.

The *Simple Logging Facade for Java* (SLF4J) provides a facade for multiple logging frameworks, such as **java.util.logging**, **logback** and **log4j**. SLF4J allows the end-user to plug in the desired logging framework at deployment time.

SLF4J provides a sophisticated facility to report information about your program with almost the same efficiency of the technique in the preceding example. For very simple informational logging, you can do something like this:

```
// validating/SLF4JLogging.java
import org.slf4j.*;
public class SLF4JLogging {
```

```
private static Logger log =
LoggerFactory.getLogger(SLF4JLogging.class);
public static void main(String[] args) {
log.info("hello logging");
}
}
/* Output:
2017-05-09T06:07:53.418
[main] INFO SLF4JLogging - hello logging
```

```
*/
```

The format and information in the output, and even whether the output is considered normal or “error,” depends on the back-end package connected to SLF4J. In the above example it’s connected to the **logback** library (via this book’s **build.gradle** file) and appears as standard output.

If we modify **build.gradle** to instead use the logging package that comes built into the JDK as the back end, the output appears as error

output, and looks like this:

Aug 16, 2016 5:40:31 PM InfoLogging main

INFO: hello logging

The logging system detects the class name and method name where the log message originated. It’s not guaranteed that these names are correct, so don’t rely on their accuracy.

Logging Levels

SLF4J provides multiple levels of reporting. This example shows them all, in increasing order of “seriousness”:

```
// validating/SLF4JLevels.java
import org.slf4j.*;
public class SLF4JLevels {
private static Logger log =
LoggerFactory.getLogger(SLF4JLevels.class);
public static void main(String[] args) {
log.trace("Hello");
log.debug("Logging");
log.info("Using");
log.warn("the SLF4J");
log.error("Facade");
```

}

}

/ Output:*

2017-05-09T06:07:52.846

[main] TRACE SLF4JLevels - Hello

2017-05-09T06:07:52.849

[main] DEBUG SLF4JLevels - Logging

2017-05-09T06:07:52.849

[main] INFO SLF4JLevels - Using

2017-05-09T06:07:52.850

[main] WARN SLF4JLevels - the SLF4J

2017-05-09T06:07:52.851

[main] ERROR SLF4JLevels - Facade

**/*

These different levels let you look for messages of a certain level. The level is typically set inside a separate configuration file, so you can reconfigure without recompiling. The configuration file format depends on which back-end logging implementation you are using. Here is one for **logback**, which uses XML:

<!-- validating/logback.xml -->

<?xml version="1.0" encoding="UTF-8" ?>

<configuration>

<appender name="STDOUT"

class="ch.qos.logback.core.ConsoleAppender" >

<encoder>

<pattern>

%d{yyyy-MM-dd'T'HH:mm:ss.SSS}

[%thread] %-5level %logger - %msg%n

</pattern>

</encoder>

</appender>

<root level="TRACE" >

<appender-ref ref="STDOUT" />

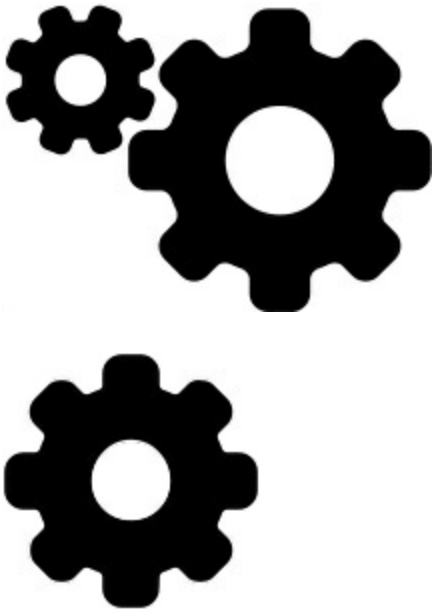
</root>

</configuration>

Try changing the **<root level="TRACE">** line to a different level

and re-run the program to see how the output changes. If you provide

no **logback.xml** file you'll still get a default configuration.



This has only been the briefest introduction to SLF4J and logging in general, enough to give you the basics of logging—which will actually take you a long way. Visit the SLF4J Documentation for more depth.

Debugging

Although judicious use of **System.out** statements or logging information produces valuable insight into the behavior of a program, for difficult problems this approach becomes cumbersome and time-consuming.

You might also need to peek more deeply into the program than print statements allow. For this, you need a *debugger*.

In addition to more quickly and easily displaying information than you

could produce with print statements, a debugger will also set *breakpoints* and stop the program when it reaches those breakpoints. A debugger can display the state of the program at any instant, view the values of variables, step through the program line-by-line, connect to a remotely running program, and more. Especially when you start building larger systems (where bugs can easily become buried), it pays to become familiar with debuggers.

Debugging with JDB

The *Java Debugger* (JDB) is a command-line tool that ships with the JDK. JDB is at least conceptually a descendant of the Gnu Debugger (GDB, which was inspired by the original Unix DB), in terms of the instructions for debugging and its command-line interface. JDB is useful for learning about debugging and performing simple debugging tasks, and it's helpful to know it's always available wherever the JDK is installed. However, for larger projects you'll want a graphical debugger, described later.

Suppose you've written the following program:

```
// validating/SimpleDebugging.java
// {ThrowsException}
public class SimpleDebugging {
```

```
private static void foo1() {
System.out.println("In foo1");
foo2();
}
private static void foo2() {
System.out.println("In foo2");
foo3();
}
private static void foo3() {
System.out.println("In foo3");
int j = 1;
j--;
int i = 5 / j;
}
public static void main(String[] args) {
foo1();
}
}
/* Output:
In foo1
```

In foo2

In foo3

___[Error Output]___

Exception in thread "main"

java.lang.ArithmeticException: / by zero

at

SimpleDebugging.foo3(SimpleDebugging.java:17)

at

SimpleDebugging.foo2(SimpleDebugging.java:11)

at SimpleDebugging.foo1(SimpleDebugging.java:7)

at

SimpleDebugging.main(SimpleDebugging.java:20)

**/*

If you look at **foo3()**, the problem is obvious: You're dividing by zero. But suppose this code is buried in a large program (as is implied here by the sequence of calls) and you don't know where to start looking for the problem. As it turns out, the exception gives enough information for you to locate the problem. But let's suppose things are more difficult than that, and you must drill into it more deeply and get more information than what an exception provides.

To run JDB, you first tell the compiler to generate debugging information by compiling **SimpleDebugging.java** with the **–g** flag. Then you start debugging the program with the command line:

jdb SimpleDebugging

This brings up JDB and gives you a command prompt. You can view the list of available JDB commands by typing **?** at the prompt.

Here's an interactive debugging trace that shows how to chase down a problem:

Initializing jdb ...

> catch Exception

The **>** indicates that JDB is waiting for a command. The command **catch Exception** sets a breakpoint any place an exception is thrown (however, the debugger will stop anyway, even if you don't explicitly give this directive—exceptions appear to be default breakpoints in JDB).

Deferring exception catch Exception.

It will be set after the class is loaded.

> run

Now the program will run until the next breakpoint, which in this case is where the exception occurs. Here's the result of the **run** command:

run SimpleDebugging

Set uncaught java.lang.Throwable

Set deferred uncaught java.lang.Throwable

>

VM Started: In foo1

In foo2

In foo3

Exception occurred: java.lang.ArithmeticException

(uncaught)"thread=main",

SimpleDebugging.foo3(), line=16 bci=15

16 int i = 5 / j;

The program runs until line 16 where the exception occurs, but JDB does not exit when it hits the exception. The debugger also displays the line of code that caused the exception. You can list the point where execution stopped in the program source using the **list** command:

main[1] list

12 private static void foo3() {

13 System.out.println("In foo3");

14 int j = 1;

15 j--;

16 => int i = 5 / j;

17 }

18 public static void main(String[] args) {

19 foo1();

20 }

21 }

/* Output:

The pointer (“=> ”) in this listing shows the current point from where the execution will resume. You *could* resume the execution with the **cont** (continue) command, but that makes JDB exit at the exception, printing the stack trace.

The **locals** command dumps the value of all local variables:

main[1] locals

Method arguments:

Local variables:

j = 0

The **wherei** command prints the stack frames pushed in the method stack of the current thread:

main[1] wherei

[1] SimpleDebugging.foo3 (SimpleDebugging.java:16), pc = 15

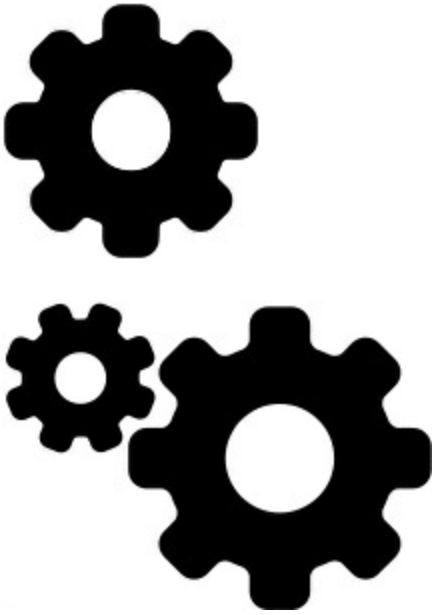
[2] SimpleDebugging.foo2 (SimpleDebugging.java:10), pc = 8

[3] SimpleDebugging.foo1 (SimpleDebugging.java:6), pc = 8

[4] SimpleDebugging.main (SimpleDebugging.java:19), pc = 0

Each line after **wherei** represents a method call and the point where the call returns (which is shown by the value of the *program counter* **pc**). Here the calling sequence is **main(), foo1(), foo2()**, and **foo3()**.

Because the **list** command shows where the execution stopped, you



often get a good enough idea of what happened that you can fix it. The **help** command will tell you more of what you can do with **jdb**, but before you spend too much time learning it, keep in mind that command-line debuggers tend to require far too much work to get results. Use **jdb** to learn the basics of debugging, then move to a

graphical debugger.

Graphical Debuggers

Using a command-line debugger like JDB can be inconvenient. It requires explicit commands to look at the state of the variables (**locals**, **dump**), list the point of execution in the source code (**list**), find out the threads in the system (**threads**), set breakpoints (**stop in**, **stop at**), etc. A graphical debugger provides these features with a few clicks, and also displays the latest details of the program being debugged without using explicit commands.

Thus, although you may get started by experimenting with JDB, you'll probably find it much more productive to learn to use a graphical debugger to quickly track down your bugs. The IBM *Eclipse*, Oracle *NetBeans* and JetBrains *IntelliJ* development environments all contain good graphical debuggers for Java.

Benchmarking

"We should forget about small efficiencies, say about 97% of the time: Premature optimization is the root of all evil."— *Donald Knuth*

If you find yourself on the slippery slope of premature optimization, you can lose months of time if you get ambitious. Usually a simple, straightforward coding approach is good enough. If you unnecessarily optimize, you make your code needlessly complicated and hard to understand.

Benchmarking means timing pieces of code or algorithms to see which runs faster, as opposed to see Profiling and Optimizing which looks at an entire program and finds sections where that program spends most of its time.

Can't you simply time the execution of a piece of code? In a straightforward language like C, this approach actually works. In a language with a complex runtime system like Java, benchmarking becomes far more challenging. To produce reliable data, the experimental setup must control variables such as CPU frequency, power saving features, other processes running on the same machine, optimizer options, and more.

Microbenchmarking

It’s tempting to write a timing utility to compare speeds of different pieces of code. It seems like this might produce some useful data. For example, here is a simple **Timer** class that can be used two ways:

1. Create a **Timer** object, perform your operations and then call the **duration()** method on your **Timer** to produce the time elapsed in milliseconds.
2. Pass a **Runnable** to the static **duration()** method. Anything conforming to the **Runnable interface** has a functional method **run()** with a function signature that takes no arguments and returns nothing.

```
// onjava/Timer.java
package onjava;
import static java.util.concurrent.TimeUnit.*;
public class Timer {
private long start = System.nanoTime();
public long duration() {
return NANOSECONDS.toMillis(
System.nanoTime() - start);
}
public static long duration(Runnable test) {
```

```
Timer timer = new Timer();
test.run();
return timer.duration();
}
}
```

This is a straightforward way to time something. Can't we just run some code and see how long it takes?

There are many factors that impact your results, even to the point of producing indicators that are upside-down. Here's a seemingly-innocent example using the standard Java **Arrays** library (described more fully in Arrays):

```
// validating/BadMicroBenchmark.java
// {ExcludeFromTravisCI}
import java.util.*;
import onjava.Timer;
public class BadMicroBenchmark {
static final int SIZE = 250_000_000;
public static void main(String[] args) {
try { // For machines with insufficient memory
long[] la = new long[SIZE];
```

```
System.out.println("setAll: " +
Timer.duration(() ->
Arrays.setAll(la, n -> n)));
System.out.println("parallelSetAll: " +
Timer.duration(() ->
Arrays.parallelSetAll(la, n -> n)));
} catch(OutOfMemoryError e) {
System.out.println("Insufficient memory");
System.exit(0);
}
}
}
/* Output:
setAll: 272
parallelSetAll: 301
*/
```

The body of **main()** is inside a **try** block because one machine3 ran out of memory and this would stop the build.

For an array of 250 million **long**s (just short of producing an “out of memory” exception on most machines), we “compare” the performance of **Arrays.setAll()** and

Arrays.parallelSetAll(). The parallel version attempts to use multiple processors to get the job done faster. (Although I refer to some parallel ideas in this section, these concepts are not explained in detail until the Concurrent Programming chapter). Despite that, the non-parallel version appears to run faster, although the results may vary across machines.

Each operation in *BadMicroBenchmark.java* is independent, but if your operation depends on a common resource, the parallel version can end up being much slower, as the separate processes contend for that resource:

```
// validating/BadMicroBenchmark2.java
// Relying on a common resource
import java.util.*;
import onjava.Timer;
public class BadMicroBenchmark2 {
// SIZE reduced to make it run faster:
static final int SIZE = 5_000_000;
public static void main(String[] args) {
long[] la = new long[SIZE];
Random r = new Random();
System.out.println("parallelSetAll: " +
```

```
Timer.duration(() ->
Arrays.parallelSetAll(la, n -> r.nextLong())));
System.out.println("setAll: " +
Timer.duration(() ->
Arrays.setAll(la, n -> r.nextLong())));
SplittableRandom sr = new SplittableRandom();
System.out.println("parallelSetAll: " +
Timer.duration(() ->
Arrays.parallelSetAll(la, n -> sr.nextLong())));
System.out.println("setAll: " +
Timer.duration(() ->
Arrays.setAll(la, n -> sr.nextLong())));
}
}
/* Output:
parallelSetAll: 1147
setAll: 174
parallelSetAll: 86
setAll: 39
*/
```

SplittableRandom is designed for parallel algorithms, and it certainly does seem to run faster than plain **Random** in **parallelSetAll()**. But it still appears to take longer than the non-parallel **setAll()**, which seems unlikely (And yet might be true. We just can't tell by using bad microbenchmarking).

This only touches the microbenchmark problem. The JVM Hotspot technologies significantly affect performance. If you don't "warm up" the JVM by running your code awhile before you run the test, you can get "cold" results that don't reflect the speed after it's been running awhile (And what if your running application doesn't end up using it enough to "warm up" the JVM? You won't get the performance you expect, and might even decrease speed).

The optimizer can sometimes detect when you create something and don't use it, or when the result of running some code has no effect on

the program. If it optimizes away your tests then you get bad results. A good microbenchmarking system automatically compensates for issues like this (and many others) to produce reasonable results, but

creating such a system is quite tricky and requires deep knowledge.

Introducing JMH

At this writing, the only microbenchmark system for Java that produces decent results is The *Java Microbenchmarking Harness* JMH. This book's **build.gradle** automates JMH setup so you can use it easily.

It's possible to write JMH code to run it from the command line, but the recommended approach is to let the JMH system run the tests for you; the **build.gradle** file is configured to run JMH tests with a single command.

JMH attempts to make benchmarks as easy as possible. For example, we'll rewrite **BadMicroBenchmark.java** to use JMH. The only annotations necessary here are **@State** and **@Benchmark**. The remaining annotations are included to either produce more understandable output or to make the benchmarks run faster for this example (JMH benchmarks often take a long time to run):

```
// validating/jmh/JMH1.java
package validating.jmh;
import java.util.*;
import org.openjdk.jmh.annotations.*;
import java.util.concurrent.TimeUnit;
```

```
@State(Scope.Thread)
@BenchmarkMode(Mode.AverageTime)
@OutputTimeUnit(TimeUnit.MICROSECONDS)
// Increase these three for more accuracy:
@Warmup(iterations = 5)
@Measurement(iterations = 5)
@Fork(1)
public class JMH1 {
private long[] la;
@Setup
public void setup() {
la = new long[250_000_000];
}
@Benchmark
public void setAll() {
Arrays.setAll(la, n -> n);
}
@Benchmark
public void parallelSetAll() {
Arrays.parallelSetAll(la, n -> n);
```

}

}

The default number of “forks” is ten, which means each test set runs ten times. To speed things up, I’ve used the **@Fork** annotation to reduce this to one. I’ve also reduced the number of warmup iterations and measurement iterations from the default of twenty down to five using the **@Warmup** and **@Measurement** annotations. Although this reduces the overall accuracy, the results are nearly identical to those with the default values. Try commenting out the **@Warmup**, **@Measurement** and **@Fork** annotations to see the default values and whether the tests show any noticeable variation; normally you should only see the error factors go down using the longer-running tests, and not changes in the results.

Running the benchmark requires an explicit gradle command (executed from the root directory of the example code). This prevents time-consuming benchmarking from running for any other **gradlew** commands:

gradlew validating:jmh

It takes several minutes, depending on your machine (without the annotation adjustments, it takes hours). The console output displays

the path to a **results.txt** file, which summarizes the results. Note that **results.txt** contains the results for all **jmh** tests in this chapter: **JMH1.java**, **JMH2.java**, and **JMH3.java**.

Because the output is in absolute time, results vary between machines and operating systems. The important factor is not the absolute times. What we're really looking for is how one algorithm compares to another; in particular, how much faster or slower it is. If you run the tests on your machine, you'll see different numbers but the same patterns.

I've tested this code on numerous machines, and while the absolute numbers vary from machine to machine, the relative values stay reasonably consistent. I only display the appropriate snippets from **results.txt**, and I edit the output to make it easier to understand, and to fit on the page. The **Mode** for all tests is displayed as **avgt** for "Average Time." The **Cnt** (number of tests) is 200, although you'll see a **Cnt** of 5 when you run the examples as configured here. The **Units** are **us/op** for "Microseconds per operation", thus smaller numbers indicate faster performance.

I'm also showing the output from the default number of warmups, measurements and forks. I deleted the corresponding annotations

from the examples in order to run my tests with greater accuracy (this takes hours). The pattern of the numbers should still look the same regardless of how you run the tests.

Here are the results for **JMH1.java**:

Benchmark Score

JMH1.setAll 196280.2

JMH1.parallelSetAll 195412.9

Even for a sophisticated benchmarking tool like JMH, the process of benchmarking is nontrivial and you must exercise care. Here, the test produces counterintuitive results: the parallel version takes about the same time as the non-parallel **setAll()**, and both seem to take a rather long time.

My assumption when I created the example was that, if we are testing array initialization, it makes sense to use very large arrays. So I chose the largest array I could; if you experiment you'll see that when you start making the array larger than 250 million[4] you begin to get out-of-memory exceptions. However, it's possible that performing mass operations on an array this large is thrashing the memory system and producing these unexpected results. Whether or not that's a correct hypothesis, it *does* seem that we're not actually testing what we think we're testing.

Consider other factors:

C: The number of client threads performing operations.

P: The amount of parallelism used by a parallel algorithm.

N: The size of the array: **10^(2*k)**, where **k=1..7** is usually enough to exercise different cache footprints.

Q: The cost of the setter operation.

This C/P/N/Q model surfaced during early JDK 8 Lambda development, and most parallel **Stream** operations (**parallelSetAll()** is quite similar) agree with these conclusions:

N*Q (basically, the amount of work) is critical to parallel performance. With less work, the parallel algorithm may actually run slower.

There are cases where operations are so contended that parallelism is no help at all, no matter how large **N*Q** is.

When **C** is high, **P** is much less relevant (an abundance of external parallelism makes internal parallelism redundant). Moreover, in some cases, the cost of parallel decomposition makes **C** clients running a parallel algorithm run slower than the same **C** clients running sequential code.

Based on this information, we re-run the test using different array

sizes (values of **N**):

```
// validating/jmh/JMH2.java
package validating.jmh;
import java.util.*;
import org.openjdk.jmh.annotations.*;
import java.util.concurrent.TimeUnit;
@State(Scope.Thread)
@BenchmarkMode(Mode.AverageTime)
@OutputTimeUnit(TimeUnit.MICROSECONDS)
@Warmup(iterations = 5)
@Measurement(iterations = 5)
@Fork(1)
public class JMH2 {
private long[] la;
@Param({
"1",
"10",
"100",
"1000",
"10000",
```

```
"100000",
"1000000",
"10000000",
"100000000",
"250000000"
})
int size;
@Setup
public void setup() {
la = new long[size];
}
@Benchmark
public void setAll() {
Arrays.setAll(la, n -> n);
}
@Benchmark
public void parallelSetAll() {
Arrays.parallelSetAll(la, n -> n);
}
}
```

@Param automatically inserts each of its values into the variable it annotates. The values must be **String**s and are converted to the appropriate type, **int** in this case.

Here are the edited results along with a calculated speedup:

JMH2 Benchmark Size Score % Speedup

setAll 1 0.001

parallelSetAll 1 0.036 0.028

setAll 10 0.005

parallelSetAll 10 3.965 0.001

setAll 100 0.031

parallelSetAll 100 3.145 0.010

setAll 1000 0.302

parallelSetAll 1000 3.285 0.092

setAll 10000 3.152

parallelSetAll 10000 9.669 0.326

setAll 100000 34.971

parallelSetAll 100000 20.153 1.735

setAll 1000000 420.581

parallelSetAll 1000000 165.388 2.543

setAll 10000000 8160.054

parallelSetAll 10000000 7610.190 1.072

setAll 100000000 79128.752

parallelSetAll 100000000 76734.671 1.031

setAll 250000000 199552.121

parallelSetAll 250000000 191791.927 1.040

Around 100,000 elements, **parallelSetAll()** starts to pull ahead, but then drops back to about par. Even when it's winning, it doesn't seem to be enough of an improvement to justify its existence. Does the amount of work in the calculation performed by **setAll()**/**parallelSetAll()** make a difference? In the previous examples, all we did was assign the value of the index into the array location, which is one of the simplest tasks possible. So even when the **N** becomes large, **N*Q** still isn't that great, so it looks like we aren't providing enough opportunity for parallelism. (JMH provides a

way to simulate a variable Q; to learn more, search for **Blackhole.consumeCPU**.)

By making the task more complex using the following method **f()**, we produce more parallel opportunities:

```
// validating/jmh/JMH3.java
package validating.jmh;
import java.util.*;
import org.openjdk.jmh.annotations.*;
import java.util.concurrent.TimeUnit;
@State(Scope.Thread)
@BenchmarkMode(Mode.AverageTime)
@OutputTimeUnit(TimeUnit.MICROSECONDS)
@Warmup(iterations = 5)
@Measurement(iterations = 5)
@Fork(1)
public class JMH3 {
private long[] la;
@Param({
"1",
"10",
```

```
"100",
"1000",
"10000",
"100000",
"1000000",
"10000000",
"100000000",
"250000000"
})
int size;
@Setup
public void setup() {
la = new long[size];
}
public static long f(long x) {
long quadratic = 42 * x * x + 19 * x + 47;
return Long.divideUnsigned(quadratic, x + 1);
}
@Benchmark
public void setAll() {
```

```
Arrays.setAll(la, n -> f(n));
}
@Benchmark
public void parallelSetAll() {
Arrays.parallelSetAll(la, n -> f(n));
}
}
```

f() provides a more complex and time-consuming operation. Now, instead of simply assigning the index into its corresponding location, both **setAll()** and **parallelSetAll()** have more work to do, and this definitely affects the results:

JMH3 Benchmark Size Score % Speedup

setAll 1 0.012

parallelSetAll 1 0.047 0.255

setAll 10 0.107

parallelSetAll 10 3.894 0.027

setAll 100 0.990

parallelSetAll 100 3.708 0.267

setAll 1000 133.814

parallelSetAll 1000 11.747 11.391

setAll 10000 97.954

parallelSetAll 10000 37.259 2.629

setAll 100000 988.475

parallelSetAll 100000 276.264 3.578

setAll 1000000 9203.103

parallelSetAll 1000000 2826.974 3.255

setAll 10000000 92144.951

parallelSetAll 10000000 28126.202 3.276

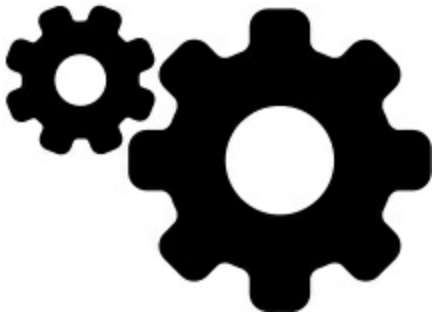
setAll 100000000 921701.863

parallelSetAll 100000000 266750.543 3.455

setAll 250000000 2299127.273

parallelSetAll 250000000 538173.425 4.272

You can see that somewhere around an array size of 1000, **parallelSetAll()** pulls ahead of **setAll()**. It appears that **parallelSetAll()** depends heavily on the complexity of the calculation combined with the size of the array. This is exactly the value of benchmarking, because we've learned subtle things about how **setAll()** and **parallelSetAll()** work and when to use them. This is not obvious from studying the Javadocs.



Much of the time, simple applications of JMH will produce good results (as you shall see in examples later in the book), but we've learned here that you can't assume this is always the case. The JMH site has samples to help you get started.

Profiling and

Optimizing

Sometimes you must detect where your program spends all its time, to see whether you can improve the performance of those sections. A *profiler* finds the slow spots so you can look for the easiest, most obvious way to speed things up.

A profiler gathers information showing which parts of the program consume memory and which methods consume maximum time. Some profilers even disable the garbage collector to help determine patterns of memory allocation.

A profiler is also useful for detecting thread deadlock in your program.

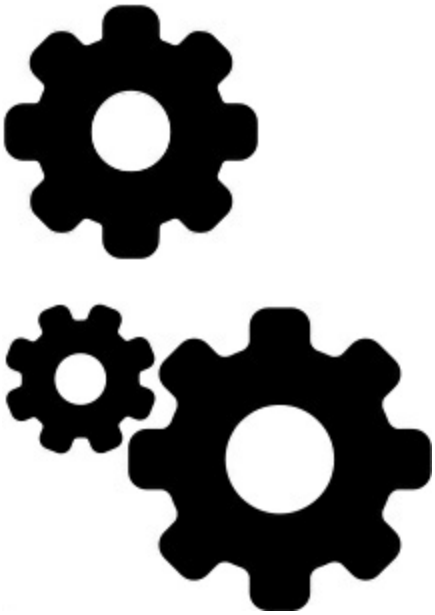
Note the difference between profiling and benchmarking. Profiling

looks at your completed program working on your actual data, whereas benchmarking looks at an isolated fragment of a program, typically to optimize an algorithm.

The Java Development Kit (JDK) installation comes with a visual profiler called **VisualVM**. This is automatically installed in the same directory as **javac**, which you should already have in your execution path. To start **VisualVM**, the console command is:

> jvisualvm

This command opens a window containing links to help information.



Optimization Guidelines

Avoid sacrificing code readability for performance.

Don’t look at performance in isolation. Weigh the amount of effort required versus the advantage gained.

The size of the program matters. Performance optimization is generally valuable only for large projects that run for a long time. Performance is often not a concern for small projects.

Making the program work is a higher priority than delving into its performance. Once you have a working program you can, if necessary, use the profiler to make it more efficient. Consider performance during the initial design/development process only if it is a critical factor.

Do not guess where the bottlenecks are. Run a profiler to get that data.

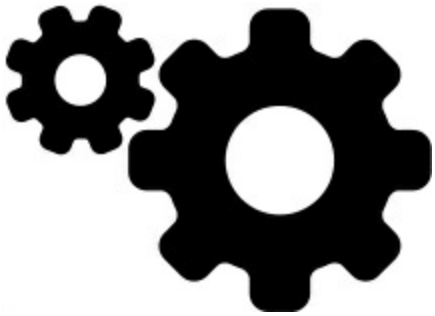
Whenever possible, explicitly discard an instance by setting it to null. This can be a useful hint to the garbage collector.

static final variables can be optimized by the JVM to improve program speed. Program constants should thus be declared **static** and **final**.

Style Checking

When you're working on a project in a team (including and especially open-source projects), it's very helpful if everyone follows the same coding style. This way, reading code for the project doesn't produce mental interrupts due to style differences. However, if you're used to

coding a different style it can be difficult to remember all the style



guidelines for a particular project. Fortunately, tools exist to point out places in your code that don't follow your guidelines.

A popular style checker is Checkstyle. Look at the **gradle.build** and **checkstyle.xml** files in the book's Example Code to see one way to configure Checkstyle. **checkstyle.xml** is a set of common checks, with some of those checks commented out to allow for the style used in this book.

To run all the style checks, the command is:

gradlew checkstyleMain

Some files still produce Checkstyle warnings, typically because those examples demonstrate something you don't normally do in production code.

You can also run the style checks for a specific chapter. For example, here's how to check the Annotations chapter:

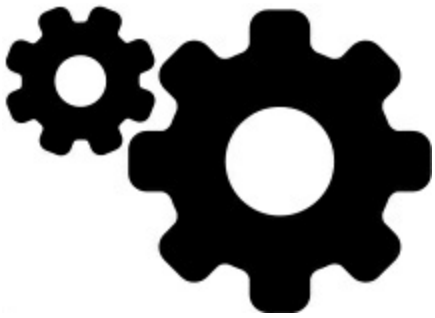
gradlew annotations:checkstyleMain

Static Error Analysis

Although Java's static type checking finds basic syntax errors, additional analysis tools can find more sophisticated bugs that elude **javac**. One such tool is Findbugs. This book's **build.gradle** file in the Example Code contains a configuration for Findbugs so you can enter the command:

gradlew findbugsMain

This produces an HTML report for each chapter, called **main.html**,



showing potential issues in the code. The Gradle command output shows you where each report resides.

When you look at the reports you'll see there are many *false positives* suggesting there's a problem when the code is actually fine. Some of the positives are indeed correct for files where I was demonstrating how *not* to do something.

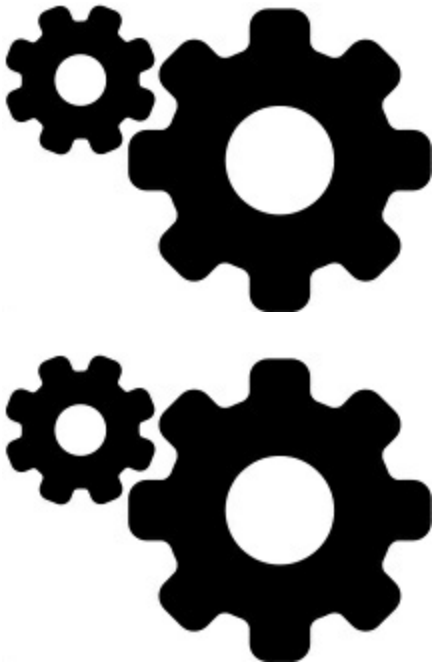
When I initially reviewed the Findbugs output for the book, I found a few things that weren't technically errors but enabled me to improve the code. If you're hunting for a bug, it's worth running Findbugs before starting up your debugger, as it might quickly find something

that could otherwise require hours.

Code Reviews

Unit Testing finds significant and important classes of bugs. Checkstyle and Findbugs perform automatic code reviews to find additional problems. Eventually you reach the point where you must add human eyeballs to the mix. Code reviews are various ways of taking a piece of code written by one person or group and having it read and evaluated by someone else or a group. Initially this can seem intimidating, and it does require emotional trust, but the goal is definitely not to shame or ridicule anyone. The objective is to find program errors, and code reviews are one of the most successful ways to do this. Alas, they are also usually considered “too expensive” (and sometimes that excuse can be a way for programmers to avoid the perceived embarrassment of a review).

Code reviews can be performed as part of *pair programming*, as part of the code check-in process (another programmer is automatically assigned the task of reviewing new code), or with a group, using a *walkthrough*, where everyone reads the code and discusses it. This latter approach has the significant benefit of sharing knowledge and coding culture.



Pair Programming

Pair programming is the practice of two programmers coding together. Typically, one programmer “drives” (sits at the keyboard and types) and the other (the “observer” or “navigator”) reviews and analyzes the code, and also considers strategies. This produces a kind of real-time code review. Normally programmers regularly switch roles.

Pair programming has numerous benefits, but the two most compelling ones are sharing knowledge and preventing blockage. One of the best ways to transfer information is by solving problems together, and I have used pair programming in numerous seminars to great effect (also, people in the seminar get to know each other this

way). And with two people working together, it's far easier to keep moving forward whereas a single programmer can easily get stuck. Pair programmers generally report higher satisfaction in their work. Pair programming can sometimes be a difficult sell to managers who might immediately observe that two programmers working on one problem are less productive than if they are each working on their own projects. While this is often true in the short term, the code produced is of higher quality; along with the other benefits of pair programming this produces greater productivity if you consider a longer view.

Wikipedia's pair programming article is a good start if you want more information.

Refactoring

Technical debt is all those quick-and-dirty solutions that accumulate in your software and make the design impossible to understand and the code unreadable. This is particularly problematic when you must

make changes and add features.

Refactoring is the antidote to technical debt. The key to refactoring is

that it improves the code design, structure and readability (thus reducing technical debt), but it *doesn't change the behavior of the code*.

This can be a hard sell to management: "We're going to put in a lot of work but we won't be adding any features and from the outside there will be no noticeable changes when we're done. But trust us, things will be a lot better." Unfortunately, management only realizes the value of refactoring at the moment it's too late: when they ask for "just one more feature" and you have to tell them it's impossible because the code base has become a huge accumulation of hacks and it will collapse if you try to add another feature, even if you *could* figure out how to do it.

Foundations For Refactoring

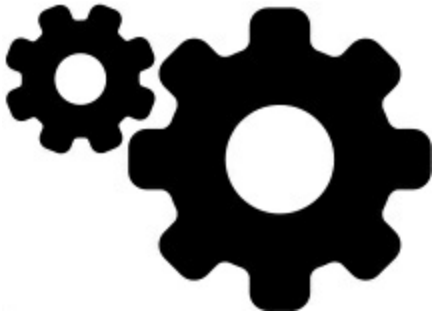
Before you can start refactoring your code, you must have three support systems in place:

1. Tests (typically, JUnit tests as a minimum foundation), so you can ensure your refactorings do not change the behavior of the code.
2. Build automation, so you can easily build the code and run all the tests. This way it's effortless to make a small change and verify it hasn't broken anything. This book uses the Gradle build system,

and you can find the **build.gradle** file in the download that contains the examples.

3. Version control, so you can always provide/go back to a working version of the code, and keep track of the steps along the way.

This book's example code is hosted on Github and uses the **git** version control system.



Without these three systems, refactoring is virtually impossible.

Indeed, without these, building, maintaining and adding to code in the first place is a big challenge. Surprisingly, there are many successful companies that manage to get by for quite awhile without using any of these three systems. However, with such companies it's usually just a matter of time before they run into serious problems.

The Wikipedia article on refactoring provides further details.

Continuous

Integration

In the early days of software development, people could only manage one step at a time, so they took on the belief that they were always

traveling “the happy path,” and each development stage was going to flow seamlessly into the next. This delusion was often called “The Waterfall Model” of software development. I’ve had people tell me that Waterfall was their method of choice, as if it were actually a selected tool and not just wishful thinking.

In this fairy-tale land, each step finished perfectly and on time according to the made-up schedule, and then the next step could start. By the time you reached the end, all the pieces would slide seamlessly together and voila! A shipping product!

In reality, of course, nothing ever went to plan or to schedule. Believing it should, and then believing harder when it didn’t, just made the whole thing worse. Denying evidence doesn’t produce good results.

On top of all this, the product itself often wasn’t something valuable for customers. Sometimes a whole raft of features were a complete waste of time, because the need for those features was invented by someone other than the customer.

Because it came from assembly-line mentality, each development stage had its own team. Schedule slips from an upstream team were passed to a downstream team, and by the time you got to testing and

integration, those teams were expected to somehow catch up to the schedule, and when they inevitably couldn't they were considered "bad team players." The combination of impossible schedules and negative associations created a self-fulfilling prophecy: only the most desperate of developers were willing to do those jobs.

On top of this, business schools continued to produce managers who were only trained to turn the crank on existing processes—processes based on the ideas of industrial-age manufacturing. Business schools that teach creativity rather than conformity continue to be very rare. Eventually people from within the programming ranks couldn't stand it anymore and started experimenting. Some of these initial experiments were called "extreme programming" because they were very different than industrial-age thinking. As the experiments showed results the ideas began to look like common sense. These experiments evolved the now-obvious idea of putting a working product—albeit very minimal—into the hands of customers and asking them if (A) they even wanted it (B) if they liked the way it worked and (C) what other features they might find useful. Then it's back to development to produce a new version. Version by version, the project evolves into something that truly produces value for the customer.

This is completely upside-down from the waterfall approach. You stop assuming that you handle things like product testing and deployment "as the final step." Instead, everything from beginning to end—even for a product that has virtually no features at the outset (in which case you're probably just testing the installation)—must be in play. Doing so has the huge benefit of finding even more problems early in the development cycle. In addition, rather than doing a lot of big, up-front planning and spending time and money on a lot of useless features, you're in a constant feedback cycle with the customer. When the customer doesn't want any more features, you're done. This saves lots of time and money and produces lots of customer satisfaction.

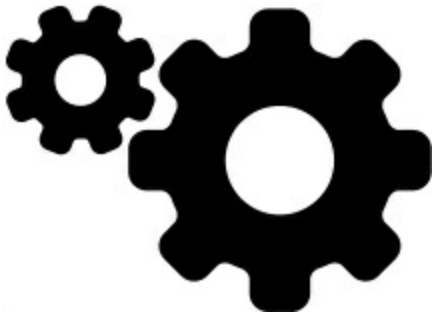
There have been many different pieces and ideas leading up to this approach, but the current over-arching term is *continuous integration* (CI). The difference between CI and the ideas leading up to it is that CI is a distinct mechanical process that encompasses those ideas; it is a well-defined way of doing things. So well-defined, in fact, that the whole process is automated.

The current apex of CI technology is the *continuous integration server*. This is a separate machine or virtual machine, and is commonly a completely separate service hosted by a third-party

company. They typically provide a basic service for free, and if you need additional features like more processors or memory or specialized tools or systems, you pay for those. The CI server starts out as a completely blank slate with only the most minimal operating system available. This is important because it's easy to forget if you have already installed some piece on your development machine, and then not include that piece in your build and deployment systems.

Just like refactoring, *continuous integration* requires a foundation of distributed version control, build automation, and automated testing. The CI server is typically tied into your version control repository. When the CI server sees a change in the repository, it checks out the latest version and begins the process specified in your CI script. This includes installing all necessary tools and libraries (remember, the CI server starts with nothing but a clean, basic operating system), so if there are any problems in that process you discover them. Then it performs any builds and tests specified in your script; the script typically uses exactly the same commands that a human will use in the installation and testing process. If it succeeds or fails the CI server has numerous ways to report that to you, including a simple badge that appears on your code repository.

Using Continuous Integration, every change you check into the repository is automatically validated from beginning to end. This way you find out immediately if you begin to have problems. Even better, when you are ready to ship a new version of the product there's no delay or any extra steps necessary (being able to deliver at any time is



called *Continuous Delivery*).

This book's example code is automatically tested on Travis-CI (for Linux-based systems) and AppVeyor (for Windows). You can see the pass/fail badges on the Readme at the Github repository.

Summary

"It works on my machine." "We are not

shipping your machine!"

Code validation is not a single process or technique. Any one approach only finds certain categories of bugs, and as you develop as a programmer you learn that every additional technique adds to the reliability and robustness of your code. Validation helps you discover more errors not only during development but also during the project

lifetime, as you add capabilities to your application. Modern development means much more than just writing code, and every testing technique you fold into your development process—including and especially custom tools you create to fit a particular application—results in better, faster, more pleasant development and improved value and a more satisfying experience for your customer.

1. I say “mostly” because it’s possible to write code the compiler can’t check, as shown in Type Information↩

2. Design by contract is described in detail in Chapter 11 of *Object-Oriented Software Construction, 2nd Edition*, by Bertrand Meyer (Prentice Hall, 1997).↩

3. An off-the-shelf Mac Mini with 8Gb of memory↩

4. For limited machine configurations this number can be much lower.↩

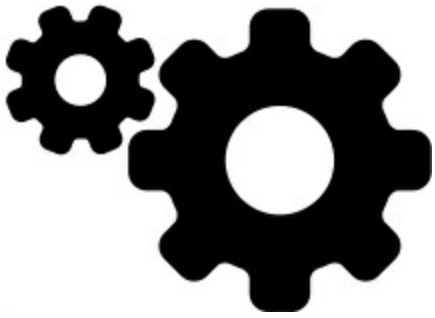
Files

After many years of awkward file I/O programming, Java finally simplified the basic act of reading and writing files.

The full details of “the hard way” are in the Appendix: I/O Streams. If you read that, you might come to the conclusion that the Java designers didn’t care about the experience of their users. Opening and reading a file—which is a rather common experience with most programming languages—required such awkward code that no one could remember how to open a file without looking up the code every single time.

Java 7 introduced great improvements, as if the designers had finally heard the years of pain from their users. These new elements are packaged under **java.nio.file**, where the **n** in **nio** formerly meant “new” but now means “non-blocking” (**io** is for *input/output*). The **java.nio.file** library finally brings Java file manipulation into the same arena as other programming languages. On top of that, Java 8 adds streams to the mix, which makes file programming even nicer.

We shall look at the two basic components to manipulating files:



1. The path to the file or directory.

2. The file itself.

File and Directory

Paths

A **Path** object represents a path to a file or a directory, abstracted across operating systems (OSes) and file systems. The intent is that you don’t have to pay attention to the underlying OS when constructing a path, and your code will work on different OSes without rewriting.

The **java.nio.file.Paths** class contains a single overloaded **static get()** method to take either a sequence of **String**s or a *Uniform Resource Identifier* (URI) and convert it to a **Path** object:

```
// files/PathInfo.java
import java.nio.file.*;
import java.net.URI;
import java.io.File;
import java.io.IOException;
public class PathInfo {
static void show(String id, Object p) {
System.out.println(id + ": " + p);
```

```
}
static void info(Path p) {
show("toString", p);
show("Exists", Files.exists(p));
show("RegularFile", Files.isRegularFile(p));
show("Directory", Files.isDirectory(p));
show("Absolute", p.isAbsolute());
show("FileName", p.getFileName());
show("Parent", p.getParent());
show("Root", p.getRoot());
System.out.println("********************");
}
public static void main(String[] args) {
System.out.println(System.getProperty("os.name"));
info(Paths.get(
"C:", "path", "to", "nowhere", "NoFile.txt")); Path p =
Paths.get("PathInfo.java");
info(p);
Path ap = p.toAbsolutePath();
info(ap);
info(ap.getParent());
```

```
try {
info(p.toRealPath());
} catch(IOException e) {
System.out.println(e);
}
URI u = p.toUri();
System.out.println("URI: " + u);
Path puri = Paths.get(u);
System.out.println(Files.exists(puri));
File f = ap.toFile(); // Don't be fooled
}
}
/* Output:
Windows 10
toString: C:\path\to\nowhere\NoFile.txt
Exists: false
RegularFile: false
Directory: false
Absolute: true
FileName: NoFile.txt
```

Parent: C:\path\to\nowhere

Root: C:

****

toString: PathInfo.java

Exists: true

RegularFile: true

Directory: false

Absolute: false

FileName: PathInfo.java

Parent: null

Root: null

****

toString: C:\Users\Bruce\Documents\GitHub\on-

java\ExtractedExamples\files\PathInfo.java

Exists: true

RegularFile: true

Directory: false

Absolute: true

FileName: PathInfo.java

Parent: C:\Users\Bruce\Documents\GitHub\on-

java\ExtractedExamples\files

Root: C:

****

toString: C:\Users\Bruce\Documents\GitHub\on-

java\ExtractedExamples\files

Exists: true

RegularFile: false

Directory: true

Absolute: true

FileName: files

Parent: C:\Users\Bruce\Documents\GitHub\on-

java\ExtractedExamples

Root: C:

****

toString: C:\Users\Bruce\Documents\GitHub\on-

java\ExtractedExamples\files\PathInfo.java

Exists: true

RegularFile: true

Directory: false

Absolute: true

FileName: PathInfo.java

Parent: C:\Users\Bruce\Documents\GitHub\on-java\ExtractedExamples\files

Root: C:

****

URI: file:///C:/Users/Bruce/Documents/GitHub/on-java/ExtractedExamples/files/PathInfo.java

true

*/

I've added the first line of **main()** to appropriate programs in this chapter to display the OS name, so you can see what differences there are between one OS and another. Ideally the differences are relatively few and isolated to expected places, such as whether / or \ is the path separator. You can see from the output I'm developing on Windows 10.

While **toString()** produces a full representation of the path, you can see that **getFileName()** always produces the name of the file. Using the **Files** utility class (which we'll see more of) you can test to see whether a file exists, is a "regular" file, is a directory, and more. The "Nofile.txt" example shows it is possible to describe a file which isn't there; this allows you to create a new path. "PathInfo.java" lives

in the current directory, and initially it's just the file name without a path, although it still checks out as "existing." Once we convert it to an absolute path, we get the full path starting from the "C:" drive (this was tested on a Windows machine). Now it has a parent, as well.

The definition of the "real" path is a bit vague in the documentation because it depends on the particular file system. If a filename comparison is case-insensitive, for example, you might get a positive match even if the path doesn't look exactly the same because of casing. On such a platform, **toRealPath()** will return the **Path** with the actual case. It also removes any redundant elements.

Here, you see what a URI looks like for a file, but it can be used to describe most things; see Wikipedia for a detailed description. Then we successfully convert the URI back into a **Path**.

Finally, you see something slightly deceiving, which is the call to **toFile()** to produce a **File** object. This sounds like you might get something file-like (it's called **File**, after all) but this method exists for backwards-compatibility to the old-style way of doing things. In that world, **File** actually means either a file or a directory—which sounds like it should have been called "path" instead. Very sloppy and confusing naming, but you can safely ignore it now that **java.nio.file** exists.

Selecting Pieces of a Path

Path objects can easily yield parts of their path:

```
// files/PartsOfPaths.java
import java.nio.file.*;
public class PartsOfPaths {
public static void main(String[] args) {
System.out.println(System.getProperty("os.name"));
Path p =
Paths.get("PartsOfPaths.java").toAbsolutePath();
for(int i = 0; i < p.getNameCount(); i++)
System.out.println(p.getName(i));
System.out.println("ends with '.java': " +
p.endsWith(".java"));
for(Path pp : p) {
System.out.print(pp + ": ");
System.out.print(p.startsWith(pp) + " : ");
System.out.println(p.endsWith(pp));
```

```
}
System.out.println("Starts with " + p.getRoot() +
" " + p.startsWith(p.getRoot()));
}
}
/* Output:
Windows 10
Users
Bruce
Documents
GitHub
on-java
ExtractedExamples
files
PartsOfPaths.java
ends with '.java': false
Users: false : false
Bruce: false : false
Documents: false : false
GitHub: false : false
```

on-java: false : false

ExtractedExamples: false : false

files: false : false

PartsOfPaths.java: false : true

Starts with C:\ true

**/*

You can index into the parts of a **Path** using **getName()**, respecting the upper bound with **getNameCount()**. A **Path** also produces an **Iterator** so you can step through using for-in. Note that, even though my path here *does* end with **.java**, **endsWith()** produces **false**. This is because **endsWith()** is comparing the entire path component, not a substring within the name. This is shown within the for-in body by checking the current piece of the path using **startsWith()** and **endsWith()**. However, we see that iterating through the **Path** does *not* include the root, and only when we check **startsWith()** against the root does it produce **true**.

Analyzing a Path

The **Files** utility class contains a full set of tests to discover information about a **Path**:

```
// files/PathAnalysis.java
import java.nio.file.*;
import java.io.IOException;
public class PathAnalysis {
static void say(String id, Object result) {
System.out.print(id + ": ");
System.out.println(result);
}
public static void
main(String[] args) throws IOException {
System.out.println(System.getProperty("os.name"));
Path p =
Paths.get("PathAnalysis.java").toAbsolutePath();
say("Exists", Files.exists(p));
say("Directory", Files.isDirectory(p));
say("Executable", Files.isExecutable(p));
say("Readable", Files.isReadable(p));
say("RegularFile", Files.isRegularFile(p));
```

```
say("Writable", Files.isWritable(p));
say("notExists", Files.notExists(p));
say("Hidden", Files.isHidden(p));
say("size", Files.size(p));
say("FileStore", Files.getFileStore(p));
say("LastModified: ", Files.getLastModifiedTime(p));
say("Owner", Files.getOwner(p));
say("ContentType", Files.probeContentType(p));
say("SymbolicLink", Files.isSymbolicLink(p));
if(Files.isSymbolicLink(p))
say("SymbolicLink", Files.readSymbolicLink(p));
if(FileSystems.getDefault()
.supportedFileAttributeViews().contains("posix"))
say("PosixFilePermissions",
Files.getPosixFilePermissions(p));
}
}
/* Output:
Windows 10
Exists: true
```

Directory: false

Executable: true

Readable: true

RegularFile: true

Writable: true

notExists: false

Hidden: false

size: 1631

FileStore: SSD (C:)

LastModified: : 2017-05-09T12:07:00.428366Z

Owner: MINDVIEWTOSHIBA\Bruce (User)

ContentType: null

SymbolicLink: false

**/*

For the final test, I had to figure out whether the file system supported Posix before calling **getPosixFilePermissions()**, otherwise it produces a runtime exception.

Adding and Subtracting Paths

We must be able to construct **Path** objects by adding and subtracting pieces to our **Path**. To subtract the base of a **Path** we use **relativize()** and to add pieces at the end of a **Path** we use **resolve()** (not exactly “discoverable” names).

For this example I use **relativize()** to remove the **base** path from all the output, partly as a demonstration and partly to simplify the output. It turns out you can only **relativize()** a **Path** if it is absolute.

This version of show includes **id** numbers to make it easier to track the output:

```
// files/AddAndSubtractPaths.java
import java.nio.file.*;
import java.io.IOException;
public class AddAndSubtractPaths {
static Path base = Paths.get("..", "..", "..")
.toAbsolutePath()
.normalize();
static void show(int id, Path result) {
if(result.isAbsolute())
```

```
System.out.println("(" + id + ")r " +
base.relativize(result));
else
System.out.println("(" + id + ") " + result);
try {
System.out.println("RealPath: "
+ result.toRealPath());
} catch(IOException e) {
System.out.println(e);
}
}
public static void main(String[] args) {
System.out.println(System.getProperty("os.name"));
System.out.println(base);
Path p = Paths.get("AddAndSubtractPaths.java")
.toAbsolutePath();
show(1, p);
Path convoluted = p.getParent().getParent()
.resolve("strings")
.resolve("..")
```

```
.resolve(p.getParent().getFileName());
show(2, convoluted);
show(3, convoluted.normalize());
Path p2 = Paths.get("..", "..");
show(4, p2);
show(5, p2.normalize());
show(6, p2.toAbsolutePath().normalize());
Path p3 = Paths.get(".").toAbsolutePath();
Path p4 = p3.resolve(p2);
show(7, p4);
show(8, p4.normalize());
Path p5 = Paths.get("").toAbsolutePath();
show(9, p5);
show(10, p5.resolveSibling("strings"));
show(11, Paths.get("nonexistent"));
}
}
/* Output:
Windows 10
C:\Users\Bruce\Documents\GitHub
```

(1)r on-

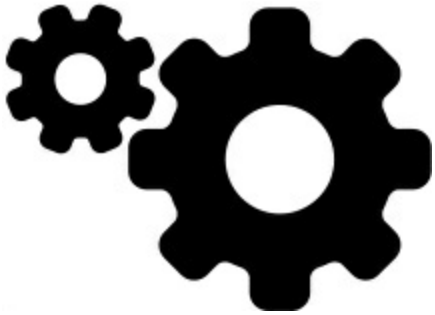
java\ExtractedExamples\files\AddAndSubtractPaths.java

RealPath: C:\Users\Bruce\Documents\GitHub\on-

java\ExtractedExamples\files\AddAndSubtractPaths.java

(2)r on-java\ExtractedExamples\strings\..\files

RealPath: C:\Users\Bruce\Documents\GitHub\on-



java\ExtractedExamples\files

(3)r on-java\ExtractedExamples\files

RealPath: C:\Users\Bruce\Documents\GitHub\on-

java\ExtractedExamples\files

(4) ..\..

RealPath: C:\Users\Bruce\Documents\GitHub\on-java

(5) ..\..

RealPath: C:\Users\Bruce\Documents\GitHub\on-java

(6)r on-java

RealPath: C:\Users\Bruce\Documents\GitHub\on-java

(7)r on-java\ExtractedExamples\files\.\..\..

RealPath: C:\Users\Bruce\Documents\GitHub\on-java

(8)r on-java

RealPath: C:\Users\Bruce\Documents\GitHub\on-java

(9)r on-java\ExtractedExamples\files

RealPath: C:\Users\Bruce\Documents\GitHub\on-java\ExtractedExamples\files

(10)r on-java\ExtractedExamples\strings

RealPath: C:\Users\Bruce\Documents\GitHub\on-java\ExtractedExamples\strings

(11) nonexistent

java.nio.file.NoSuchFileException: C:\Users\Bruce\Documents\GitHub\on-java\ExtractedExamples\files\nonexistent

**/*

I've also added further tests for **toRealPath()**. This always expands and normalizes the **Path**, except when the path doesn't exist, in which case it throws an exception.

Directories

The **Files** utility class contains most of the operations you'll need for

directory and file manipulation. For some reason, however, they did not include a tool to delete directory trees, so we'll create one and add it to the **onjava** library.

```
// onjava/RmDir.java
package onjava;
import java.nio.file.*;
import java.nio.file.attribute.BasicFileAttributes;
import java.io.IOException;
public class RmDir {
public static void rmdir(Path dir)
throws IOException {
Files.walkFileTree(dir,
new SimpleFileVisitor<Path>() {
@Override
public FileVisitResult
visitFile(Path file, BasicFileAttributes attrs)
throws IOException {
Files.delete(file);
return FileVisitResult.CONTINUE;
}
```

```
@Override
public FileVisitResult
postVisitDirectory(Path dir, IOException exc)
throws IOException {
Files.delete(dir);
return FileVisitResult.CONTINUE;
}
});
}
}
```

This relies on **Files.walkFileTree()**; “walking” the tree means looking at every subdirectory and file. The *Visitor* design pattern provides a standard mechanism to visit every object in a collection, then you provide the action you want executed on each of those objects. This action is defined by how you implement the **FileVisitor** argument, which contains:

preVisitDirectory(): Runs on a directory before entries in the directory are visited.

visitFile(): Runs on each file in the directory.

visitFileFailed(): Called for a file that cannot be visited.

postVisitDirectory(): Runs on a directory after entries in the directory—including all the subdirectories beneath it—are visited.

To make things simpler, **java.nio.file.SimpleFileVisitor** provides default definitions for all methods. That way, in our anonymous inner class, we only override the methods with nonstandard behavior: **visitFile()** deletes the file, and **postVisitDirectory()** deletes the directory. Both return flags indicate that the walk should continue (this way you can walk only until you find what you're looking for).

Now we can conditionally delete an existing directory, as part of our exploration of creating and populating directories. In the following example, **makeVariant()** takes a base directory **test** and produces different subdirectory paths by rotating through the **parts** list. These rotations are pasted together with the path separator **sep** using **String.join()**, then the result is returned as a **Path**.

```
// files/Directories.java
import java.util.*;
import java.nio.file.*;
import onjava.RmDir;
```

```
public class Directories {
static Path test = Paths.get("test");
static String sep =
FileSystems.getDefault().getSeparator();
static List<String> parts =
Arrays.asList("foo", "bar", "baz", "bag");
static Path makeVariant() {
Collections.rotate(parts, 1);
return Paths.get("test", String.join(sep, parts));
}
static void refreshTestDir() throws Exception {
if(Files.exists(test))
RmDir.rmdir(test);
if(!Files.exists(test))
Files.createDirectory(test);
}
public static void
main(String[] args) throws Exception {
refreshTestDir();
Files.createFile(test.resolve("Hello.txt"));
```

```
Path variant = makeVariant();
// Throws exception (too many levels):
try {
Files.createDirectory(variant);
} catch(Exception e) {
System.out.println("Nope, that doesn't work.");
}
populateTestDir();
Path tempdir =
Files.createTempDirectory(test, "DIR_");
Files.createTempFile(tempdir, "pre", ".non");
Files.newDirectoryStream(test)
.forEach(System.out::println);
System.out.println("**********");
Files.walk(test).forEach(System.out::println);
}
static void populateTestDir() throws Exception {
for(int i = 0; i < parts.size(); i++) {
Path variant = makeVariant();
if(!Files.exists(variant)) {
```

```
Files.createDirectories(variant);
Files.copy(Paths.get("Directories.java"),
variant.resolve("File.txt"));
Files.createTempFile(variant, null, null);
}
}
}
}
/* Output:
Nope, that doesn't work.
test\bag
test\bar
test\baz
test\DIR_5142667942049986036
test\foo
test\Hello.txt
**********
test
test\bag
test\bag\foo
```

test\bag\foo\bar

test\bag\foo\bar\baz

test\bag\foo\bar\baz\8279660869874696036.tmp

test\bag\foo\bar\baz\File.txt

test\bar

test\bar\baz

test\bar\baz\bag

test\bar\baz\bag\foo

test\bar\baz\bag\foo\12740431342404261.tmp

test\bar\baz\bag\foo\File.txt

test\baz

test\baz\bag

test\baz\bag\foo

test\baz\bag\foo\bar

test\baz\bag\foo\bar\6130572530014544105.tmp

test\baz\bag\foo\bar\File.txt

test\DIR_5142667942049986036

test\DIR_5142667942049986036\pre7704286843227113253.non

test\foo

test\foo\bar

test\foo\bar\baz

test\foo\bar\baz\bag

test\foo\bar\baz\bag\5412864507741775436.tmp

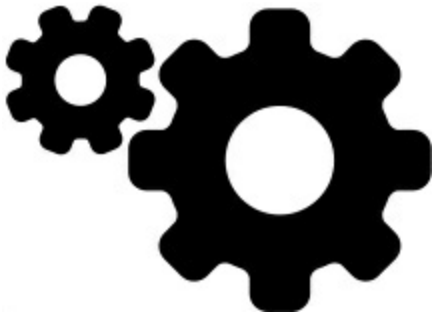
test\foo\bar\baz\bag\File.txt

test\Hello.txt

/

First, **refreshTestDir()** checks to see if **test** already exists. If so, its whole directory is removed using our new **rmdir()** utility. Checking to see whether it **exists()** is then redundant, but I wanted to make the point because if you call **createDirectory()** for a directory that already exists, you'll get an exception.

createFile() makes an empty file with the argument **Path**;



resolve() adds the file name to the end of the **test Path**.

We attempt to use **createDirectory()** to create a path with more than one level, but this throws an exception because that method can only create a single directory.

I've made **populateTestDir()** a separate method because it's reused in a later example. For each variant, we create the full directory path using **createDirectories()**, then populate that terminal directory with a copy of this file but using a different destination name. Then we add a temporary file generated with **createTempFile()**. Here we let the method generate the entire temporary file name by passing it **null** for the second two arguments. After the call to **populateTestDir()**, we create a temporary directory underneath **test**. Note that **createTempDirectory()** only has a prefix option for the name, unlike **createTempFile()** which we again use to put a temporary file in our new temporary directory. You can see from the output that if you don't specify a postfix, the ".tmp" postfix will automatically be used.

To display the results, we first try **newDirectoryStream()** which seems promising, but it turns out to only stream the contents of the **test** directory, and no further down. To get a stream of the entire contents of the directory tree, use **Files.walk()**.

File Systems

For completeness, we need a way to find out the rest of the information about the file system. Here, we get the "default" file

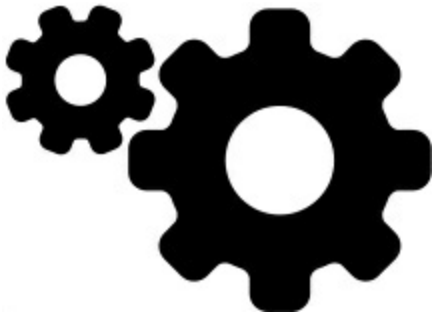
system using the **static FileSystems** utility, but you can also call

getFileSystem() on a **Path** object to get the file system that created that **Path**. You can get a file system given a URI, and you can

also construct a new file system (for OSes that support it).

```
// files/FileSystemDemo.java

import java.nio.file.*;

public class FileSystemDemo {

static void show(String id, Object o) {

System.out.println(id + ": " + o);

}

public static void main(String[] args) {

System.out.println(System.getProperty("os.name"));

FileSystem fsys = FileSystems.getDefault();

for(FileStore fs : fsys.getFileStores())

show("File Store", fs);

for(Path rd : fsys.getRootDirectories())

show("Root Directory", rd);

show("Separator", fsys.getSeparator());

show("UserPrincipalLookupService",

fsys.getUserPrincipalLookupService());

show("isOpen", fsys.isOpen());
```

```
show("isReadOnly", fsys.isReadOnly());
show("FileSystemProvider", fsys.provider());
show("File Attribute Views",
fsys.supportedFileAttributeViews());
}
}
/* Output:
Windows 10
File Store: SSD (C:)
Root Directory: C:\
Root Directory: D:\
Separator: \
UserPrincipalLookupService:
sun.nio.fs.WindowsFileSystem$LookupService$1@15db9742
isOpen: true
isReadOnly: false
FileSystemProvider:
sun.nio.fs.WindowsFileSystemProvider@6d06d69c
File Attribute Views: [owner, dos, acl, basic, user]
```



*/

A **FileSystem** can also produce a **WatchService** and a **PathMatcher**.

Watching a Path

A **WatchService** enables you to set up a process that reacts to changes within a directory. In this example, **delTxtFiles()** runs as a separate task that goes through the whole directory tree and deletes all files that have names ending with **.txt**, and the **WatchService** reacts to file deletions:

```
// files/PathWatcher.java
// {ExcludeFromGradle}
import java.io.IOException;
import java.nio.file.*;
import static java.nio.file.StandardWatchEventKinds.*;
import java.util.concurrent.*;
public class PathWatcher {
```

```
static Path test = Paths.get("test");
static void delTxtFiles() {
try {
Files.walk(test)
.filter(f ->
f.toString().endsWith(".txt"))
.forEach(f -> {
try {
System.out.println("deleting " + f);
Files.delete(f);
} catch(IOException e) {
throw new RuntimeException(e);
}
});
} catch(IOException e) {
throw new RuntimeException(e);
}
}
public static void
main(String[] args) throws Exception {
```

```
Directories.refreshTestDir();
Directories.populateTestDir();
Files.createFile(test.resolve("Hello.txt"));
WatchService watcher =
FileSystems.getDefault().newWatchService();
test.register(watcher, ENTRY_DELETE);
Executors.newSingleThreadScheduledExecutor()
.schedule(
PathWatcher::delTxtFiles,
250, TimeUnit.MILLISECONDS);
WatchKey key = watcher.take();
for(WatchEvent evt : key.pollEvents()) {
System.out.println(
"evt.context(): " + evt.context() +
"\nevt.count(): " + evt.count() +
"\nevt.kind(): " + evt.kind());
System.exit(0);
}
}
}
```

/ *Output:*

deleting test\bag\foo\bar\baz\File.txt

deleting test\bar\baz\bag\foo\File.txt

deleting test\baz\bag\foo\bar\File.txt

deleting test\foo\bar\baz\bag\File.txt

deleting test\Hello.txt

evt.context(): Hello.txt

evt.count(): 1

evt.kind(): ENTRY_DELETE

**/*

The **try** blocks in **delTxtFiles()** look redundant, because they're

both catching the same type of exception, and it seems like the outer

try should be enough. However, Java demands both for some reason

(this might be a bug). Also note that in **filter()** I must explicitly

convert **f.toString()**, otherwise I'll get the **endsWith()** that compares to an entire **Path** object rather than part of its **String**

name.

Once we get a **WatchService** from the **FileSystem**, we register it

with the **test Path** along with the variable argument list of items

we are interested in—you have a choice of watching for

ENTRY_CREATE, **ENTRY_DELETE** or **ENTRY_MODIFY** (creation

and deletion doesn’t qualify as modification).

Because the upcoming call to **watcher.take()** stops everything until something happens, I want **delTxtFiles()** to start running in parallel so it can generate our event of interest. To do this, I first procure a **ScheduledExecutorService** by calling **Executors.newSingleThreadScheduledExecutor()**, then call **schedule()**, handing it the method reference of the desired function and how long it should wait before running it.

At this point, **watcher.take()** sits and waits. When something happens that fits our target pattern, a **WatchKey** is returned containing **WatchEvent**s. The three methods shown are all you can do with a **WatchEvent**.

Look at the output and see what happens. Even though we are deleting files that end with **.txt**, the **WatchService** doesn’t get triggered until **Hello.txt** gets deleted. You might *think* that if you say “watch this directory,” it would naturally include the entire subtree, but it’s very literal: it only watches *that* directory, and *not* everything beneath it. If you want to watch the entire directory tree, you must put a **WatchService** on every subdirectory in the whole tree:

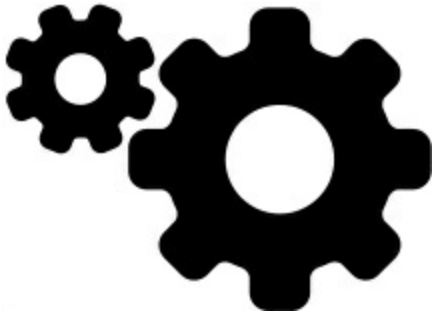
// files/TreeWatcher.java

```
// {ExcludeFromGradle}
import java.io.IOException;
import java.nio.file.*;
import static java.nio.file.StandardWatchEventKinds.*;
import java.util.concurrent.*;
public class TreeWatcher {
static void watchDir(Path dir) {
try {
WatchService watcher =
FileSystems.getDefault().newWatchService();
dir.register(watcher, ENTRY_DELETE);
Executors.newSingleThreadExecutor().submit(() -> {
try {
WatchKey key = watcher.take();
for(WatchEvent evt : key.pollEvents()) {
System.out.println(
"evt.context(): " + evt.context() +
"\nevt.count(): " + evt.count() +
"\nevt.kind(): " + evt.kind());
System.exit(0);
```

```
}
} catch(InterruptedException e) {
return;
}
});
} catch(IOException e) {
throw new RuntimeException(e);
}
}
public static void
main(String[] args) throws Exception {
Directories.refreshTestDir();
Directories.populateTestDir();
Files.walk(Paths.get("test"))
.filter(Files::isDirectory)
.forEach(TreeWatcher::watchDir);
PathWatcher.delTxtFiles();
}
}
/* Output:
```

deleting test\bag\foo\bar\baz\File.txt

deleting test\bar\baz\bag\foo\File.txt



evt.context(): File.txt

evt.count(): 1

evt.kind(): ENTRY_DELETE

**/*

The **watchDir()** method puts a **WatchSevice** for **ENTRY_DELETE** on its argument, and also starts an independent process to monitor that **WatchService**. Here, we don't **schedule()** a task to run later, but instead **submit()** it to run right now. We walk the entire directory tree and apply **watchDir()** to each subdirectory. Now when we run **delTxtFiles()**, one of the **WatchService**s detects the very first deletion.

Finding Files

To find files up until now, we've been using the rather crude approach of calling **toString()** on the **Path**, then using **String** operations

to look at the result. It turns out that **java.nio.file** has a better solution: the **PathMatcher**. You get one by calling **getPathMatcher()** on the **FileSystem** object, and you pass in your pattern of interest. There are two options for patterns: **glob** and **regex**. **glob** is simpler and is actually quite powerful so you'll be able to solve many problems using **glob**. If your problem is more complex, you can use **regex**, which is explained in the upcoming **Strings** chapter.

Here we use **glob** to find all the **Path**s that end with **.tmp** or **.txt**:

```
// files/Find.java
// {ExcludeFromGradle}
import java.nio.file.*;
public class Find {
public static void
main(String[] args) throws Exception {
Path test = Paths.get("test");
Directories.refreshTestDir();
Directories.populateTestDir();
// Creating a *directory*, not a file:
Files.createDirectory(test.resolve("dir.tmp"));
```

```
PathMatcher matcher = FileSystems.getDefault()
.getPathMatcher("glob:**/*.{tmp,txt}");
Files.walk(test)
.filter(matcher::matches)
.forEach(System.out::println);
System.out.println("***************");
PathMatcher matcher2 = FileSystems.getDefault()
.getPathMatcher("glob:*.tmp");
Files.walk(test)
.map(Path::getFileName)
.filter(matcher2::matches)
.forEach(System.out::println);
System.out.println("***************");
Files.walk(test) // Only look for files
.filter(Files::isRegularFile)
.map(Path::getFileName)
.filter(matcher2::matches)
.forEach(System.out::println);
}
}
```

/ Output:*

test\bag\foo\bar\baz\5208762845883213974.tmp

test\bag\foo\bar\baz\File.txt

test\bar\baz\bag\foo\7918367201207778677.tmp

test\bar\baz\bag\foo\File.txt

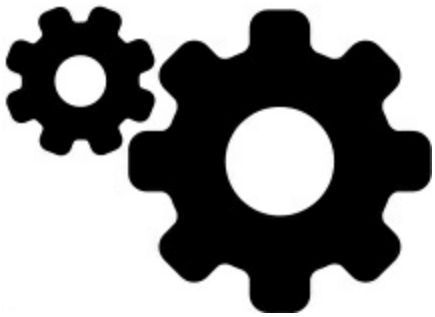
test\baz\bag\foo\bar\8016595521026696632.tmp

test\baz\bag\foo\bar\File.txt

test\dir.tmp

test\foo\bar\baz\bag\5832319279813617280.tmp

test\foo\bar\baz\bag\File.txt



****

5208762845883213974.tmp

7918367201207778677.tmp

8016595521026696632.tmp

dir.tmp

5832319279813617280.tmp

****

5208762845883213974.tmp

7918367201207778677.tmp

8016595521026696632.tmp

5832319279813617280.tmp

*/

In **matcher**, the ****/** at the beginning of the **glob** expression means "all subdirectories," and it's essential if you want to match more than just **Path**s ending in the base directory because it matches the full path up until your desired result. The single ***** is "anything," then a dot, then the curly braces indicate a list of possibilities—we are looking for anything ending with either **.tmp** or **.txt**. You can find further details in the **getPathMatcher()** documentation.

matcher2 just uses ***.tmp**, which would ordinarily not match anything, but adding the **map()** operation reduces the full path to just the name at the end.

Notice in both cases that **dir.tmp** shows up in the output even though it's a directory and not a file. To only find files, you must filter for them as in the last **Files.walk()**.

Reading & Writing

Files

At this point we can do just about anything with paths and directories. Now let’s look at manipulating the contents of the files themselves.

If a file is “small,” for some definition of “small” (which just means “it runs fast enough for you and doesn’t run out of memory”), the **java.nio.file.Files** class contains utilities for easily reading and writing both text and binary files.

Files.readAllLines() reads the whole file in at once (thus, the importance of it being a “small” file), producing a **List<String>** .

For an example file, we’ll reuse **streams/Cheese.dat**:

```
// files/ListOfLines.java
import java.util.*;
import java.nio.file.*;
public class ListOfLines {
public static void
main(String[] args) throws Exception {
Files.readAllLines(
Paths.get("../streams/Cheese.dat"))
.stream()
.filter(line -> !line.startsWith("//"))
```

```
.map(line ->
line.substring(0, line.length()/2))
.forEach(System.out::println);
}
}
/* Output:
Not much of a cheese
Finest in the
And what leads you
Well, it's
It's certainly uncon
*/
```

Comment lines are skipped, and the rest are only printed halfway.

Notice how easy it is: you just hand a **Path** to **readAllLines()** (it was far messier in the past). There's an overloaded version of **readAllLines()** that includes a **Charset** argument to establish the Unicode encoding of the file.

Files.write() is overloaded to write either an array of **byte**s or anything **Iterable** (which also includes a **Charset** option):

```
// files/Writing.java
```

```
import java.util.*;
import java.nio.file.*;
public class Writing {
static Random rand = new Random(47);
static final int SIZE = 1000;
public static void
main(String[] args) throws Exception {
// Write bytes to a file:
byte[] bytes = new byte[SIZE];
rand.nextBytes(bytes);
Files.write(Paths.get("bytes.dat"), bytes);
System.out.println("bytes.dat: " +
Files.size(Paths.get("bytes.dat")));
// Write an iterable to a file:
List<String> lines = Files.readAllLines(
Paths.get("../streams/Cheese.dat"));
Files.write(Paths.get("Cheese.txt"), lines);
System.out.println("Cheese.txt: " +
Files.size(Paths.get("Cheese.txt")));
}
```

}

/ *Output:*

bytes.dat: 1000

Cheese.txt: 199

**/*

We use **Random** to create a thousand random **byte**s; you can see the resulting file size is 1000.

A **List** is written to a file here, but anything **Iterable** will work.

What if file size is an issue? Perhaps:

1. The file is so big you might run out of memory if you read the whole thing at once.

2. You only need to work partway through the file to get the results you want, so reading the whole file wastes time.

Files.lines() conveniently turns a file into a **Stream** of lines:

// files/ReadLineStream.java

import java.nio.file.*;

public class ReadLineStream {

public static void

main(String[] args) **throws** Exception {

Files.lines(Paths.get("PathInfo.java"))

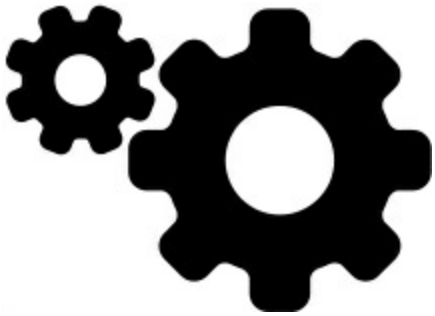
```
.skip(13)
.findFirst()
.ifPresent(System.out::println);
}
}
/* Output:
show("RegularFile", Files.isRegularFile(p));
*/
```

This streams the first example in this chapter, skips 13 lines, takes the next line and prints it.

Files.lines() is very useful for processing a file as an *incoming* **Stream** of lines, but what if you want to read, process, and write, all in a single **Stream**? This requires slightly more complex code:

```
// files/StreamInAndOut.java
import java.io.*;
import java.nio.file.*;
import java.util.stream.*;
public class StreamInAndOut {
public static void main(String[] args) {
try(
```

```
Stream<String> input =
```



```
Files.lines(Paths.get("StreamInAndOut.java"));
PrintWriter output =
new PrintWriter("StreamInAndOut.txt")
) {
input
.map(String::toUpperCase)
.forEachOrdered(output::println);
} catch(Exception e) {
throw new RuntimeException(e);
}
}
}
```

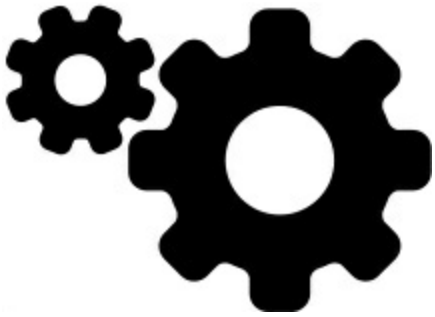
Because we're performing all the manipulation within the same block, both files can be opened within the same try-with-resources statement. **PrintWriter** is an old-style **java.io** class that allows

you to “print to” a file, so it’s ideal for this application. If you look at **StreamInAndOut.txt** you’ll see it is indeed in all uppercase.

Summary

Although this has been a fairly thorough introduction to file and directory manipulation, there are still unexplored features in the library—be sure to study the Javadocs for **java.nio.file**, especially **java.nio.file.Files**.

The Java 7 & 8 improvements in libraries for working with files and directories are monumental. If you’re just getting started with Java, you’re lucky. In the past, it was so unpleasant I was convinced that the Java designers just didn’t consider file manipulation important enough to make it easy. It was a definite turnoff for beginner, and for teaching the language to beginners. I don’t understand why it took so long to fix this glaring issue but however it happened, I’m glad. Working with files is now easy and even fun, something you could never say before.



Strings

String manipulation is arguably one of the most common activities in computer programming.

This is especially true in Web systems, where Java is a major player. In this chapter, we'll look more deeply at what may be the most heavily used class in the language, **String**, along with some of its associated classes and utilities.

Immutable Strings

Objects of the **String** class are immutable. If you examine the JDK documentation for the **String** class, you'll see that every method in the class that appears to modify a **String** actually creates and returns a brand new **String** object containing the modification. The original **String** is left untouched.

Consider the following code:

// strings/Immutable.java

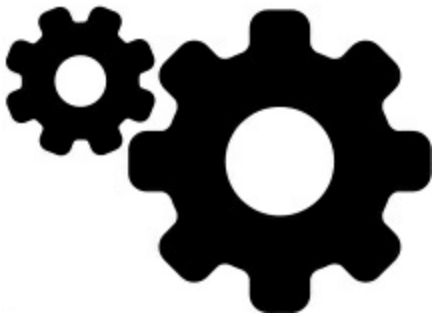
```
public class Immutable {
public static String upcase(String s) {
return s.toUpperCase();
}
public static void main(String[] args) {
String q = "howdy";
System.out.println(q); // howdy
String qq = upcase(q);
System.out.println(qq); // HOWDY
System.out.println(q); // howdy
}
}
/* Output:
howdy
HOWDY
howdy
*/
```

When **q** is passed in to **upcase()** it's actually a copy of the reference to **q**. The object this reference is connected to stays in a single physical location. The references are copied as they are passed around.

Looking at the definition for **upcase()**, notice that the reference that's passed in has the name **s**, and it exists for only as long as the body of **upcase()** is being executed. When **upcase()** completes, the local reference **s** vanishes. **upcase()** returns the result: a reference to the original **String**, with all the characters set to uppercase. But the reference it returns is for a new object, and the original **q** is left alone.

This behavior is usually what you want. Suppose you say:

```
String s = "asdf";
String x = Immutable.upcase(s);
```



Do you really want the **upcase()** method to *change* the argument? To the reader of the code, an argument usually looks like a piece of information provided to the method, not something to be modified. This is an important guarantee, since it makes code easier to write and understand.

Overloading + vs.

StringBuilder

Since **String** objects are immutable, you can alias to a particular **String** as many times as you want. Because a **String** is read-only, there's no possibility that one reference will change something that affect the other references.

Immutability can have efficiency issues. A case in point is the operator **+** that is overloaded for **String** objects. Overloading means an operation has extra meaning when used with a particular class. (The **+** and **+=** for **String** are the only operators overloaded in Java, and Java does not allow the programmer to overload any others.)1

The **+** operator concatenates **String**s:

```
// strings/Concatenation.java
public class Concatenation {
public static void main(String[] args) {
String mango = "mango";
String s = "abc" + mango + "def" + 47;
System.out.println(s);
}
}
/* Output:
```

abcmangodef47

*/

Imagine how this *might* work. The **String** “abc” could have a method **append()** that creates a new **String** object containing “abc” concatenated with the contents of **mango**. The new **String** object would then create another new **String** that added “def,” and so on.

This would certainly work, but it requires the creation of many **String** objects just to put together this new **String**, then you have a bunch of intermediate **String** objects that must be garbage collected. I suspect that the Java designers tried this approach first (a lesson in software design—you don’t really know anything about a system until you try it out in code and get something working). I also suspect they discovered it delivered unacceptable performance.

To see what really happens, you can decompile the above code using the **javap** tool that comes as part of the JDK. Here’s the command line:

javap -c Concatenation

The **-c** flag will produce the JVM bytecodes. After we strip out the parts we’re not interested in and do a bit of editing, here are the

relevant bytecodes:

public static void main(java.lang.String[]);

Code:

Stack=2, Locals=3, Args_size=1

0: ldc #2; *//String mango*

2: astore_1

3: **new** #3; *//class StringBuilder*

6: dup

7: invokespecial #4; *//StringBuilder."<init>":()*

10: ldc #5; *//String abc*

12: invokevirtual #6; *//StringBuilder.append:(String)*

15: aload_1

16: invokevirtual #6; *//StringBuilder.append:(String)*

19: ldc #7; *//String def*

21: invokevirtual #6; *//StringBuilder.append:(String)*

24: bipush 47

26: invokevirtual #8; *//StringBuilder.append:(I)*

29: invokevirtual #9; *//StringBuilder.toString:()*

32: astore_2

33: getstatic #10; *//Field System.out:PrintStream;*

36: aload_2

37: invokevirtual #11; *//PrintStream.println:(String)*

40: **return**

If you've had experience with assembly language, this might look familiar to you—statements like **dup** and **invokevirtual** are the Java Virtual Machine (JVM) equivalent of assembly language. If you've never seen assembly language, don't worry about it—the important part to notice is the introduction by the compiler of the **java.lang.StringBuilder** class. There was no mention of **StringBuilder** in the source code, but the compiler decided to use it anyway, because it is much more efficient.

here, the compiler creates a **StringBuilder** object to build the **String s**, and calls **append()** four times, one for each of the pieces. Finally, it calls **toString()** to produce the result, which it stores (with **astore_2**) as **s**.

Before you assume you can just use **String**s everywhere and that the compiler will make everything efficient, let's look a little more closely at what the compiler is doing. Here's an example that produces a **String** result in two ways: using **String**s, and by hand-coding with **StringBuilder**:

```
// strings/WhitherStringBuilder.java
public class WhitherStringBuilder {
public String implicit(String[] fields) {
String result = "";
for(String field : fields) {
result += field;
}
return result;
}
public String explicit(String[] fields) {
StringBuilder result = new StringBuilder();
for(String field : fields) {
result.append(field);
}
return result.toString();
}
}
```

Now if you run **javap -c WitherStringBuilder**, you see the code for the two different methods (I've removed needless details). First, **implicit()**:

public java.lang.String implicit(java.lang.String[]);

0: ldc #2 *// String*

2: astore_2

3: aload_1

4: astore_3

5: aload_3

6: arraylength

7: istore 4

9: iconst_0

10: istore 5

12: iload 5

14: iload 4

16: if_icmpge 51

19: aload_3

20: iload 5

22: aaload

23: astore 6

25: **new** #3 *// StringBuilder*

28: dup

29: invokespecial #4 *// StringBuilder."<init>"*

32: aload_2

33: invokevirtual #5 *// StringBuilder.append:(String)*

36: aload 6

38: invokevirtual #5 *// StringBuilder.append:(String;)*

41: invokevirtual #6 *// StringBuilder.toString:()*

44: astore_2

45: iinc 5, 1

48: **goto** 12

51: aload_2

52: areturn

Notice **16:** and **35:**, which together form a loop. **16:** does an "integer compare greater than or equal to" of the operands on the stack and jumps to **51:** when the loop is done. **48:** is a goto back to the beginning of the loop, at **12:**. Notice that the **StringBuilder** construction happens *inside* this loop, which means you're going to get a new **StringBuilder** object every time you pass through the loop.

Here are the bytecodes for **explicit()**:

public java.lang.String explicit(java.lang.String[]);

0: **new** #3 *// StringBuilder*

3: dup

4: invokespecial #4 *// StringBuilder."<init>"*

7: astore_2

8: aload_1

9: astore_3

10: aload_3

11: arraylength

12: istore 4

14: iconst_0

15: istore 5

17: iload 5

19: iload 4

21: if_icmpge 43

24: aload_3

25: iload 5

27: aaload

28: astore 6

30: aload_2

31: aload 6

33: invokevirtual #5 *// StringBuilder.append:(String)*

36: pop

37: iinc 5, 1

40: **goto** 17

43: aload_2

44: invokevirtual #6 *// StringBuilder.toString:()*

47: areturn

Not only is the loop code shorter and simpler, the method only creates a single **StringBuilder** object. With an explicit **StringBuilder**, you can preallocate its size if you know how big it might be, so it doesn't constantly reallocate the buffer.

Thus, when you create a **toString()** method, if the operations are simple ones the compiler can figure out on its own, you can generally rely on it to build the result in a reasonable fashion. But if looping is involved *and performance is an issue*, explicitly use a **StringBuilder** in your **toString()**, like this:

```
// strings/UsingStringBuilder.java
import java.util.*;
import java.util.stream.*;
public class UsingStringBuilder {
public static String string1() {
Random rand = new Random(47);
```

```
StringBuilder result = new StringBuilder("[");
for(int i = 0; i < 25; i++) {
result.append(rand.nextInt(100));
result.append(", ");
}
result.delete(result.length()-2, result.length());
result.append("]");
return result.toString();
}
public static String string2() {
String result = new Random(47)
.ints(25, 0, 100)
.mapToObj(Integer::toString)
.collect(Collectors.joining(", "));
return "[" + result + "]";
}
public static void main(String[] args) {
System.out.println(string1());
System.out.println(string2());
}
```

}

/ *Output:*

[58, 55, 93, 61, 61, 29, 68, 0, 22, 7, 88, 28, 51, 89,

9, 78, 98, 61, 20, 58, 16, 40, 11, 22, 4]

[58, 55, 93, 61, 61, 29, 68, 0, 22, 7, 88, 28, 51, 89,

9, 78, 98, 61, 20, 58, 16, 40, 11, 22, 4]

**/*

In **string1()**, each piece of the result is added with an **append()** statement. If you try to take shortcuts and do something like **append(a + ": " + c)**, the compiler will jump in and start making more **StringBuilder** objects again. If you are in doubt about which approach to use, you can always run **javap** to double-check.

Although **StringBuilder** has a full complement of methods, including **insert()**, **replace()**, **substring()** and even **reverse()**, the ones you generally use are **append()** and **toString()**. Note how the call to **delete()** removes the last comma and space before adding the closing square bracket.

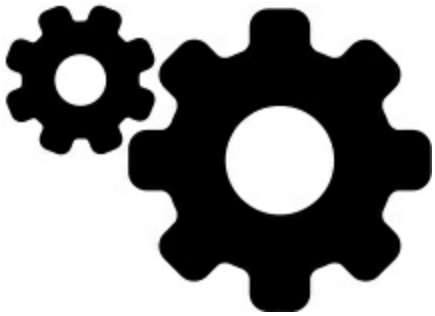
string2() uses **Stream**s and the resulting code is far more aesthetically pleasing. As it turns out, **Collectors.joining()**

also uses a **StringBuilder** internally, so you lose nothing!

StringBuilder was introduced in Java 5. Prior to this, Java used

StringBuffer, which ensured thread safety (see the Concurrent

Programming chapter) and so was significantly more expensive. With **StringBuilder**, **String** operations should be faster.



Unintended Recursion

Because (like every other class) the Java standard collections are

ultimately inherited from **Object**, they contain a **toString()**

method. This is overridden so they produce a **String** representation

of themselves, including the objects they hold.

ArrayList.toString(), for example, steps through the elements

of the **ArrayList** and calls **toString()** for each one:

// strings/ArrayListDisplay.java

import java.util.*;

import java.util.stream.*;

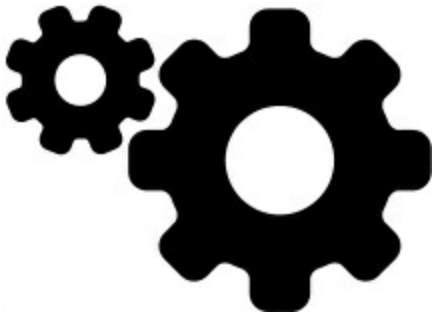
import generics.coffee.*;

```
public class ArrayListDisplay {
public static void main(String[] args) {
List<Coffee> coffees =
Stream.generate(new CoffeeSupplier())
.limit(10)
.collect(Collectors.toList());
System.out.println(coffees);
}
}
/* Output:
[Americano 0, Latte 1, Americano 2, Mocha 3, Mocha 4,
Breve 5, Americano 6, Latte 7, Cappuccino 8, Cappuccino
9]
*/
```

Suppose you'd like your **toString()** to print the address of your class. It seems to make sense to refer to **this**:

```
// strings/InfiniteRecursion.java
// Accidental recursion
// {ThrowsException}
// {VisuallyInspectOutput} Throws very long exception
```

```
import java.util.*;
```



```
import java.util.stream.*;
public class InfiniteRecursion {
@Override
public String toString() {
return
" InfiniteRecursion address: " + this + "\n";
}
public static void main(String[] args) {
Stream.generate(InfiniteRecursion::new)
.limit(10)
.forEach(System.out::println);
}
}
```

If you create an **InfiniteRecursion** object, then display it, you'll get a very long sequence of exceptions. This is also true if you place the

InfiniteRecursion objects in an **ArrayList** and print that **ArrayList** as shown here. What's happening is *automatic type conversion* for **String**s. When you say:

"InfiniteRecursion address: " + **this**

The compiler sees a **String** followed by a **+** and something that's not a **String**, so it tries to convert **this** to a **String**. It does this conversion by calling **toString()**, which produces a recursive call.

If you really want to print the address of the object, the solution is to call the **Object toString()** method, which does just that. So instead of saying **this**, say **super.toString()**.

Operations on Strings

Here are most of the methods available for **String** objects. Overloaded methods are summarized in a single row:

Arguments,

Method

Use

Overloading

Overloaded:

default, **String**,

StringBuilder,

Constructor

Creating **String**

StringBuffer,

objects.

char arrays, **byte**

arrays.

Number of

length()

characters in the

String.

The **char** at a

charAt()

int Index

location in the

String.

The beginning and

end from which to

Copy **char**s or

copy, the array to

getChars(), **getBytes()**

copy into, an index

bytes into an

into the destination

external array.

array.

Produces a

char[]

toCharArray()

containing the

characters in the

String.

An equality check

on the contents of

equals(),

A **String** to

the two **String**

equalsIgnoreCase()

compare with.

Result is **true**

the contents are

equal.

Result is negative,

zero, or positive

depending on the

lexicographical

compareTo()

A **String** to

ordering of the

compareToIgnoreCase() compare with.

String and the

argument.

Uppercase and

lowercase are not

equal!

The

Result is **true**

the argument is

contains()

CharSequence

contained in the

you want to find.

String.

A **CharSequence**

Result is **true**

or

contentEquals()

there’s an exact

StringBuffer

match with the

to compare.

argument.

boolean result

indicates whether

isEmpty()

the **String** is

length 0.

Offset into this

String, the other

boolean result

regionMatches()

String and its

indicates whether

offset and length to

the region

compare. Overload

matches.

adds “ignore case.”

String that it

boolean result

might start with.

indicates whether

startsWith()

Overload adds

the **String** starts

offset into

argument.

with the argument.

String that

boolean result

endsWith()

might be a suffix of

indicates whether

the argument is a

this **String**.

suffix.

Returns -1 if the

argument is not

found within this

Overloaded: **char**,

String;

indexOf()

char and starting

,

otherwise, returns

the index where

lastIndexOf()

index, **String**,

the argument

String and

starting index.

starts.

lastIndexOf()

searches backward

from end.

Returns **boolean**

indicating whether

A regular

matches()

expression.

this **String**

matches the given

regular expression.

A regular

Splits the **String**

expression.

Optional second

around the regular

split()

argument is

expression.

maximum number

Returns an array

of splits to make.

of results.

Delimiter,

elements. Produces

Pieces become a

join() (introduced in Java

a new **String** by

new **String**

8)

joining together

separated by

elements with

delimiter.

delimiter.

Returns a new

Overloaded:

substring() (also

String

starting index;

object

containing the

subSequence())

starting index +

ending index.

specified character

set.

Returns a new

String object

containing the

concat()

The **String** to

original **String**

concatenate.

characters

followed by the

characters in the

argument.

The old character

Returns a new

to search for, the

new character to

String object

replace it with. Can

with the

replace()

also replace a

replacements

CharSequence

made. Uses the old

with a

String if no

CharSequence

match is found.

.

A regular

Returns a new

expression to

String

replaceFirst()

search for, the new

object

String

with the

to replace

replacement made.

it with.

A regular

Returns a new

expression to

String object

replaceAll()

search for, the new

with all

String to replace

replacements

it with.

made.

Returns a new

toLowerCase(),

String object

toUpperCase()

with the case of all

letters changed.

Uses the old

String if no

changes are made.

Returns a new

String object

with the

whitespace

trim()

removed from

each end. Uses the

old **String** if no

changes are made.

Overloaded:

Object, **char[]**,

Returns a **String**

char[] and offset

containing a

valueOf() (**static**)

and count,

character

boolean, **char**,

representation of

int, **long**,

the argument.

float, **double**.

Produces one and

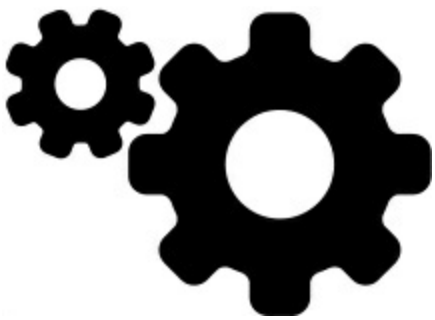
only one **String**

intern()

reference per

unique character

sequence.



Format string and

Produces

arguments for

formatted result

format()

substitution into

String.

the format

specifiers.

Every **String** method carefully returns a new **String** object when it's necessary to change the contents. If the contents don't need changing, the method just returns a reference to the original **String**. This saves storage and overhead.

The **String** methods involving *regular expressions* are explained later in this chapter.

Formatting Output

One of the long-awaited features that finally appeared in Java 5 is

output formatting in the style of C's **printf()** statement. Not only does this allow for simplified output code, but it also gives Java developers powerful control over output formatting and alignment.

printf()

C's **printf()** doesn't assemble strings the way Java does, but takes a single *format string* and inserts values into it, formatting as it goes. Instead of using the overloaded **+** operator (which C doesn't overload) to concatenate quoted text and variables, **printf()** uses special placeholders to show where the data should go. The arguments inserted into the format **String** follow in a comma-separated list. For example:

```
System.out.printf("Row 1: [%d %f]%n", x, y);
```

At run time, the value of **x** is inserted into **%d** and the value of **y** is inserted into **%f**. These placeholders are called *format specifiers* and, in addition to telling where to insert the value, they also tell what kind of variable is inserted and how to format it. For instance, the **%d** above says that **x** is an integer and the **%f**says **y** is a floating point value (a **float** or **double**).

System.out.format()

Java 5 introduced the **format()** method, available to **PrintStream** or **PrintWriter** objects (which you'll learn more about in the Appendix: I/O Streams), which includes **System.out**. The **format()** method is modeled after C's **printf()**. There's even a convenience **printf()** method you can use if you're feeling nostalgic, which just calls **format()**. Here's a simple example:

```
// strings/SimpleFormat.java
public class SimpleFormat {
public static void main(String[] args) {
int x = 5;
double y = 5.332542;
// The old way:
System.out.println("Row 1: [" + x + " " + y + "]");
// The new way:
System.out.format("Row 1: [%d %f]%n", x, y);
// or
System.out.printf("Row 1: [%d %f]%n", x, y);
}
}
```

/ *Output:*

Row 1: [5 5.332542]

Row 1: [5 5.332542]

Row 1: [5 5.332542]

**/*

format() and **printf()** are equivalent. In both cases, there's only a single format **String**, followed by one argument for each format specifier.

The **String** class also has a **static format()** method which produces a formatted **String**.

The Formatter Class

All of Java's formatting functionality is handled by the **Formatter** class in the **java.util** package. You can think of **Formatter** as a translator that converts your format **String** and data into the desired result. When you create a **Formatter** object, you tell it where you want this result to go by passing that information to the constructor:

```
// strings/Turtle.java
import java.io.*;
import java.util.*;
public class Turtle {
private String name;
private Formatter f;
public Turtle(String name, Formatter f) {
this.name = name;
this.f = f;
}
public void move(int x, int y) {
f.format("%s The Turtle is at (%d,%d)%n",
name, x, y);
}
```

```
public static void main(String[] args) {
PrintStream outAlias = System.out;
Turtle tommy = new Turtle("Tommy",
```

```
new Formatter(System.out));
Turtle terry = new Turtle("Terry",
new Formatter(outAlias));
tommy.move(0,0);
terry.move(4,8);
tommy.move(3,4);
terry.move(2,5);
tommy.move(3,3);
terry.move(3,3);
}
}
/* Output:
Tommy The Turtle is at (0,0)
Terry The Turtle is at (4,8)
Tommy The Turtle is at (3,4)
Terry The Turtle is at (2,5)
Tommy The Turtle is at (3,3)
Terry The Turtle is at (3,3)
*/
```

The **%s** format specifier indicates a **String** argument.

All the **tommy** output goes to **System.out** and all the **terry** output goes to an alias of **System.out**. The constructor is overloaded to

take a range of output locations, but the most useful are **PrintStream**s (as above), **OutputStream**s, and **File**s. You'll learn more about these in the Appendix: I/O Streams.

Format Specifiers

To control spacing and alignment when inserting data, you need more elaborate format specifiers. Here's the general syntax:

%[argument_index$][flags][width][.precision]conversion

Often, you must control the minimum size of a field. This can be accomplished by specifying a *width*. The **Formatter** guarantees that a field is at least a certain number of characters wide by padding it with spaces if necessary. By default, the data is right justified, but this can be overridden by including a **-**in the flags section.

The opposite of *width* is *precision*, used to specify a maximum. Unlike the *width*, which is applicable to all data conversion types and behaves the same with each, *precision* has a different meaning for different types. For **String**s, the *precision* specifies the maximum number of **String** characters to print. For floating point numbers, *precision* specifies the number of decimal places to display (the default is 6), rounding if there are too many or adding trailing zeroes if there are too few. Since integers have no fractional part, *precision* isn't applicable to

them and you'll get an exception if you use precision with an integer conversion type.

Here, we'll use format specifiers to print a shopping receipt. This is a very simple example of the *Builder* design pattern, where you create a starting object, add things to it, and finally complete it with the **build()** method:

```
// strings/ReceiptBuilder.java
import java.util.*;
public class ReceiptBuilder {
private double total = 0;
private Formatter f =
new Formatter(new StringBuilder());
public ReceiptBuilder() {
f.format(
"%-15s %5s %10s%n", "Item", "Qty", "Price");
f.format(
"%-15s %5s %10s%n", "----", "---", "-----");
}
public void add(String name, int qty, double price) {
f.format("%-15.15s %5d %10.2f%n", name, qty, price);
```

```
total += price * qty;
}
public String build() {
f.format("%-15s %5s %10.2f%n", "Tax", "",
total * 0.06);
f.format("%-15s %5s %10s%n", "", "", "-----");
f.format("%-15s %5s %10.2f%n", "Total", "",
total * 1.06);
return f.toString();
}
public static void main(String[] args) {
ReceiptBuilder receiptBuilder =
new ReceiptBuilder();
receiptBuilder.add("Jack's Magic Beans", 4, 4.25);
receiptBuilder.add("Princess Peas", 3, 5.1);
receiptBuilder.add(
"Three Bears Porridge", 1, 14.29);
System.out.println(receiptBuilder.build());
}
}
```

/ *Output:*

Item Qty Price

---- --- -----

Jack's Magic Be 4 4.25

Princess Peas 3 5.10

Three Bears Por 1 14.29

Tax 2.80

Total 49.39

**/*

By passing a **StringBuilder** to the **Formatter** constructor, I give it a place to build the **String**; you can also send it to standard output or even a file using the constructor argument.

Formatter provides powerful control over spacing and alignment with fairly concise notation. Here, the format **String**s are copied to produce the appropriate spacing.

Formatter Conversions

These are the conversion characters you’ll come across most frequently:

d

Integral (as decimal)

c

Unicode character

b

Boolean value

s

String

f

Floating point (as decimal)

Floating point (in scientific

e

notation)

x

Integral (as hex)

h

Hash code (as hex)

%

Literal “%”

Here’s an example that shows these conversions in action:

```
// strings/Conversion.java
import java.math.*;
import java.util.*;
public class Conversion {
public static void main(String[] args) {
Formatter f = new Formatter(System.out);
char u = 'a';
System.out.println("u = 'a'");
f.format("s: %s%n", u);
// f.format("d: %d%n", u);
f.format("c: %c%n", u);
f.format("b: %b%n", u);
// f.format("f: %f%n", u);
// f.format("e: %e%n", u);
// f.format("x: %x%n", u);
f.format("h: %h%n", u);
int v = 121;
System.out.println("v = 121");
```

```
f.format("d: %d%n", v);
f.format("c: %c%n", v);
f.format("b: %b%n", v);
f.format("s: %s%n", v);
// f.format("f: %f%n", v);
// f.format("e: %e%n", v);
f.format("x: %x%n", v);
f.format("h: %h%n", v);
BigInteger w = new BigInteger("50000000000000");
System.out.println(
"w = new BigInteger(\"50000000000000\")");
f.format("d: %d%n", w);
// f.format("c: %c%n", w);
f.format("b: %b%n", w);
f.format("s: %s%n", w);
// f.format("f: %f%n", w);
// f.format("e: %e%n", w);
f.format("x: %x%n", w);
f.format("h: %h%n", w);
double x = 179.543;
```

```
System.out.println("x = 179.543");
// f.format("d: %d%n", x);
// f.format("c: %c%n", x);
f.format("b: %b%n", x);
f.format("s: %s%n", x);
f.format("f: %f%n", x);
f.format("e: %e%n", x);
// f.format("x: %x%n", x);
f.format("h: %h%n", x);
Conversion y = new Conversion();
System.out.println("y = new Conversion()");
// f.format("d: %d%n", y);
// f.format("c: %c%n", y);
f.format("b: %b%n", y);
f.format("s: %s%n", y);
// f.format("f: %f%n", y);
// f.format("e: %e%n", y);
// f.format("x: %x%n", y);
f.format("h: %h%n", y);
boolean z = false;
```

```
System.out.println("z = false");
// f.format("d: %d%n", z);
// f.format("c: %c%n", z);
f.format("b: %b%n", z);
f.format("s: %s%n", z);
// f.format("f: %f%n", z);
// f.format("e: %e%n", z);
// f.format("x: %x%n", z);
f.format("h: %h%n", z);
}
}
/* Output:
u = 'a'
s: a
c: a
b: true
h: 61
v = 121
d: 121
c: y
```

b: true

s: 121

x: 79

h: 79

w = new BigInteger("50000000000000")

d: 50000000000000

b: true

s: 50000000000000

x: 2d79883d2000

h: 8842a1a7

x = 179.543

b: true

s: 179.543

f: 179.543000

e: 1.795430e+02

h: 1ef462c

y = new Conversion()

b: true

s: Conversion@15db9742

h: 15db9742

z = false

b: false

s: false

h: 4d5

**/*

The commented lines are invalid conversions for that particular variable type; executing them will trigger an exception.

Notice that the **b** conversion works for each variable above. Although it's valid for any argument type, it might not behave as you'd expect. For **boolean** primitives or **Boolean** objects, the result is **true** or **false**, accordingly. However, for any other argument, as long as the argument type is not **null** the result is always **true**. Even the numeric value of zero, synonymous with **false** in many languages (including C), will produce **true**, so be careful when using this conversion with non-boolean types.

There are more obscure conversion types and other format specifier options. You can read about these in the JDK documentation for the

Formatter class.

String.format()

Java 5 also took a cue from C's **sprintf()**, which is used to create **String**s. **String.format()** is a **static** method which takes all the same arguments as **Formatter**s **format()** but returns a **String**. It can come in handy when you only call **format()** once:

```
// strings/DatabaseException.java
public class DatabaseException extends Exception {
public DatabaseException(int transactionID,
int queryID, String message) {
super(String.format("(t%d, q%d) %s", transactionID,
queryID, message));
}
public static void main(String[] args) {
try {
throw new DatabaseException(3, 7, "Write failed");
} catch(Exception e) {
System.out.println(e);
}
}
```

}

/ *Output:*

DatabaseException: (t3, q7) Write failed

**/*

Under the hood, all **String.format()** does is instantiate a **Formatter** and pass your arguments to it, but using this convenience method can often be clearer and easier than doing it by hand.

A Hex Dump Tool

As a second example, let's format the bytes in a binary file as hexadecimal. Here's a small utility that displays a binary array of bytes in a readable hex format, using **String.format()**:

// strings/Hex.java

// {java onjava.Hex}

package onjava;

import java.io.*;

import java.nio.file.*;

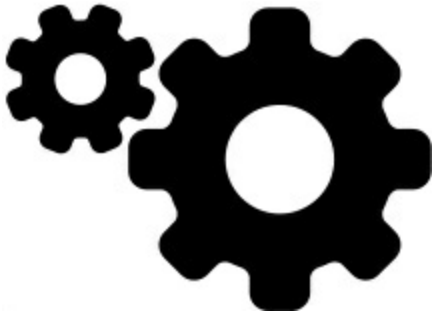
public class Hex {

public static String format(byte[] data) {

StringBuilder result = **new** StringBuilder();

```
int n = 0;
for(byte b : data) {
if(n % 16 == 0)
result.append(String.format("%05X: ", n));
result.append(String.format("%02X ", b));
n++;
if(n % 16 == 0) result.append("\n");
}
result.append("\n");
return result.toString();
}
public static void
main(String[] args) throws Exception {
if(args.length == 0)
// Test by displaying this class file:
System.out.println(format(
Files.readAllBytes(Paths.get(
"build/classes/main/onjava/Hex.class"))));
else
System.out.println(format(
```

```
Files.readAllBytes(Paths.get(args[0])));
}
}
/* Output: (First 6 Lines)
00000: CA FE BA BE 00 00 00 34 00 61 0A 00 05 00 31 07
00010: 00 32 0A 00 02 00 31 08 00 33 07 00 34 0A 00 35
```



```
00020: 00 36 0A 00 0F 00 37 0A 00 02 00 38 08 00 39 0A
00030: 00 3A 00 3B 08 00 3C 0A 00 02 00 3D 09 00 3E 00
00040: 3F 08 00 40 07 00 41 0A 00 42 00 43 0A 00 44 00
00050: 45 0A 00 14 00 46 0A 00 47 00 48 07 00 49 01 00
...
*/
```

To open and read the binary file, this uses another utility that is

introduced in the Files chapter: **Files.readAllBytes()**, which returns the entire file as a **byte** array.

Regular Expressions

Regular expressions have long been integral to standard Unix utilities like sed and awk, and languages like Python and Perl (some would argue they are the predominant reason for Perl's success). String manipulation tools were previously delegated to the **String**, **StringBuffer**, and **StringTokenizer** classes in Java, which had relatively simple facilities compared to regular expressions. Regular expressions are powerful and flexible text-processing tools. They allow you to specify, programmatically, complex patterns of text that can be discovered in an input **String**. Once you discover these patterns, you can then react to them any way you want. Although the syntax of regular expressions can be intimidating at first, they provide a compact and dynamic language that can be employed to solve all sorts of **String** processing, matching and selection, editing, and verification problems in a completely general way.

Basics

A regular expression is a way to describe strings in general terms, so you can say, "If a string has these things in it, it matches my search criteria." For example, to say that a number might or might not be

preceded by a minus sign, you put in the minus sign followed by a question mark, like this:

-?

To describe an integer, you say it's one or more digits. In regular expressions, a digit is described by saying **\d**. If you have any experience with regular expressions in other languages, you'll immediately notice a difference in the way backslashes are handled. In other languages, \\ means "insert a plain old (literal) backslash in the regular expression. Don't give it any special meaning." In Java, \\ means "I'm inserting a regular expression backslash, so the following character has special meaning." For example, to indicate a digit, your regular expression string is **\\d**. To insert a literal backslash, you say \\\. However, things like newlines and tabs just use a single backslash: **\n\t**.2

To indicate "one or more of the preceding expression," you use a **+**. So to say, "possibly a minus sign, followed by one or more digits," you write:

-?\\d+

The simplest way to use regular expressions is to use the functionality built into the **String** class. For example, we can see whether a

String matches the regular expression above:

```
// strings/IntegerMatch.java
public class IntegerMatch {
public static void main(String[] args) {
System.out.println("-1234".matches("-?\\d+"));
System.out.println("5678".matches("-?\\d+"));
System.out.println("+911".matches("-?\\d+"));
System.out.println("+911".matches("(-|\\+)?\\d+"));
}
}
/* Output:
true
true
false
true
*/
```

The first two expressions match, but the third one starts with a +, a legitimate sign but then the number doesn’t match the regular expression. So we need a way to say, “can start with a + or a -.” In regular expressions, parentheses have the effect of grouping an

expression, and the vertical bar | means OR. So

(-|\\+)?

means this part of the **String** can be either a **-** or a **+** or nothing (because of the **?**). Because the **+** character has special meaning in regular expressions, it must be escaped with a \\ to appear as an ordinary character in the expression.

A useful regular expression tool that's built into **String** is **split()**, which means, "Split this **String** around matches of the given regular expression."

```
// strings/Splitting.java
import java.util.*;
public class Splitting {
public static String knights =
"Then, when you have found the shrubbery, " +
"you must cut down the mightiest tree in the " +
"forest...with... a herring!";
public static void split(String regex) {
System.out.println(
Arrays.toString(knights.split(regex)));
}
```

```
public static void main(String[] args) {
split(" "); // Doesn't have to contain regex chars
split("\\W+"); // Non-word characters
split("n\\W+"); // 'n' followed by non-words
}
}
/* Output:
[Then,, when, you, have, found, the, shrubbery,, you,
must, cut, down, the, mightiest, tree, in, the,
forest...with..., a, herring!]
[Then, when, you, have, found, the, shrubbery, you,
must, cut, down, the, mightiest, tree, in, the, forest,
with, a, herring]
[The, whe, you have found the shrubbery, you must cut
dow, the mightiest tree i, the forest...with... a
herring!]
*/
```

First, note you can use ordinary characters as regular expressions—a regular expression doesn’t have to contain special characters, as shown in the first call to **split()**, which just splits on whitespace.

The second and third calls to **split()** use **\\W**, which means a non-word character (the lowercase version, **\\w**, means a word character)—the punctuation is removed in the second case. The third call to **split()** says, “the letter **n** followed by one or more non-word characters.” The split patterns do not appear in the result.

An overloaded version of **String.split()** limits the number of splits that occur.

With regular expression replacement, you can either replace the first occurrence, or all of them:

// strings/Replacing.java

```
public class Replacing {
static String s = Splitting.knights;
public static void main(String[] args) {
System.out.println(
s.replaceFirst("f\\w+", "located"));
System.out.println(
s.replaceAll("shrubbery|tree|herring","banana"));
```

```
}
}
/* Output:
Then, when you have located the shrubbery, you must cut
down the mightiest tree in the forest...with... a
herring!
Then, when you have found the banana, you must cut down
the mightiest banana in the forest...with... a banana!
*/
```

The first expression matches the letter **f** followed by one or more word characters (note that the **w** is lowercase this time). It only replaces the first match it finds, so the word “found” is replaced by the word “located.”

The second expression matches any of the three words separated by the OR vertical bars, and it replaces all matches it finds.

You’ll see that the non-**String** regular expressions have more powerful replacement tools—for example, you can call methods to perform replacements. Non-**String** regular expressions are also significantly more efficient if you use the regular expression more than once.

Creating Regular Expressions

You can begin learning with a subset of the possible constructs for building regular expressions. A complete list is found in the JDK documentation for the **Pattern** class for package **java.util.regex**.

B

The specific character **B**

Character with hex value

\xhh

0xhh

The Unicode character

\uhhhh

with hex representation

0xhhhh

\t

Tab

\n

Newline

\r

Carriage return

\f

Form feed

\e

Escape

The power of regular expressions begins to appear when you are defining character classes. Here are some typical ways to create character classes, and some predefined classes:

.

Any character

Any of the characters **a**, **b**, or **c**

[abc]

(same as **a**|**b**|**c**)

[^abc]

Any character except **a**, **b**, or **c**

(negation)

Any character **a** through **z** or **A**

[a-zA-Z]

through **Z** (range)

Any of **a**, **b**, **c**, **h**, **i**, **j** (same as

[abc[hij]]

a|b|c|h|i|j) (union)

[a-z&&

Either **h**, **i**, or **j** (intersection)

[hij]]

A whitespace character (space,

\s

tab, newline, form feed, carriage

return)

A non-whitespace character

\S

(**[^\s]**)

\d

A numeric digit (**[0-9]**)

\D

A non-digit (**[^0-9]**)

A word character (**[a-zA-**

\w

Z_0-9])

\W

A non-word character (**[^\w]**)

What’s shown here is only a sample; bookmark the JDK documentation page for **java.util.regex.Pattern** to easily access all the possible regular expression patterns.

Logical

Meaning

Operator

XY

X followed by **Y**

X|Y

X or **Y**

A *capturing group*. You can refer

(X)

to the *i* th captured group later in

the expression with **\i**.

Here are the different boundary matchers:

Boundary

Meaning

Matcher

^

Beginning of a line

$

End of a line

\b

Word boundary

\B

Non-word boundary

End of the previous

\G

match

As an example, each of the following successfully matches the

character sequence “Rudolph”:

```
// strings/Rudolph.java
public class Rudolph {
public static void main(String[] args) {
for(String pattern : new String[]{
"Rudolph",
"[rR]udolph",
"[rR][aeiou][a-z]ol.*",
"R.*" })
System.out.println("Rudolph".matches(pattern));
```

```
}
}
/* Output:
true
true
true
true
*/
```

Your goal should not be to create the most obfuscated regular

expression, but rather the simplest one necessary to do the job. You'll find that you'll often use your old code as a reference when writing new regular expressions.

Quantifiers

A *quantifier* describes the way that a pattern absorbs input text:

Greedy

Quantifiers are greedy unless otherwise altered. A greedy expression finds as many possible matches for the pattern as

possible. A typical cause of problems is to assume that your pattern will only match the first possible group of characters, when it's actually greedy and will keep going until it matches the largest possible **String**.

Reluctant

Specified with a question mark, this quantifier matches the minimum number of characters necessary to satisfy the pattern. Also called *lazy*, *minimal matching*, *non-greedy*, or *ungreedy*.

Possessive

Currently this is only available in Java (not in other languages) and is more advanced, so you probably won't use it right away. As a regular expression is applied to a **String**, it generates many states so it can backtrack if the match fails. Possessive quantifiers do not keep those intermediate states, and thus prevent backtracking. They can prevent a regular expression from running away and also to make it execute more efficiently.

Greedy Reluctant Possessive Matches

X?

X??

X?+

X, one or

none

X*

X*?

X*+

X, zero or

more

X+

X+?

X++

X, one or

more

X{n}

X{n}?

X{n}+

X, exactly **n**

times

X{n,}

X{n,}?

X{n,}+

X, at least **n**

times

X, at least **n**

but not

X{n,m}

X{n,m}?

X{n,m}+

more than **m**

times

Keep in mind that the expression **X** must often be surrounded in parentheses for it to work the way you desire. For example:

abc+

might seem like it would match the sequence **abc** one or more times, and if you apply it to the input **String abcabcabc**, you will in fact get three matches. However, the expression *actually* says, “Match **ab**

followed by one or more occurrences of **c**.” To match the entire **String abc** one or more times, you must say:

(abc)+

You can easily be fooled when using regular expressions; it’s an orthogonal language, on top of Java.

CharSequence

The interface called **CharSequence** establishes a generalized definition of a character sequence abstracted from the **CharBuffer**, **String**, **StringBuffer**, or **StringBuilder** classes:

```
interface CharSequence {
char charAt(int i);
int length();
CharSequence subSequence(int start, int end);
String toString();
}
```

The aforementioned classes implement this interface. Many regular expression operations take **CharSequence** arguments.

Pattern and Matcher

You’ll usually compile regular expression objects rather than using the fairly limited **String** utilities. To do this, import **java.util.regex**, then compile a regular expression with the **static Pattern.compile()** method. This produces a

Pattern object based on its **String** argument. You use this

Pattern by calling the **matcher()** method, passing the **String** to search. The **matcher()** method produces a **Matcher** object, which

has a set of operations to choose from (All of these appear in the JDK

documentation for **java.util.regex.Matcher**). For example,

replaceAll() replaces all matches with its argument.

As a first example, the following class tests regular expressions against

an input **String**. The first command-line argument is the input

String to match against, followed by one or more regular

expressions applied to the input. Under Unix/Linux, the regular

expressions must be quoted on the command line. This program can

be useful in testing regular expressions as you construct them, to see

that they produce your intended matching behavior. 3

```
// strings/TestRegularExpression.java
// Simple regular expression demonstration
// {java TestRegularExpression
// abcabcabcdefabc "abc+" "(abc)+" }
import java.util.regex.*;
public class TestRegularExpression {
public static void main(String[] args) {
if(args.length < 2) {
```

```
System.out.println(
"Usage:\njava TestRegularExpression " +
"characterSequence regularExpression+");
System.exit(0);
}
System.out.println("Input: \"" + args[0] + "\"");
for(String arg : args) {
System.out.println(
"Regular expression: \"" + arg + "\"");
Pattern p = Pattern.compile(arg);
Matcher m = p.matcher(args[0]);
while(m.find()) {
System.out.println(
"Match \"" + m.group() + "\" at positions " +
m.start() + "-" + (m.end() - 1));
}
}
}
}
/* Output:
```

Input: "abcabcabcdefabc"

Regular expression: "abcabcabcdefabc"

Match "abcabcabcdefabc" at positions 0-14

Regular expression: "abc+"

Match "abc" at positions 0-2

Match "abc" at positions 3-5

Match "abc" at positions 6-8

Match "abc" at positions 12-14

Regular expression: "(abc)+"

Match "abcabcabc" at positions 0-8

Match "abc" at positions 12-14

*/

Also try adding **"(abc){2,}"** to the command line.

A **Pattern** object represents the compiled version of a regular expression. As seen in the preceding example, you can use the **matcher()** method and the input **String** to produce a **Matcher** object from the compiled **Pattern** object. **Pattern** also has a **static** method:

static boolean matches(String regex, CharSequence input)

This checks whether **regex** matches the entire **input**

CharSequence. There's also a **split()** method that produces an array of **String** broken around matches of the **regex**.

A **Matcher** object is generated by calling **Pattern.matcher()** with the input **String** as an argument. The **Matcher** object is then used to access the results with methods to evaluate the success or failure of different types of matches:

boolean matches()

boolean lookingAt()

boolean find()

boolean find(int start)

The **matches()** method is successful if the pattern matches the entire input **String**, while **lookingAt()** is successful if the input **String**, starting at the beginning, is a match to the pattern.

find()

Matcher.find() discovers multiple pattern matches in the **CharSequence** to which it is applied. For example:

```
// strings/Finding.java
import java.util.regex.*;
public class Finding {
public static void main(String[] args) {
```

```
Matcher m = Pattern.compile("\\w+")
.matcher(
"Evening is full of the linnet's wings");
while(m.find())
System.out.print(m.group() + " ");
System.out.println();
int i = 0;
while(m.find(i)) {
System.out.print(m.group() + " ");
i++;
}
}
}
/* Output:
Evening is full of the linnet s wings
Evening vening ening ning ing ng g is is s full full
ull ll l of of f the the he e linnet linnet innet nnet
net et t s s wings wings ings ngs gs s
*/
```

The pattern **\\w+** splits the input into words. **find()** is like an iterator, moving forward through the input **String**. However, the

second version of **find()** can be given an integer argument that tells it the character position for the beginning of the search—this version resets the search position to the value of the argument, as shown in the output.

Groups

Groups are regular expressions set off by parentheses that can be called up later with their group number. Group 0 indicates the whole expression match, group 1 is the first parenthesized group, etc. Thus, in

A(B(C))D

there are three groups: Group 0 is **ABCD**, group 1 is **BC**, and group 2 is **C**.

The **Matcher** object has methods to give you information about groups:

public int groupCount() returns the number of groups in this matcher's pattern. Group 0 is not included in this count.

public String group() returns group 0 (the entire match) from the previous match operation (**find()**, for example).

public String group(int i) returns the given group number during the previous match operation. If the match was

successful, but the group specified failed to match any part of the input **String**, **null** is returned.

public int start(int group) returns the start index of the group found in the previous match operation.

public int end(int group) returns the index of the last character, plus one, of the group found in the previous match operation.

Here’s an example:

```
// strings/Groups.java
import java.util.regex.*;
public class Groups {
public static final String POEM =
"Twas brillig, and the slithy toves\n" +
"Did gyre and gimble in the wabe.\n" +
"All mimsy were the borogoves,\n" +
"And the mome raths outgrabe.\n\n" +
"Beware the Jabberwock, my son,\n" +
"The jaws that bite, the claws that catch.\n" +
"Beware the Jubjub bird, and shun\n" +
"The frumious Bandersnatch.";
```

```
public static void main(String[] args) {
Matcher m = Pattern.compile(
"(?m)(\\S+)\\s+((\\S+)\\s+(\\S+))$")
.matcher(POEM);
while(m.find()) {
for(int j = 0; j <= m.groupCount(); j++)
System.out.print("[" + m.group(j) + "]");
System.out.println();
}
}
}
/* Output:
[the slithy toves][the][slithy toves][slithy][toves]
[in the wabe.][in][the wabe.][the][wabe.]
[were the borogoves,][were][the
borogoves,][the][borogoves,]
[mome raths outgrabe.][mome][raths
outgrabe.][raths][outgrabe.]
[Jabberwock, my son,][Jabberwock,][my son,][my][son,]
[claws that catch.][claws][that catch.][that][catch.]
```

[bird, and shun][bird,][and shun][and][shun]

[The frumious Bandersnatch.][The][frumious

Bandersnatch.][frumious][Bandersnatch.]

/

The poem is the first part of Lewis Carroll's "Jabberwocky," from *Through the Looking Glass*. The regular expression pattern has a number of parenthesized groups, consisting of any number of non-whitespace characters (**S+**) followed by any number of whitespace characters (**s+**). The goal is to capture the last three words on each line; the end of a line is delimited by **\$**. However, the normal behavior is to match **\$** with the end of the entire input sequence, so you must explicitly tell the regular expression to pay attention to newlines within the input. This is accomplished with the **(?m)** pattern flag at the beginning of the sequence (pattern flags are shown shortly).

start() and end()

Following a successful matching operation, **start()** returns the start index of the previous match, and **end()** returns the index of the last character matched, plus one. Invoking either **start()** or **end()** following an unsuccessful matching operation (or before attempting a matching operation) produces an **IllegalStateException**. The

following program also demonstrates **matches()** and **lookingAt()**:4

```
// strings/StartEnd.java
import java.util.regex.*;
public class StartEnd {
public static String input =
"As long as there is injustice, whenever a\n" +
"Targathian baby cries out, wherever a distress\n" +
"signal sounds among the stars " +
"... We'll be there.\n"+
"This fine ship, and this fine crew ...\n" +
"Never give up! Never surrender!";
private static class Display {
private boolean regexPrinted = false;
private String regex;
Display(String regex) { this.regex = regex; }
void display(String message) {
if(!regexPrinted) {
System.out.println(regex);
regexPrinted = true;
```

```
}
System.out.println(message);
}
}
static void examine(String s, String regex) {
Display d = new Display(regex);
Pattern p = Pattern.compile(regex);
Matcher m = p.matcher(s);
while(m.find())
d.display("find() '" + m.group() +
"' start = "+ m.start() + " end = " + m.end());
if(m.lookingAt()) // No reset() necessary
d.display("lookingAt() start = "
+ m.start() + " end = " + m.end());
if(m.matches()) // No reset() necessary
d.display("matches() start = "
+ m.start() + " end = " + m.end());
}
public static void main(String[] args) {
for(String in : input.split("\n")) {
```

```
System.out.println("input : " + in);
for(String regex : new String[]{"\\w*ere\\w*",
"\\w*ever", "T\\w+", "Never.*?!"})
examine(in, regex);
}
}
}
/* Output:
input : As long as there is injustice, whenever a
\w*ere\w*
find() 'there' start = 11 end = 16
\w*ever
find() 'whenever' start = 31 end = 39
input : Targathian baby cries out, wherever a distress
\w*ere\w*
find() 'wherever' start = 27 end = 35
\w*ever
find() 'wherever' start = 27 end = 35
T\w+
find() 'Targathian' start = 0 end = 10
```

lookingAt() start = 0 end = 10

input : signal sounds among the stars ... We'll be

there.

*\w*ere\w**

find() 'there' start = 43 end = 48

input : This fine ship, and this fine crew ...

T\w+

find() 'This' start = 0 end = 4

lookingAt() start = 0 end = 4

input : Never give up! Never surrender!

*\w*ever*

find() 'Never' start = 0 end = 5

find() 'Never' start = 15 end = 20

lookingAt() start = 0 end = 5

Never.?!*

find() 'Never give up!' start = 0 end = 14

find() 'Never surrender!' start = 15 end = 31

lookingAt() start = 0 end = 14

matches() start = 0 end = 31

**/*

find() will locate the regular expression anywhere in the input, but **lookingAt()** and **matches()** only succeed if the regular expression starts matching at the very beginning of the input. While **matches()** only succeeds if the *entire* input matches the regular expression, **lookingAt()**5 succeeds if only the first part of the input matches.

Pattern Flags

An alternative **compile()** method accepts flags that affect matching behavior:

Pattern Pattern.compile(String regex, int flag)

where **flag** is drawn from among the following **Pattern** class constants:

Compile Flag	**Effect**
Pattern.CANON_EQ	Two characters are considered to match if, and only if, their full canonical decompositions match. The expression **\u003F**, for example, will match the

String ? when this flag is specified. By default, matching does not take canonical equivalence into account.

By default, case-insensitive matching assumes that only characters in the US-ASCII character set are matched.

This flag allows your pattern **Pattern.CASE_INSENSITIVE** to match without regard to

(?i)

case (upper or lower).

Unicode-aware case-insensitive matching can be enabled by specifying the **UNICODE_CASE** flag in conjunction with this flag.

In this mode, whitespace is ignored, and embedded

Pattern.COMMENTS

comments starting with **#**

are ignored until the end of a

(?x)

line. Unix lines mode can

also be enabled via the

embedded flag expression.

In dotall mode, the

expression **.** matches any

Pattern.DOTALL

character, including a line

(?s)

terminator. By default, the **.**

expression does not match

line terminators.

In multiline mode, the

expressions ^ and **$** match

the beginning and ending of

a line, respectively. ^ also

matches the beginning of the

Pattern.MULTILINE

input **String**, and **$** also

(?m)

matches the end of the input

String. By default, these

expressions only match at

the beginning and the end of

the entire input **String**.

Case-insensitive matching,

when enabled by the

CASE_INSENSITIVE flag,

Pattern.UNICODE_CASE

is done in a manner

consistent with the Unicode

(?u)

Standard. By default, case-

insensitive matching

assumes that only characters

in the US-ASCII character

set are matched.

In this mode, only the **\n**

Pattern.UNIX_LINES

line terminator is recognized

(?d)

in the behavior of **.** , ^, and

$.

Particularly useful among these flags are

Pattern.CASE_INSENSITIVE, **Pattern.MULTILINE**, and

Pattern.COMMENTS (helpful for clarity and/or documentation).

Note that the behavior of most of the flags can also be obtained by inserting the parenthesized characters, shown beneath the flags in the table, into your regular expression preceding the place where you want the mode to take effect.

You can combine the effect of these and other flags through an “OR” (|) operation:

```
// strings/ReFlags.java
import java.util.regex.*;
public class ReFlags {
public static void main(String[] args) {
Pattern p = Pattern.compile("^java",
```

```
Pattern.CASE_INSENSITIVE | Pattern.MULTILINE);
Matcher m = p.matcher(
"java has regex\nJava has regex\n" +
"JAVA has pretty good regular expressions\n" +
"Regular expressions are in Java");
```

```
while(m.find())
System.out.println(m.group());
}
}
/* Output:
java
Java
JAVA
*/
```

This creates a pattern that matches lines starting with “java,” “Java,” “JAVA,” etc., and attempts a match for lines within a multiline set (matches starting at the beginning of the character sequence and

following each line terminator within the character sequence). Note that the **group()** method only produces the matched portion.

split()

split() divides an input **String** into an array of **String** objects, delimited by the regular expression.

String[] split(CharSequence input)

String[] split(CharSequence input, int limit)

This is a handy way to break input text on a common boundary:

```
// strings/SplitDemo.java
import java.util.regex.*;
import java.util.*;
public class SplitDemo {
public static void main(String[] args) {
String input =
"This!!unusual use!!of exclamation!!points";
System.out.println(Arrays.toString(
Pattern.compile("!!").split(input)));
// Only do the first three:
System.out.println(Arrays.toString(
```

Pattern.compile("!!").split(input, 3)));

}

}

/ *Output:*

[This, unusual use, of exclamation, points]

[This, unusual use, of exclamation!!points]

**/*

The second form of **split()** limits the number of splits that occur.

Replace Operations

Regular expressions are especially useful to replace text. Here are the available methods:

replaceFirst(String replacement) replaces the first matching part of the input **String** with **replacement**.

replaceAll(String replacement) replaces every matching part of the input **String** with **replacement**.

appendReplacement(StringBuffer sbuf, String replacement) performs step-by-step replacements into **sbuf**,

rather than replacing only the first one or all of them, as in **replaceFirst()** and **replaceAll()**, respectively. This is a *very* important method, because you can call methods and perform other processing to produce **replacement** (**replaceFirst()** and **replaceAll()** are only able to put in fixed **String**s). With this method, you can programmatically pick apart the groups and create powerful replacements.

appendTail(StringBuffer sbuf) is invoked after one or more invocations of the **appendReplacement()** method to copy the remainder of the input **String**.

Here's an example that shows all the replace operations. The block of commented text at the beginning is extracted and processed with regular expressions for use as input in the rest of the example:

```
// strings/TheReplacements.java
import java.util.regex.*;
import java.nio.file.*;
import java.util.stream.*;
/*! Here's a block of text to use as input to
the regular expression matcher. Note that we
first extract the block of text by looking for
```

```
the special delimiters, then process the
extracted block. !*/
public class TheReplacements {
public static void
main(String[] args) throws Exception {
String s = Files.lines(
Paths.get("TheReplacements.java"))
.collect(Collectors.joining("\n"));
// Match specially commented block of text above:
Matcher mInput = Pattern.compile(
"/\\*!(.*)!\\*/", Pattern.DOTALL).matcher(s);
if(mInput.find())
s = mInput.group(1); // Captured by parentheses
// Replace two or more spaces with a single space:
s = s.replaceAll(" {2,}", " ");
// Replace 1+ spaces at the beginning of each
// line with no spaces. Must enable MULTILINE mode:
s = s.replaceAll("(?m)^ +", "");
System.out.println(s);
s = s.replaceFirst("[aeiou]", "(VOWEL1)");
```

```
StringBuffer sbuf = new StringBuffer();
Pattern p = Pattern.compile("[aeiou]");
Matcher m = p.matcher(s);
// Process the find information as you
// perform the replacements:
while(m.find())
m.appendReplacement(
sbuf, m.group().toUpperCase());
// Put in the remainder of the text:
m.appendTail(sbuf);
System.out.println(sbuf);
}
}
/* Output:
Here's a block of text to use as input to
the regular expression matcher. Note that we
first extract the block of text by looking for
the special delimiters, then process the
extracted block.
H(VOWEL1)rE's A blOck Of tExt tO UsE As InpUt tO
```

thE rEgUlAr ExprEssIOn mAtchEr. NOtE thAt wE

fIrst ExtrAct thE blOck Of tExt by lOOkIng fOr

thE spEcIAl dElImItErs, thEn prOcEss thE

ExtrActEd blOck.

*/

The file is opened and read using the **Files** class introduced in the Files chapter. **Files.lines()** produces a **Stream** of lines, and **Collectors.joining()** combines them into a single **String**, attaching the argument to the end of each line.

mInput matches all the text (notice the grouping parentheses) between **/*!** and **!*/**. Then, more than two spaces are reduced to a single space, and any space at the beginning of each line is removed (to do this on all lines and not just the beginning of the input, multiline mode must be enabled). These two replacements are performed with the equivalent (but more convenient, in this case) **replaceAll()** that's part of **String**. Note that since each replacement is only used once in the program, there's no extra cost to doing it this way rather than precompiling it as a **Pattern**.

replaceFirst() only performs the first replacement it finds. In addition, the replacement **String**s in **replaceFirst()** and

replaceAll() are just literals, so when performing some processing on each replacement, they don’t help. In that case, use **appendReplacement()** to write any amount of code in the process of performing the replacement. In the preceding example, a **group()** is selected and processed—in this situation, setting the vowel found by the regular expression to uppercase—as the resulting **sbuf** is built. Normally, you step through and perform all the replacements, then call **appendTail()**, but to simulate **replaceFirst()** (or “replace n”), you only do the replacement one time, then call **appendTail()** to put the rest into **sbuf**. **appendReplacement()** also refers to captured groups directly in the replacement **String** by saying **\$g**, where **g** is the group number. However, this is for simpler processing and wouldn’t give you the desired results in the preceding program.

reset()

An existing **Matcher** object can be applied to a new character sequence using the **reset()** methods:

```
// strings/Resetting.java
import java.util.regex.*;
public class Resetting {
public static void
main(String[] args) throws Exception {
Matcher m = Pattern.compile("[frb][aiu][gx]")
.matcher("fix the rug with bags");
while(m.find())
System.out.print(m.group() + " ");
System.out.println();
m.reset("fix the rig with rags");
```

```
while(m.find())
System.out.print(m.group() + " ");
}
}
/* Output:
fix rug bag
```

fix rig rag

*/

reset() without any arguments sets the **Matcher** to the beginning of the current sequence.

Regular Expressions and Java I/O

Most of the examples so far have shown regular expressions applied to static **String**s. The following example shows one way to apply regular expressions to search for matches in a file. Inspired by Unix's *grep*, **JGrep.java** takes two arguments: a file name and the regular expression to match. The output shows each line where a match occurs and the match position(s) within the line.

```
// strings/JGrep.java
// A very simple version of the "grep" program
// {java JGrep
// WhitherStringBuilder.java 'return|for|String'}
import java.util.regex.*;
import java.nio.file.*;
import java.util.stream.*;
public class JGrep {
```

```
public static void
main(String[] args) throws Exception {
if(args.length < 2) {
System.out.println(
"Usage: java JGrep file regex");
System.exit(0);
}
Pattern p = Pattern.compile(args[1]);
// Iterate through the lines of the input file:
int index = 0;
Matcher m = p.matcher("");
for(String line :
Files.readAllLines(Paths.get(args[0]))) {
m.reset(line);
while(m.find())
System.out.println(index++ + ": " +
m.group() + ": " + m.start());
}
}
}
```

/ *Output:*

0: for: 4

1: for: 4

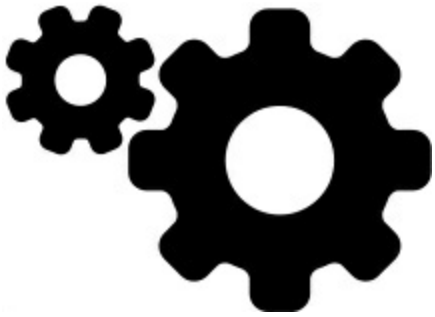
**/*

Files.readAllLines() produces a **List<String>** , which means the *for-in* can iterate through it.

Although it's possible to create a new **Matcher** object within the **for** loop, it is slightly more optimal to create an empty **Matcher** object outside the loop and use the **reset()** method to assign each line of the input to the **Matcher**. The result is scanned with **find()**.

The test arguments open the **JGrep.java** file to read as input, and search for words starting with **[Ssct]**.

You can learn much more about regular expressions in *Mastering Regular Expressions, 2nd Edition*, by Jeffrey E. F. Friedl (O'Reilly, 2002). There are also numerous introductions to regular expressions on the Internet, and you can often find helpful information in the documentation for languages like Perl and Python.



Scanning Input

Until now it was relatively painful to read data from a human-readable file or from standard input. The usual solution is to read in a line of text, tokenize it, then use the various parse methods of **Integer**, **Double**, etc., to parse the data:

```
// strings/SimpleRead.java
import java.io.*;
public class SimpleRead {
public static BufferedReader input =
new BufferedReader(new StringReader(
"Sir Robin of Camelot\n22 1.61803"));
public static void main(String[] args) {
try {
System.out.println("What is your name?");
String name = input.readLine();
System.out.println(name);
```

```
System.out.println("How old are you? " +
"What is your favorite double?");
System.out.println("(input: <age> <double>)");
String numbers = input.readLine();
System.out.println(numbers);
String[] numArray = numbers.split(" ");
int age = Integer.parseInt(numArray[0]);
double favorite = Double.parseDouble(numArray[1]);
System.out.format("Hi %s.%n", name);
System.out.format("In 5 years you will be %d.%n",
age + 5);
System.out.format("My favorite double is %f.",
favorite / 2);
} catch(IOException e) {
System.err.println("I/O exception");
}
}
}
/* Output:
What is your name?
```

Sir Robin of Camelot

How old are you? What is your favorite double?

(input: <age> <double>)

22 1.61803

Hi Sir Robin of Camelot.

In 5 years you will be 27.

My favorite double is 0.809015.

**/*

The **input** field uses classes from **java.io** which are described in

the Appendix: I/O Streams. A **StringReader** turns a **String** into a readable stream, and this object is used to create a

BufferedReader because **BufferedReader** has a

readLine() method. The result is that the **input** object can be

read a line at a time, just as if it were standard input from the console.

readLine() is used to get the **String** for each line of input. It's

fairly straightforward when you want one input for each line of data,

but if two input values are on a single line, things get messy—the line

must be split so we can parse each input separately. Here, the splitting

takes place when creating **numArray**.

The **Scanner** class, added in Java 5, relieves much of the burden of

scanning input:

```
// strings/BetterRead.java
import java.util.*;
public class BetterRead {
public static void main(String[] args) {
Scanner stdin = new Scanner(SimpleRead.input);
System.out.println("What is your name?");
String name = stdin.nextLine();
System.out.println(name);
System.out.println(
"How old are you? What is your favorite double?");
System.out.println("(input: <age> <double>)");
int age = stdin.nextInt();
double favorite = stdin.nextDouble();
System.out.println(age);
System.out.println(favorite);
System.out.format("Hi %s.%n", name);
System.out.format("In 5 years you will be %d.%n",
age + 5);
System.out.format("My favorite double is %f.",
favorite / 2);
```

}

}

/ Output:*

What is your name?

Sir Robin of Camelot

How old are you? What is your favorite double?

(input: <age> <double>)

22

1.61803

Hi Sir Robin of Camelot.

In 5 years you will be 27.

My favorite double is 0.809015.

**/*

The **Scanner** constructor can take just about any kind of input object, including a **File** object, an **InputStream**, a **String**, or in this case a **Readable**, an interface introduced in Java 5 to describe "something that has a **read()** method." The **BufferedReader** from the previous example falls into this category.

With **Scanner**, the input, tokenizing, and parsing are all ensconced in various different kinds of "next" methods. A plain **next()** returns

the next **String** token, and there are “next” methods for all the primitive types (except **char**) as well as for **BigDecimal** and **BigInteger**. All “next” methods *block*, meaning they will return only after a complete data token is available for input. There are also corresponding “hasNext” methods that return **true** if the next input token is of the correct type.

In **BetterRead.java** there is no **try** block for **IOException**.

One of the assumptions made by the **Scanner** is that an **IOException** signals the end of input, and so these are swallowed by the **Scanner**. However, the most recent exception is available through the **ioException()** method, so you are able to examine it if necessary.

Scanner Delimiters

By default, a **Scanner** splits input tokens along whitespace, but you can also specify your own delimiter pattern in the form of a regular expression:

// strings/ScannerDelimiter.java

```
import java.util.*;
public class ScannerDelimiter {
public static void main(String[] args) {
Scanner scanner = new Scanner("12, 42, 78, 99, 42");
scanner.useDelimiter("\\s*,\\s*");
while(scanner.hasNextInt())
System.out.println(scanner.nextInt());
}
}
/* Output:
12
42
78
99
42
*/
```

This example uses commas (surrounded by arbitrary amounts of whitespace) as the delimiter when reading from the given **String**.

This same technique can read from comma-delimited files. In addition

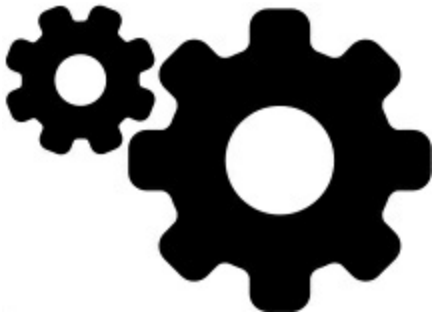
to **useDelimiter()** for setting the delimiter pattern, there is also **delimiter()**, which returns the current **Pattern** being used as a delimiter.

Scanning with Regular Expressions

In addition to scanning for predefined primitive types, you can also scan for your own user-defined patterns, helpful when scanning more complex data. This example scans threat data from a log that your firewall might produce:

```
// strings/ThreatAnalyzer.java
import java.util.regex.*;
import java.util.*;
public class ThreatAnalyzer {
static String threatData =
"58.27.82.161@08/10/2015\n" +
"204.45.234.40@08/11/2015\n" +
"58.27.82.161@08/11/2015\n" +
```

```
"58.27.82.161@08/12/2015\n" +
"58.27.82.161@08/12/2015\n" +
"[Next log section with different data format]";
public static void main(String[] args) {
Scanner scanner = new Scanner(threatData);
String pattern = "(\\d+[.]\\d+[.]\\d+[.]\\d+)@" +
"(\\d{2}/\\d{2}/\\d{4})";
while(scanner.hasNext(pattern)) {
scanner.next(pattern);
MatchResult match = scanner.match();
String ip = match.group(1);
String date = match.group(2);
System.out.format(
"Threat on %s from %s%n", date,ip);
}
}
}
```



/ Output:*

Threat on 08/10/2015 from 58.27.82.161

Threat on 08/11/2015 from 204.45.234.40

Threat on 08/11/2015 from 58.27.82.161

Threat on 08/12/2015 from 58.27.82.161

Threat on 08/12/2015 from 58.27.82.161

**/*

When you use **next()** with a specific pattern, that pattern is matched against the next input token. The result is made available by the **match()** method, and as you see above, it works just like the regular expression matching you saw earlier.

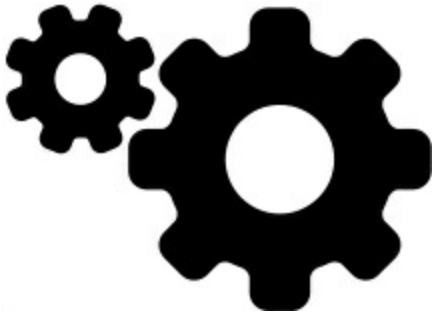
There's one caveat when scanning with regular expressions. The pattern is matched against the next input token only, so if your pattern contains a delimiter it will never be matched.

StringTokenizer

Before regular expressions (in Java 1.4) or the **Scanner** class (in Java

5), the way to split a **String** into parts was to “tokenize” it with **StringTokenizer**. But now it’s much easier and more succinct to do the same thing with regular expressions or the **Scanner** class. Here’s a simple comparison of **StringTokenizer** to the other two techniques:

```
// strings/ReplacingStringTokenizer.java
import java.util.*;
public class ReplacingStringTokenizer {
public static void main(String[] args) {
String input =
"But I'm not dead yet! I feel happy!";
StringTokenizer stoke = new StringTokenizer(input);
while(stoke.hasMoreElements())
```



```
System.out.print(stoke.nextToken() + " ");
System.out.println();
System.out.println(
```

```
Arrays.toString(input.split(" ")));
Scanner scanner = new Scanner(input);
while(scanner.hasNext())
System.out.print(scanner.next() + " ");
}
}
/* Output:
But I'm not dead yet! I feel happy!
[But, I'm, not, dead, yet!, I, feel, happy!]
But I'm not dead yet! I feel happy!
*/
```

With regular expressions or **Scanner** objects, you can also split a **String** into parts using more complex patterns—something that's difficult with **StringTokenizer**. It seems safe to say that **StringTokenizer** is obsolete.

Summary

In the beginning, Java support for **String** manipulation was rudimentary, but in later editions of the language we saw far more sophisticated support adopted from other languages. Now the support for **String**s is reasonably complete, although you must sometimes

pay attention to efficiency details such as the appropriate use of **StringBuilder**.

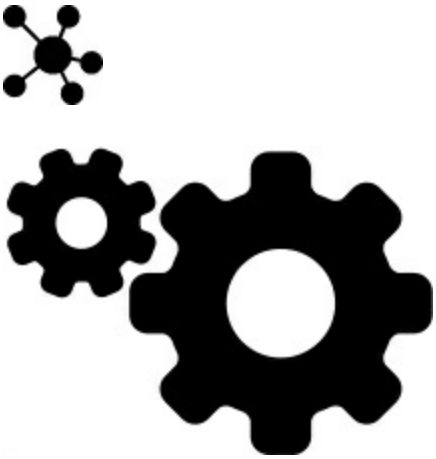
1. C++ allows the programmer to overload operators at will. Because this can often be a complicated process (see Chapter 10 of *Thinking in C++, 2nd Edition*, Prentice Hall, 2000), the Java designers deemed it a “bad” feature that shouldn’t be included in Java. It wasn’t so bad they didn’t end up doing it themselves, and ironically enough, operator overloading would be much easier to use in Java than in C++. This can be seen in Python (see *www.Python.org*) and C#, which have garbage collection and straightforward operator overloading.↩

2. Java wasn’t designed from the beginning for regular expressions, so this awkward syntax was all they could shoehorn in.↩

3. There are far more useful and sophisticated regular expression helper tools on the Internet.↩

4. **input** is from one of Commander Taggart’s speeches in Galaxy Quest.↩

5. I have no idea how they came up with this method name, or to what it refers. This is just one reason that code reviews are important. ↩



Type Information

Runtime type information (RTTI)

discovers and uses type information while

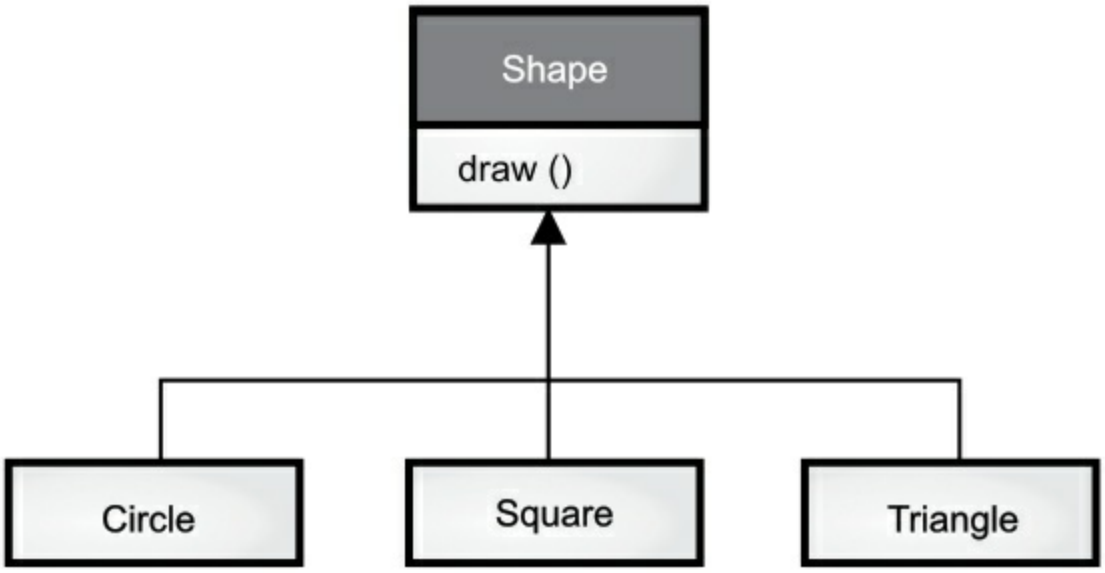
a program is running.

It frees you from the constraint of doing type-oriented things only at compile time, and can enable some very powerful programs. The need for RTTI uncovers a plethora of interesting (and often perplexing) OO design issues, and raises fundamental questions about how to structure your programs.

This chapter looks at the ways that Java discovers information about objects and classes at run time. This takes two forms: “traditional” RTTI, which assumes you have all the types available at compile time, and the *reflection* mechanism, which discovers and use class information solely at run time.

The Need for RTTI

Consider the now-familiar example of a class hierarchy that uses polymorphism. The generic type is the base class **Shape**, and the specific derived types are **Circle**, **Square**, and **Triangle**:



This is a typical class hierarchy diagram, with the base class at the top and the derived classes growing downward. A common goal in object-oriented programming is to write code that manipulates references to the base type (**Shape**, in this case), so if you decide to extend the program by adding a new class (such as **Rhomboid**, derived from **Shape**), the bulk of the code is not affected. In this example, the dynamically bound method in the **Shape** interface is **draw()**, so the intent is for the client programmer to call **draw()** through a generic **Shape** reference. In all derived classes, **draw()** is overridden, and

because it is a dynamically bound method, the proper behavior will occur even though it is called through a generic **Shape** reference. That's polymorphism.

Thus, you generally create a specific object (**Circle**, **Square**, or **Triangle**), upcast it to a **Shape** (forgetting the specific type of the object), and use that anonymous **Shape** reference in the rest of the program.

You might code the **Shape** hierarchy as follows:

```
// typeinfo/Shapes.java
import java.util.stream.*;
abstract class Shape {
void draw() { System.out.println(this + ".draw()"); }
@Override
public abstract String toString();
}
class Circle extends Shape {
@Override
public String toString() { return "Circle"; }
}
class Square extends Shape {
```

```
@Override
public String toString() { return "Square"; }
}
class Triangle extends Shape {
@Override
public String toString() { return "Triangle"; }
}
public class Shapes {
public static void main(String[] args) {
Stream.of(
new Circle(), new Square(), new Triangle())
.forEach(Shape::draw);
}
}
/* Output:
Circle.draw()
Square.draw()
Triangle.draw()
*/
```

The base class contains a **draw()** method that indirectly uses

toString() to print an identifier for the class by passing **this** to **System.out.println()** (**toString()** is declared **abstract** to force inheritors to override it, and to prevent the instantiation of a plain **Shape**). If an object appears in a **String** concatenation expression (involving + and **String** objects), the **toString()** method is automatically called to produce a **String** representation for that object. Each of the derived classes overrides the **toString()** method (from **Object**) so **draw()** ends up (polymorphically) printing something different in each case.

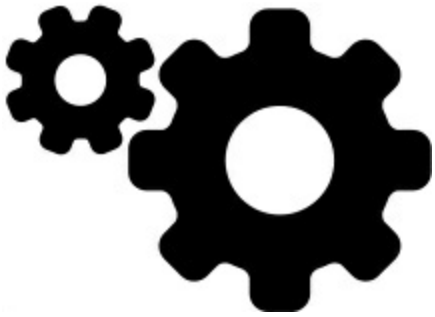
In this example, the upcast occurs when the shape is placed into the (implicit) **Stream<Shape>** . During the upcast to **Shape**, the fact that the objects are *specific types* of **Shape** is lost. To the stream, they are just **Shape**s.

Technically, the **Stream<Shape>** is actually holding everything as an **Object**. When an element emerges, it is automatically cast back to a **Shape**. This is the most basic form of RTTI, because all casts are checked at run time for correctness. That's what RTTI means: At run time, the type of an object is identified.

Here, the RTTI cast is only partial: The **Object** is cast to a **Shape**, and not all the way to a **Circle**, **Square**, or **Triangle**. That's because the only thing you *know* is that the **List<Shape>** is full of

Shapes. At compile time, this is enforced by the stream and the Java generic system, but at run time the cast ensures it.

Now polymorphism takes over and the exact code that's executed for the **Shape** is determined by whether the reference is for a **Circle**, **Square**, or **Triangle**. And in general, this is how it should be; you want the bulk of your code to know as little as possible about *specific* types of objects, and to just deal with the general representation of a family of objects (in this case, **Shape**). As a result, your code is easier to write, read, and maintain, and your designs are easier to implement, understand, and change. So polymorphism is a general goal in object-oriented programming.



But what about a special programming problem that's easiest to solve if you know the exact type of a generic reference? For example, suppose you allow your users to highlight all the shapes of any particular type by turning them a special color. This way, they can find all the triangles on the screen by highlighting them. Or perhaps your

method must “rotate” a list of shapes, but it makes no sense to rotate a circle so you’d like to skip the circles. With RTTI, you can ask a **Shape** reference the exact type it’s referring to, and thus select and isolate special cases.

The Class Object

To understand how RTTI works in Java, you must first know how type information is represented at run time. This is accomplished through a special kind of object called the *Class object*, which contains information about the class. In fact, the **Class** object is used to create all “regular” objects of your class. Java performs its RTTI using the **Class** object, even if you’re doing something like a cast. The class **Class** also has a number of other ways you can use RTTI.

There’s one **Class** object for each class that is part of your program. That is, each time you write and compile a new class, a single **Class** object is also created (and stored, appropriately enough, in an identically named **.class** file). To make an object of that class, the Java Virtual Machine (JVM) that’s executing your program uses a subsystem called a *class loader*.

The class loader subsystem can actually comprise a chain of class loaders, but there’s only one *primordial class loader*, part of the JVM

implementation. The primordial class loader loads so-called *trusted classes*, including Java API classes, typically from the local disk. Additional class loaders in the chain are usually not necessary, but for special needs (such as loading classes in a certain way to support Web server applications, or downloading classes across a network), you can hook in additional class loaders.

All classes are loaded into the JVM dynamically, upon the first use of a class. This happens when the program makes the first reference to a **static** member of that class. The constructor is also a **static** method of a class, even though the **static** keyword is not used for a constructor. Therefore, creating a new object of that class using the **new** operator also counts as a reference to a **static** member of the class.

Thus, a Java program isn't completely loaded before it begins, but instead pieces of it are loaded when necessary. This is different from many traditional languages. Dynamic loading enables behavior that is difficult or impossible to duplicate in a statically loaded language like C++.

The class loader first checks to see if the **Class** object for that type is loaded. If not, the default class loader finds the **.class** file with that

name (an add-on class loader might, for example, look for the bytecodes in a database instead). As the bytes for the class are loaded, they are *verified* to ensure they have not been corrupted and they do not comprise bad Java code (this is one of the lines of defense for security in Java).

Once the **Class** object for that type is in memory, it is used to create all objects of that type. Here's a program to prove it:

```
// typeinfo/SweetShop.java
// Examination of the way the class loader works
class Cookie {
static { System.out.println("Loading Cookie"); }
}
class Gum {
static { System.out.println("Loading Gum"); }
}
class Candy {
static { System.out.println("Loading Candy"); }
}
public class SweetShop {
public static void main(String[] args) {
```

```
System.out.println("inside main");
new Candy();
System.out.println("After creating Candy");
try {
Class.forName("Gum");
} catch(ClassNotFoundException e) {
System.out.println("Couldn't find Gum");
}
System.out.println("After Class.forName(\"Gum\")");
new Cookie();
System.out.println("After creating Cookie");
}
}
/* Output:
inside main
Loading Candy
After creating Candy
Loading Gum
After Class.forName("Gum")
Loading Cookie
```

After creating Cookie

*/

Each of the classes **Candy**, **Gum**, and **Cookie** has a **static** clause that is executed as the class is loaded for the first time. Information is displayed to tell you when loading occurs for that class. In **main()**, the object creations are spread out between print statements to help detect the time of loading.

The output shows that each **Class** object is loaded only when it's needed, and the **static** initialization is performed upon class loading.

A particularly interesting line is:

Class.forName("Gum");

All **Class** objects belong to the class **Class**. A **Class** object is like any other object, so you can get and manipulate a reference to it (that's what the loader does). One of the ways to get a reference to the **Class** object is the **static forName()** method, which takes a **String** containing the textual name (watch the spelling and capitalization!) of the your desired class. It returns a **Class** reference, which is ignored here; the call to **forName()** is made here for its side effect: to load the class **Gum** if it isn't already loaded. In the process of loading, **Gum**s **static** clause is executed.

In the preceding example, if **Class.forName()** fails because it can't find the class you're trying to load, it will throw a **ClassNotFoundException**. Here, we simply report the problem and move on, but in more sophisticated programs, you might try to fix the problem inside the exception handler (there's an example of this in the Patterns chapter).

Anytime you use type information at run time, you must first get a reference to the appropriate **Class** object. **Class.forName()** is one convenient way to do this, because you don't need an object of that type to get the **Class** reference. However, if you already have an object of the type you're interested in, you can fetch the **Class** reference by calling a method that's part of the **Object** root class: **getClass()**. This returns the **Class** reference representing the actual type of the object. **Class** has many methods; here are a few:

```
// typeinfo/toys/ToyTest.java
// Testing class Class
// {java typeinfo.toys.ToyTest}
package typeinfo.toys;
interface HasBatteries {}
interface Waterproof {}
```

```
interface Shoots {}
class Toy {
// Comment out the following no-arg
// constructor to see NoSuchMethodError
Toy() {}
Toy(int i) {}
}
class FancyToy extends Toy
implements HasBatteries, Waterproof, Shoots {
FancyToy() { super(1); }
}
public class ToyTest {
static void printInfo(Class cc) {
System.out.println("Class name: " + cc.getName() +
" is interface? [" + cc.isInterface() + "]");
System.out.println(
"Simple name: " + cc.getSimpleName());
System.out.println(
"Canonical name : " + cc.getCanonicalName());
}
```

```
public static void main(String[] args) {
Class c = null;
try {
c = Class.forName("typeinfo.toys.FancyToy");
} catch(ClassNotFoundException e) {
System.out.println("Can't find FancyToy");
System.exit(1);
}
printInfo(c);
for(Class face : c.getInterfaces())
printInfo(face);
Class up = c.getSuperclass();
Object obj = null;
try {
// Requires no-arg constructor:
obj = up.newInstance();
} catch(InstantiationException e) {
System.out.println("Cannot instantiate");
System.exit(1);
} catch(IllegalAccessException e) {
```

```
System.out.println("Cannot access");
System.exit(1);
}
printInfo(obj.getClass());
}
}
/* Output:
Class name: typeinfo.toys.FancyToy is interface?
[false]
Simple name: FancyToy
Canonical name : typeinfo.toys.FancyToy
Class name: typeinfo.toys.HasBatteries is interface?
[true]
Simple name: HasBatteries
Canonical name : typeinfo.toys.HasBatteries
Class name: typeinfo.toys.Waterproof is interface?
[true]
Simple name: Waterproof
Canonical name : typeinfo.toys.Waterproof
Class name: typeinfo.toys.Shoots is interface? [true]
```

Simple name: Shoots

Canonical name : typeinfo.toys.Shoots

Class name: typeinfo.toys.Toy is interface? [false]

Simple name: Toy

Canonical name : typeinfo.toys.Toy

*/

FancyToy inherits from **Toy** and **implements** the interfaces **HasBatteries**, **Waterproof**, and **Shoots**. In **main()**, a **Class** reference is created and initialized to the **FancyToy Class** using **forName()** inside an appropriate **try** block. Notice you must use the fully qualified name (including the package name) in the **String** you pass to **forName()**.

printInfo() uses **getName()** to produce the fully qualified class

name, and **getSimpleName()** and **getCanonicalName()** to produce the name without the package, and the fully qualified name, respectively. As its name implies, **isInterface()** tells you whether this **Class** object represents an interface. Thus, with the **Class**

object you can find out just about everything you want to know about a type.

The **Class.getInterfaces()** method called in **main()** returns an array of **Class** objects representing the interfaces contained in the **Class** object of interest.

You can also ask a **Class** object for its direct base class using **getSuperclass()**. This returns a **Class** reference you can further query. Thus you can discover an object's entire class hierarchy at run time.

The **newInstance()** method of **Class** is a way to implement a "virtual constructor," which says, "I don't know exactly what type you are, but create yourself properly anyway." In the preceding example, **up** is just a **Class** reference with no further type information known at compile time. And when you create a new instance, you get back an **Object** reference. But that reference is pointing to a **Toy** object. Before you can send any messages other than those accepted by **Object**, you must investigate it a bit and do some casting. In addition, the class that's created with **newInstance()** must have a no-arg constructor. Later in this chapter, you'll see how to dynamically create objects of classes using any constructor, with the Java *reflection*

API.

Class Literals

Java provides a second way to produce the reference to the **Class** object: the *class literal*. In the preceding program this would look like:

FancyToy.class;

This is not only simpler, but also safer since it’s checked at compile time (and thus does not have to be placed in a **try** block). Because it eliminates the **forName()** method call, it’s also more efficient.

Class literals work with regular classes as well as interfaces, arrays, and primitive types. In addition, there’s a standard field called **TYPE** that exists for each of the primitive wrapper classes. The **TYPE** field produces a reference to the **Class** object for the associated primitive type, such that:

is

boolean.class equivalent

Boolean.TYPE

to

is

char.class

equivalent

Character.TYPE

to

is

byte.class

equivalent

Byte.TYPE

to

is

short.class

equivalent

Short.TYPE

to

int.class

is

Integer.TYPE

equivalent

to

is

long.class

equivalent

Long.TYPE

to

is

float.class

equivalent

Float.TYPE

to

is

double.class

equivalent

Double.TYPE

to

is

void.class

equivalent

Void.TYPE

to

My preference is to use the "**.class**" versions if you can, since they're more consistent with regular classes.

Notice that creating a reference to a **Class** object using "**.class**"

doesn’t automatically initialize the **Class** object. There are actually

three steps in preparing a class for use:

1. *Loading*, performed by the class loader. This finds the bytecodes

(usually, but not necessarily, on your disk in your classpath) and

creates a **Class** object from those bytecodes.

2. *Linking*. The link phase verifies the bytecodes in the class,

allocates storage for **static** fields, and if necessary, resolves all references to other classes made by this class.

3. *Initialization*. If there’s a superclass, initialize that. Execute

static initializers and **static** initialization blocks.

Initialization is delayed until the first reference to a **static** method

(the constructor is implicitly **static**) or to a non-constant **static**

field:

```
// typeinfo/ClassInitialization.java
import java.util.*;
class Initable {
static final int STATIC_FINAL = 47;
static final int STATIC_FINAL2 =
ClassInitialization.rand.nextInt(1000);
static {
System.out.println("Initializing Initable");
```

```
}
}
class Initable2 {
static int staticNonFinal = 147;
static {
System.out.println("Initializing Initable2");
}
}
class Initable3 {
static int staticNonFinal = 74;
static {
System.out.println("Initializing Initable3");
}
}
public class ClassInitialization {
public static Random rand = new Random(47);
public static void
main(String[] args) throws Exception {
Class initable = Initable.class;
System.out.println("After creating Initable ref");
```

```
// Does not trigger initialization:
System.out.println(Initable.STATIC_FINAL);
// Does trigger initialization:
System.out.println(Initable.STATIC_FINAL2);
// Does trigger initialization:
System.out.println(Initable2.staticNonFinal);
Class initable3 = Class.forName("Initable3");
System.out.println("After creating Initable3 ref");
System.out.println(Initable3.staticNonFinal);
}
}
/* Output:
After creating Initable ref
47
Initializing Initable
258
Initializing Initable2
147
Initializing Initable3
After creating Initable3 ref
```

74

*/

Effectively, initialization is “as lazy as possible.” From the creation of the **initable** reference, you see that just using the **.class** syntax to get a reference to the class doesn’t cause initialization. However, **Class.forName()** initializes the class immediately to produce the **Class** reference, as seen in the creation of **initable3**.

If a **static final** value is a “compile-time constant” such as **Initable.staticFinal**, that value can be read without causing the **Initable** class to be initialized. Making a field **static** and **final**, however, does not guarantee this behavior: accessing **Initable.staticFinal2** forces class initialization because it cannot be a compile-time constant.

If a **static** field is not **final**, accessing it always requires linking (to allocate storage for the field) and initialization (to initialize that storage) before it can be read, as you see in the access to **Initable2.staticNonFinal**.

Generic Class References

A **Class** reference points to a **Class** object, which manufactures instances of classes and contains all the method code for those instances. It also contains the **static**s for that class. So a **Class** reference really does indicate the exact type of what it's pointing to: an object of the class **Class**.

However, the Java designers saw an opportunity to make this a bit more specific by allowing you to constrain the type of **Class** object to which the **Class** reference points, using the generic syntax. In the following example, both syntaxes are correct:

```
// typeinfo/GenericClassReferences.java
public class GenericClassReferences {
public static void main(String[] args) {
Class intClass = int.class;
Class<Integer> genericIntClass = int.class;
genericIntClass = Integer.class; // Same thing
intClass = double.class;
// genericIntClass = double.class; // Illegal
}
}
```

The ordinary class reference does not produce a warning. Notice, however, that the ordinary class reference can be reassigned to any other **Class** object, whereas the generic class reference can only be assigned to its declared type. By using the generic syntax, you allow the compiler to enforce extra type checking.

What if you'd like to loosen the constraint a little? Initially, it seems like you ought to do something like:

```
Class<Number> genericNumberClass = int.class;
```

This would seem to make sense because **Integer** inherits **Number**. But this doesn't work, because the **Integer Class** object is not a subclass of the **Number Class** object (this can seem like a subtle distinction; we'll look into it more deeply in the Generics chapter).

To loosen the constraints when using generic **Class** references, I use a *wildcard*, which is part of Java generics. The wildcard symbol is **?** , and it indicates "anything." So we can add wildcards to the ordinary **Class** reference in the above example and produce the same results:

```
// typeinfo/WildcardClassReferences.java
public class WildcardClassReferences {
public static void main(String[] args) {
Class<?> intClass = int.class;
```

```
intClass = double.class;
}
}
```

Class<?> is preferred over plain **Class**, even though they are equivalent and the plain **Class**, as you saw, doesn't produce a compiler warning. The benefit of **Class<?>** is it indicates you aren't just using a non-specific class reference by accident, or out of ignorance. You *chose* the non-specific version.

To create a **Class** reference that is constrained to a type *or any subtype*, you combine the wildcard with the **extends** keyword to create a *bound*. So instead of just saying **Class<Number>** , you say:

```
// typeinfo/BoundedClassReferences.java
public class BoundedClassReferences {
public static void main(String[] args) {
Class<? extends Number> bounded = int.class;
bounded = double.class;
bounded = Number.class;
// Or anything else derived from Number.
}
}
```

The reason for adding the generic syntax to **Class** references is only to provide compile-time type checking, so if you do something wrong you find out about it a little sooner. You can't actually go astray with ordinary **Class** references, but if you make a mistake you won't find out until run time, which can be inconvenient.

Here's an example that uses the generic class syntax. It stores a class reference, and later generates objects using **newInstance()**:

```
// typeinfo/DynamicSupplier.java
import java.util.function.*;
import java.util.stream.*;
class CountedInteger {
private static long counter;
private final long id = counter++;
@Override
public String toString() { return Long.toString(id); }
}
public class DynamicSupplier<T> implements Supplier<T> {
private Class<T> type;
public DynamicSupplier(Class<T> type) {
this.type = type;
```

```
}
public T get() {
try {
return type.newInstance();
} catch(InstantiationException |
IllegalAccessException e) {
throw new RuntimeException(e);
}
}
public static void main(String[] args) {
Stream.generate(
new DynamicSupplier<>(CountedInteger.class))
.skip(10)
.limit(5)
.forEach(System.out::println);
}
}
/* Output:
10
11
```

12

13

14

/

Notice this class must assume that any type it works with has a no-arg constructor (one without arguments), and you'll get an exception if that isn't the case. The compiler does not issue any warnings for this program.

When you use the generic syntax for **Class** objects, **newInstance()** will return the exact type of the object, rather than just a basic **Object** as you saw in **ToyTest.java**. This is

somewhat limited:

```
// typeinfo/toys/GenericToyTest.java
// Testing class Class
// {java typeinfo.toys.GenericToyTest}
package typeinfo.toys;
public class GenericToyTest {
public static void
main(String[] args) throws Exception {
Class<FancyToy> ftClass = FancyToy.class;
// Produces exact type:
```

```
FancyToy fancyToy = ftClass.newInstance();
Class<? super FancyToy> up =
ftClass.getSuperclass();
// This won't compile:
// Class<Toy> up2 = ftClass.getSuperclass();
// Only produces Object:
```

```
Object obj = up.newInstance();
}
}
```

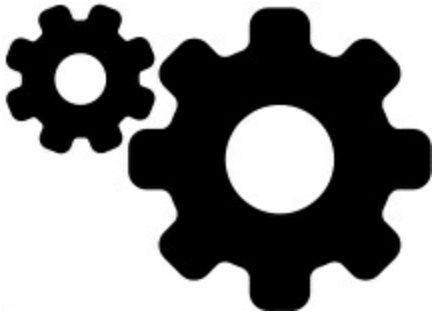
If you get the superclass, the compiler will only allow you to say that the superclass reference is “some class that is a superclass of **FancyToy**” as seen in the expression **Class<? super FancyToy>** . It will not accept a declaration of **Class<Toy>** . This seems a bit strange because **getSuperclass()** returns the base *class* (not interface) and the compiler knows what that class is at compile time—here, **Toy.class**, not just “some superclass of **FancyToy**.” In any event, because of the vagueness, the return value of **up.newInstance()** is not a precise type, but just an **Object**.

The cast() Method

There’s also a casting syntax for use with **Class** references: the **cast()** method:

```
// typeinfo/ClassCasts.java
class Building {}
class House extends Building {}
public class ClassCasts {
public static void main(String[] args) {
```

```
Building b = new House();
Class<House> houseType = House.class;
House h = houseType.cast(b);
```



```
h = (House)b; // ... or just do this.
}
}
```

The **cast()** method takes the argument object and casts it to the type of the **Class** reference. However, if you look at the above code it seems like a lot of extra work compared to the last line in **main()**, which does the same thing.

cast() is useful for situations where you *can't* just use an ordinary cast. This usually happens when you're writing generic code (which you'll learn about in the Generics chapter), and you've stored a **Class** reference to use for casting. This turns out to be a rare thing—I found only one instance where **cast()** was used in the entire Java library (it was in **com.sun.mirror.util.DeclarationFilter**).

Another feature had *no* usage in the Java library:

Class.asSubclass(). This casts the class object to a more specific type.

Checking Before a Cast

So far, you've seen forms of RTTI, including:

1. The classic cast; e.g., "**(Shape)**," which uses RTTI to make sure the cast is correct. This will throw a **ClassCastException** if you've performed a bad cast.

2. The **Class** object representing the type of your object. The **Class** object can be queried for useful runtime information.

In C++, the classic cast "**(Shape)**" does *not* perform RTTI. It simply tells the compiler to treat the object as the new type. In Java, which *does* perform the type check, this cast is often called a "type-safe downcast." The reason for the term "downcast" is the historical arrangement of the class hierarchy diagram. If casting a **Circle** to a **Shape** is an upcast, then casting a **Shape** to a **Circle** is a downcast. However, because it knows that a **Circle** is also a **Shape**, the compiler freely allows an upcast assignment, without requiring any explicit cast syntax. The compiler *cannot* know, given a **Shape**, what that **Shape** actually is—it could be exactly a **Shape**, or it could be a

subtype of **Shape**, such as a **Circle**, **Square**, **Triangle** or some other type. At compile time, the compiler only sees a **Shape**. Thus, it won't allow you to perform a downcast assignment without using an explicit cast, to tell the compiler you know this is a particular type (the compiler *will* check to see if that downcast is reasonable, so it won't let you downcast to a type that's not actually a subclass).

There's a third form of RTTI in Java. This is the keyword **instanceof**, which tells you if an object is an instance of a particular type. It returns a **boolean** so you use it in the form of a question, like this:

```
if(x instanceof Dog)
((Dog)x).bark();
```

The **if** statement checks to see if the object **x** belongs to the class **Dog** *before* you cast **x** to a **Dog**. It's important to use **instanceof** before a downcast when you don't have other information that tells you the type of the object; otherwise, you'll end up with a **ClassCastException**.

Ordinarily, you might be hunting for one type (triangles to turn purple, for example), but you can easily tally *all* objects by using **instanceof**. For example, suppose you have a family of classes to describe **Pet**s (and their people, a feature which will come in handy in

a later example). Each **Individual** in the hierarchy has an **id** and an optional name. Although the classes that follow inherit from **Individual**, there are some complexities in the **Individual** class, so that code is shown and explained in the Appendix: Collection Topics chapter. You see it's not really necessary to see the code for **Individual**—you know you can create it with or without a name, and that each **Individual** has a method **id()** that returns a unique identifier (created by counting each object). There's also a **toString()** method; if you don't provide a name for an **Individual**, **toString()** only produces the simple type name.

Here is the class hierarchy that inherits from **Individual**:

```
// typeinfo/pets/Person.java
package typeinfo.pets;
public class Person extends Individual {
public Person(String name) { super(name); }
}
// typeinfo/pets/Pet.java
package typeinfo.pets;
public class Pet extends Individual {
public Pet(String name) { super(name); }
```

```
public Pet() { super(); }
}
// typeinfo/pets/Dog.java
package typeinfo.pets;
public class Dog extends Pet {
public Dog(String name) { super(name); }
public Dog() { super(); }
}
// typeinfo/pets/Mutt.java
package typeinfo.pets;
public class Mutt extends Dog {
public Mutt(String name) { super(name); }
public Mutt() { super(); }
}
// typeinfo/pets/Pug.java
package typeinfo.pets;
public class Pug extends Dog {
public Pug(String name) { super(name); }
public Pug() { super(); }
}
```

```
// typeinfo/pets/Cat.java
package typeinfo.pets;
public class Cat extends Pet {
public Cat(String name) { super(name); }
public Cat() { super(); }
}
// typeinfo/pets/EgyptianMau.java
package typeinfo.pets;
public class EgyptianMau extends Cat {
public EgyptianMau(String name) { super(name); }
public EgyptianMau() { super(); }
}
// typeinfo/pets/Manx.java
package typeinfo.pets;
public class Manx extends Cat {
public Manx(String name) { super(name); }
public Manx() { super(); }
}
// typeinfo/pets/Cymric.java
package typeinfo.pets;
```

```
public class Cymric extends Manx {
public Cymric(String name) { super(name); }
public Cymric() { super(); }
}
// typeinfo/pets/Rodent.java
package typeinfo.pets;
public class Rodent extends Pet {
public Rodent(String name) { super(name); }
public Rodent() { super(); }
}
// typeinfo/pets/Rat.java
package typeinfo.pets;
public class Rat extends Rodent {
public Rat(String name) { super(name); }
public Rat() { super(); }
}
// typeinfo/pets/Mouse.java
package typeinfo.pets;
public class Mouse extends Rodent {
public Mouse(String name) { super(name); }
```

```
public Mouse() { super(); }
}
// typeinfo/pets/Hamster.java
package typeinfo.pets;
public class Hamster extends Rodent {
public Hamster(String name) { super(name); }
public Hamster() { super(); }
}
```

We must explicitly write the no-arg constructor in each case because we have a constructor with an argument, which precludes the compiler automatically generating the no-arg constructor.

Next, we need a way to randomly create different types of pets, and for convenience, to create arrays and **List**s of pets. To allow this tool to evolve through several different implementations, we'll define it as an abstract class:

```
// typeinfo/pets/PetCreator.java
// Creates random sequences of Pets
package typeinfo.pets;
import java.util.*;
import java.util.function.*;
```

```
public abstract
class PetCreator implements Supplier<Pet> {
private Random rand = new Random(47);
// The List of the different types of Pet to create:
public abstract List<Class<? extends Pet>> types();
public Pet get() { // Create one random Pet
int n = rand.nextInt(types().size());
try {
return types().get(n).newInstance();
} catch(InstantiationException |
IllegalAccessException e) {
throw new RuntimeException(e);
}
}
}
```

The **abstract types()** method expects a derived class to produce the **List** of **Class** objects (this is a variation of the *Template Method* design pattern). Notice that the type of class is specified as "anything derived from **Pet**," so **newInstance()** produces a **Pet** without requiring a cast. **get()** randomly indexes into the **List** and

uses the selected **Class** object to generate a new instance of that class with **Class.newInstance()**.

You can get two kinds of exceptions when calling **newInstance()**. You see these handled in the **catch** clause following the **try** block. Again, the names of the exceptions are relatively useful explanations of what went wrong (**IllegalAccessException** relates to a violation of the Java security mechanism, in this case if the no-arg constructor is **private**).

When you derive a subclass of **PetCreator**, you supply the **List** of types of **Pet** to create using **get()**. The **types()** method will normally just return a reference to this **static List**. Here's an implementation using **forName()**:

```
// typeinfo/pets/ForNameCreator.java
package typeinfo.pets;
import java.util.*;
public class ForNameCreator extends PetCreator {
private static List<Class<? extends Pet>> types =
new ArrayList<>();
// Types you want randomly created:
private static String[] typeNames = {
```

```
"typeinfo.pets.Mutt",
"typeinfo.pets.Pug",
"typeinfo.pets.EgyptianMau",
"typeinfo.pets.Manx",
"typeinfo.pets.Cymric",
"typeinfo.pets.Rat",
"typeinfo.pets.Mouse",
"typeinfo.pets.Hamster"
};
@SuppressWarnings("unchecked")
private static void loader() {
try {
for(String name : typeNames)
types.add(
(Class<? extends Pet>)Class.forName(name));
} catch(ClassNotFoundException e) {
throw new RuntimeException(e);
}
}
static { loader(); }
```

```
@Override
public List<Class<? extends Pet>> types() {
return types;
}
}
```

The **loader()** method creates the **List** of **Class** objects using **Class.forName()**. This can generate a **ClassNotFoundException**, which makes sense since you're passing it a **String** which cannot be validated at compile time. Since the **Pet** objects are in package **typeinfo**, the package name must be used when referring to the classes.

To produce a typed **List** of **Class** objects, a cast is required, which produces a compile-time warning. The **loader()** method is defined separately, then placed inside a static initialization clause because the **@SuppressWarnings** annotation cannot be placed directly onto the static initialization clause.

To count **Pet**s, we need a tool that keeps track of the quantities of various different types of **Pet**. A **Map** is perfect for this; the keys are the **Pet** type names and the values are **Integer**s to hold the **Pet** quantities. This way, you can say, "How many **Hamster** objects are

there?” We can use **instanceof** to count **Pet**s:

```
// typeinfo/PetCount.java
// Using instanceof
import typeinfo.pets.*;
import java.util.*;
public class PetCount {
static class Counter extends HashMap<String,Integer> {
public void count(String type) {
Integer quantity = get(type);
if(quantity == null)
put(type, 1);
else
put(type, quantity + 1);
}
}
public static void
countPets(PetCreator creator) {
Counter counter = new Counter();
for(Pet pet : Pets.array(20)) {
// List each individual pet:
```

```
System.out.print(
pet.getClass().getSimpleName() + " ");
if(pet instanceof Pet)
counter.count("Pet");
if(pet instanceof Dog)
counter.count("Dog");
if(pet instanceof Mutt)
counter.count("Mutt");
if(pet instanceof Pug)
counter.count("Pug");
if(pet instanceof Cat)
counter.count("Cat");
if(pet instanceof EgyptianMau)
counter.count("EgyptianMau");
if(pet instanceof Manx)
counter.count("Manx");
if(pet instanceof Cymric)
counter.count("Cymric");
if(pet instanceof Rodent)
counter.count("Rodent");
```

```
if(pet instanceof Rat)
counter.count("Rat");
if(pet instanceof Mouse)
counter.count("Mouse");
if(pet instanceof Hamster)
counter.count("Hamster");
}
// Show the counts:
System.out.println();
System.out.println(counter);
}
public static void main(String[] args) {
countPets(new ForNameCreator());
}
}
/* Output:
Rat Manx Cymric Mutt Pug Cymric Pug Manx Cymric Rat
EgyptianMau Hamster EgyptianMau Mutt Mutt Cymric Mouse
Pug Mouse Cymric
{EgyptianMau=2, Pug=3, Rat=2, Cymric=5, Mouse=2, Cat=9,
```

Manx=7, Rodent=5, Mutt=3, Dog=6, Pet=20, Hamster=1}

/

In **countPets()**, the **static Pets.array()** method (which is defined shortly) produces an array is filled with random **Pet**s. Each **Pet** in the array is tested and counted using **instanceof**.

There's a rather narrow restriction on **instanceof**: You can compare it to a named type only, and not to a **Class** object. In the

preceding example you might feel it's tedious to write out all of those **instanceof** expressions, and you're right. But there is no way to cleverly automate **instanceof** by creating an array of **Class** objects and comparing it to those instead (stay tuned—you'll see an alternative). This isn't as great a restriction as you might think, because you'll eventually understand that your design is probably flawed if you end up writing many **instanceof** expressions.

Using Class Literals

If we reimplement **PetCreator** using class literals, the result is cleaner in many ways:

```
// typeinfo/pets/LiteralPetCreator.java
// Using class literals
// {java typeinfo.pets.LiteralPetCreator}
package typeinfo.pets;
import java.util.*;
public class LiteralPetCreator extends PetCreator {
// No try block needed.
@SuppressWarnings("unchecked")
public static
final List<Class<? extends Pet>> ALL_TYPES =
Collections.unmodifiableList(Arrays.asList(
Pet.class, Dog.class, Cat.class, Rodent.class,
Mutt.class, Pug.class, EgyptianMau.class,
Manx.class, Cymric.class, Rat.class,
Mouse.class, Hamster.class));
// Types for random creation:
private static final
List<Class<? extends Pet>> TYPES =
ALL_TYPES.subList(ALL_TYPES.indexOf(Mutt.class),
ALL_TYPES.size());
```

```
@Override
public List<Class<? extends Pet>> types() {
return TYPES;
}
public static void main(String[] args) {
System.out.println(TYPES);
}
}
/* Output:
[class typeinfo.pets.Mutt, class typeinfo.pets.Pug,
class typeinfo.pets.EgyptianMau, class
typeinfo.pets.Manx, class typeinfo.pets.Cymric, class
typeinfo.pets.Rat, class typeinfo.pets.Mouse, class
typeinfo.pets.Hamster]
*/
```

In the upcoming **PetCount3.java** example, we pre-load a **Map** with all the **Pet** types (not just the ones that are randomly generated), so the **ALL_TYPES List** is necessary. The **types** list is the portion of **ALL_TYPES** (created using **List.subList()**) that includes the exact pet types, so it is used for random **Pet** generation.

This time, the creation of **types** is not surrounded by a **try** block since it's evaluated at compile time and thus won't throw any exceptions, unlike **Class.forName()**.

We now have two implementations of **PetCreator** in the **typeinfo.pets** library. To provide the second one as a default implementation, we can create a *Façade* that utilizes **LiteralPetCreator**:

```
// typeinfo/pets/Pets.java
// Facade to produce a default PetCreator
package typeinfo.pets;
import java.util.*;
import java.util.stream.*;
public class Pets {
public static final PetCreator CREATOR =
new LiteralPetCreator();
public static Pet get() {
return CREATOR.get();
}
public static Pet[] array(int size) {
Pet[] result = new Pet[size];
```

```
for(int i = 0; i < size; i++)
result[i] = CREATOR.get();
return result;
}
public static List<Pet> list(int size) {
List<Pet> result = new ArrayList<>();
Collections.addAll(result, array(size));
return result;
}
public static Stream<Pet> stream() {
return Stream.generate(CREATOR);
}
}
```

This also provides indirection to **get()**, **array()** and **list()**, and a new method to produce a **Stream<Pet>** .

Because **PetCount.countPets()** takes a **PetCreator** argument, we can easily test the **LiteralPetCreator** (via the above Façade):

```
// typeinfo/PetCount2.java
import typeinfo.pets.*;
```

```
public class PetCount2 {
public static void main(String[] args) {
PetCount.countPets(Pets.CREATOR);
}
}
/* Output:
Rat Manx Cymric Mutt Pug Cymric Pug Manx Cymric Rat
EgyptianMau Hamster EgyptianMau Mutt Mutt Cymric Mouse
Pug Mouse Cymric
{EgyptianMau=2, Pug=3, Rat=2, Cymric=5, Mouse=2, Cat=9,
Manx=7, Rodent=5, Mutt=3, Dog=6, Pet=20, Hamster=1}
```

```
*/
```

The output is the same as that of **PetCount.java**.

A Dynamic instanceof

The **Class.isInstance()** method provides a way to dynamically test the type of an object. Thus, all those tedious **instanceof** statements can be removed from **PetCount.java**:

```
// typeinfo/PetCount3.java
// Using isInstance()
import java.util.*;
import java.util.stream.*;
import onjava.*;
import typeinfo.pets.*;
public class PetCount3 {
static class Counter extends
LinkedHashMap<Class<? extends Pet>, Integer> {
Counter() {
super(LiteralPetCreator.ALL_TYPES.stream()
.map(lpc -> Pair.make(lpc, 0))
.collect(
Collectors.toMap(Pair::key, Pair::value)));
}
public void count(Pet pet) {
// Class.isInstance() eliminates instanceofs:
entrySet().stream()
.filter(pair -> pair.getKey().isInstance(pet))
.forEach(pair ->
```

```
put(pair.getKey(), pair.getValue() + 1));
}
@Override
public String toString() {
String result = entrySet().stream()
.map(pair -> String.format("%s=%s",
pair.getKey().getSimpleName(),
pair.getValue()))
.collect(Collectors.joining(", "));
return "{" + result + "}";
}
}
public static void main(String[] args) {
Counter petCount = new Counter();
Pets.stream()
.limit(20)
.peek(petCount::count)
.forEach(p -> System.out.print(
p.getClass().getSimpleName() + " "));
System.out.println("\n" + petCount);
```

}

}

/ *Output:*

Rat Manx Cymric Mutt Pug Cymric Pug Manx Cymric Rat

EgyptianMau Hamster EgyptianMau Mutt Mutt Cymric Mouse

Pug Mouse Cymric

{Rat=2, Pug=3, Mutt=3, Mouse=2, Cat=9, Dog=6, Cymric=5,

EgyptianMau=2, Rodent=5, Hamster=1, Manx=7, Pet=20}

**/*

To count all the different types of **Pet**, the **Counter Map** is pre-loaded with the types from **LiteralPetCreator.ALL_TYPES**. Without pre-loading the **Map**, you would only end up counting the randomly-generated types, not the base types like **Pet** and **Cat**.

The **isInstance()** method eliminates the need for the **instanceof** expressions. In addition, this means you can add new types of **Pet** by changing the **LiteralPetCreator.types** array; the rest of the program does not need modification (as it did when using the **instanceof** expressions).

The **toString()** method is overloaded for easier-to-read output that still matches the typical output you see when printing a **Map**.

Counting Recursively

The **Map** in **PetCount3.Counter** was pre-loaded with all the different **Pet** classes. Instead of pre-loading the map, we can use **Class.isAssignableFrom()** and create a general-purpose tool that is not limited to counting **Pet**s:

```
// onjava/TypeCounter.java
// Counts instances of a type family
package onjava;
import java.util.*;
import java.util.stream.*;
public class
TypeCounter extends HashMap<Class<?>, Integer> {
private Class<?> baseType;
public TypeCounter(Class<?> baseType) {
this.baseType = baseType;
}
public void count(Object obj) {
```

```
Class<?> type = obj.getClass();
if(!baseType.isAssignableFrom(type))
throw new RuntimeException(
obj + " incorrect type: " + type +
", should be type or subtype of " + baseType);
countClass(type);
}
private void countClass(Class<?> type) {
Integer quantity = get(type);
put(type, quantity == null ? 1 : quantity + 1);
Class<?> superClass = type.getSuperclass();
if(superClass != null &&
baseType.isAssignableFrom(superClass))
countClass(superClass);
}
@Override
public String toString() {
String result = entrySet().stream()
.map(pair -> String.format("%s=%s",
pair.getKey().getSimpleName(),
```

```
pair.getValue()))
.collect(Collectors.joining(", "));
return "{" + result + "}";
}
}
```

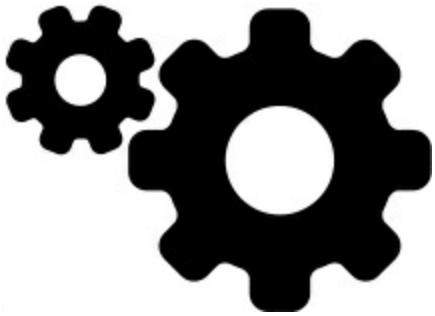
The **count()** method gets the **Class** of its argument, and uses **isAssignableFrom()** for a runtime check to verify that the object you passed actually belongs to the hierarchy of interest.

countClass() first counts the exact type of the class. Then, if **baseType** is assignable from the superclass, **countClass()** is called recursively on the superclass.

```
// typeinfo/PetCount4.java
import typeinfo.pets.*;
import onjava.*;
public class PetCount4 {
public static void main(String[] args) {
TypeCounter counter = new TypeCounter(Pet.class);
Pets.stream()
.limit(20)
.peek(counter::count)
```

```
.forEach(p -> System.out.print(
p.getClass().getSimpleName() + " "));
System.out.println("\n" + counter);
}
}
/* Output:
Rat Manx Cymric Mutt Pug Cymric Pug Manx Cymric Rat
EgyptianMau Hamster EgyptianMau Mutt Mutt Cymric Mouse
Pug Mouse Cymric
{Dog=6, Manx=7, Cat=9, Rodent=5, Hamster=1, Rat=2,
Pug=3, Mutt=3, Cymric=5, EgyptianMau=2, Pet=20,
Mouse=2}
*/
```

The output shows that both base types as well as exact types are counted.



Registered Factories

A problem with generating objects from the **Pet** hierarchy is the fact that every time you add a new type of **Pet** to the hierarchy you must remember to add it to the entries in **LiteralPetCreator.java**.

In a system where you add more classes on a regular basis this can become problematic.

You might think of adding a static initializer to each subclass, so the initializer would add its class to a list somewhere. Unfortunately, static initializers are only called when the class is first loaded, so you have a chicken-and-egg problem: The generator doesn't have the class in its list, so it can never create an object of that class, so the class won't get loaded and placed in the list.

Basically, you're forced to create the list yourself, by hand (unless you write a tool that searches through and analyzes your source code, then creates and compiles the list). So the best you can probably do is to put the list in one central, obvious place. The base class for the hierarchy of interest is probably the best place.

The other change we'll make here is to defer the creation of the object to the class itself, using the *Factory Method* design pattern. A factory method can be called polymorphically, and creates an object of the appropriate type for you. It turns out that

java.util.function.Supplier describes the prototypical factory method with its **T get()**. Covariant return types allow **get()** to return a different type for each subclass implementation of **Supplier**.

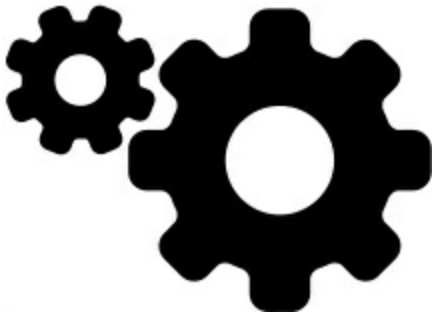
In this example, the base class **Part** contains a **static List** of factory objects (**Supplier<Part>**). Factories for types that should be produced by the **get()** method are "registered" with the base class by adding them to the **prototypes List**. These factories are, oddly enough, instances of the objects themselves. Each object in this list is a *Prototype* for creating other objects:

```
// typeinfo/RegisteredFactories.java
// Registering Factories in the base class
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
class Part implements Supplier<Part> {
@Override
public String toString() {
return getClass().getSimpleName();
}
```

```
static List<Supplier<? extends Part>> prototypes =
Arrays.asList(
new FuelFilter(),
new AirFilter(),
new CabinAirFilter(),
new OilFilter(),
new FanBelt(),
new PowerSteeringBelt(),
new GeneratorBelt()
);
private static Random rand = new Random(47);
public Part get() {
int n = rand.nextInt(prototypes.size());
return prototypes.get(n).get();
}
}
class Filter extends Part {}
class FuelFilter extends Filter {
@Override
public FuelFilter get() { return new FuelFilter(); }
```

```
}
class AirFilter extends Filter {
@Override
public AirFilter get() { return new AirFilter(); }
}
class CabinAirFilter extends Filter {
@Override
public CabinAirFilter get() {
return new CabinAirFilter();
}
}
class OilFilter extends Filter {
@Override
public OilFilter get() { return new OilFilter(); }
}
class Belt extends Part {}
class FanBelt extends Belt {
@Override
public FanBelt get() { return new FanBelt(); }
}
```

```
class GeneratorBelt extends Belt {
@Override
public GeneratorBelt get() {
return new GeneratorBelt();
}
}
class PowerSteeringBelt extends Belt {
@Override
public PowerSteeringBelt get() {
return new PowerSteeringBelt();
}
}
public class RegisteredFactories {
public static void main(String[] args) {
Stream.generate(new Part())
.limit(10)
.forEach(System.out::println);
}
}
/* Output:
```



GeneratorBelt

CabinAirFilter

GeneratorBelt

AirFilter

PowerSteeringBelt

CabinAirFilter

FuelFilter

PowerSteeringBelt

PowerSteeringBelt

FuelFilter

*/

Not all classes in the hierarchy should be instantiated; here **Filter** and **Belt** are just classifiers so you do not create an instance of either one, but only of their subclasses (note that if you try to, you get the behavior of the **Part** base class).

Because **Part implements Supplier<Part>** , a **Part** supplies

other **Part**s via its **get()**. If you call **get()** (or if **generate()** calls **get()**) for a base-class **Part**, it creates random specific **Part** subtypes, each of which are ultimately inherited from **Part** and override the appropriate **get()** to produce one of themselves.

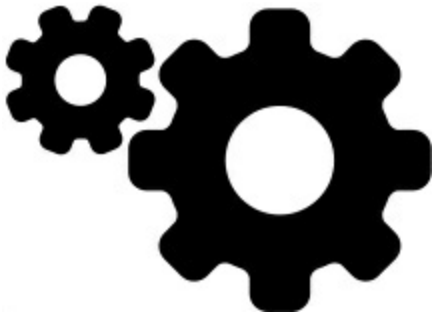
Instanceof vs. Class Equivalence

When you are querying for type information, there's an important difference between either form of **instanceof** (that is, **instanceof** or **isInstance()**, which produce equivalent results) and the direct comparison of the **Class** objects. Here's an example that demonstrates the difference:

```
// typeinfo/FamilyVsExactType.java
// The difference between instanceof and class
// {java typeinfo.FamilyVsExactType}
package typeinfo;
class Base {}
class Derived extends Base {}
public class FamilyVsExactType {
static void test(Object x) {
System.out.println(
```

```
"Testing x of type " + x.getClass());
System.out.println(
"x instanceof Base " + (x instanceof Base));
System.out.println(
"x instanceof Derived " + (x instanceof Derived));
System.out.println(
"Base.isInstance(x) " + Base.class.isInstance(x));
System.out.println(
"Derived.isInstance(x) " +
Derived.class.isInstance(x));
System.out.println(
"x.getClass() == Base.class " +
(x.getClass() == Base.class));
System.out.println(
"x.getClass() == Derived.class " +
(x.getClass() == Derived.class));
System.out.println(
"x.getClass().equals(Base.class)) "+
(x.getClass().equals(Base.class)));
System.out.println(
```

```
"x.getClass().equals(Derived.class)) " +
(x.getClass().equals(Derived.class)));
}
public static void main(String[] args) {
test(new Base());
test(new Derived());
}
}
/* Output:
Testing x of type class typeinfo.Base
x instanceof Base true
x instanceof Derived false
```



```
Base.isInstance(x) true
Derived.isInstance(x) false
x.getClass() == Base.class true
x.getClass() == Derived.class false
```

x.getClass().equals(Base.class)) true

x.getClass().equals(Derived.class)) false

Testing x of type class typeinfo.Derived

x instanceof Base true

x instanceof Derived true

Base.isInstance(x) true

Derived.isInstance(x) true

x.getClass() == Base.class false

x.getClass() == Derived.class true

x.getClass().equals(Base.class)) false

x.getClass().equals(Derived.class)) true

**/*

The **test()** method performs type checking with its argument using both forms of **instanceof**. It then gets the **Class** reference and uses == and **equals()** to test for equality of the **Class** objects. Reassuringly, **instanceof** and **isInstance()** produce exactly the same results, as do **equals()** and ==. But the tests themselves draw different conclusions. In keeping with the concept of type, **instanceof** says, “Are you this class, or a class derived from this class?” On the other hand, if you compare the actual **Class** objects

using ==, there is no concern with inheritance—it's either the exact type or it isn't.

Reflection: Runtime

Class Information

If you don't know the precise type of an object, RTTI will tell you. However, there's a limitation: The type must be known at compile time to detect it using RTTI and do something useful with the information. Put another way, the compiler must know about all the classes you use.

This doesn't seem like that much of a limitation at first, but suppose you're given a reference to an object that's not in your program space. In fact, the class of that object isn't even available to your program at compile time. Perhaps you get a bunch of bytes from a disk file or from a network connection, and you're told that those bytes represent a class. Since this class shows up long after the compiler generates the code for your program, how can you possibly use such a class?

In a traditional programming environment, this is a far-fetched scenario. But as we move into a larger programming world, there are important cases when this happens. The first is component-based programming, where you build projects using *Rapid Application*

Development (RAD) in an application builder *Integrated Development Environment* (IDE). This is a visual approach to creating a program by moving icons that represent components onto a form. These components are then configured by setting some of their values at program time. This design-time configuration requires that any component be instantiable, that it exposes parts of itself, and it allows its properties to be read and modified. In addition, components that handle *Graphical User Interface* (GUI) events must expose information about appropriate methods so the IDE can assist the programmer in overriding these event-handling methods. Reflection provides the mechanism to detect the available methods and produce the method names.

Another compelling motivation for discovering class information at run time is to provide the ability to create and execute objects on remote platforms, across a network. This is called *Remote Method Invocation* (RMI), and it enables a Java program's objects to be distributed across many machines. This distribution can happen for a number of reasons. If you want to speed up a computation-intensive task, you can break it into pieces to put onto idle machines. Or you might place code that handles particular types of tasks (e.g., "Business

Rules” in a multitier client/server architecture) on a particular machine, so the machine becomes a common repository describing those actions, and it can be easily changed to affect everyone in the system. Distributed computing also supports specialized hardware that might be good at a particular task—matrix inversions, for example—but inappropriate or too expensive for general-purpose programming.

The class **Class** supports the concept of *reflection*, along with the **java.lang.reflect** library which contains the classes **Field**, **Method**, and **Constructor** (each of which implements the **Member** interface). Objects of these types are created by the JVM at run time to represent the corresponding member in the unknown class. You can then use the **Constructor**s to create new objects, the **get()** and **set()** methods to read and modify the fields associated with **Field** objects, and the **invoke()** method to call a method associated with a **Method** object. In addition, you can call the convenience methods **getFields()**, **getMethods()**, **getConstructors()**, etc., to return arrays of objects representing the fields, methods, and constructors. (You can find out more by looking up the class **Class** in the JDK documentation.) Thus, the

class information for anonymous objects can be completely determined at run time, and nothing need be known at compile time. It's important to realize there's nothing magic about reflection. When you're using reflection to interact with an object of an unknown type, the JVM will look at the object and see it belongs to a particular class (just like ordinary RTTI). Before anything can be done with it, the **Class** object must be loaded. Thus, the **.class** file for that particular type must still be available to the JVM, either on the local machine or across the network. So the true difference between RTTI and reflection is that with RTTI, the compiler opens and examines the **.class** file at compile time. Put another way, you can call all the

methods of an object in the "normal" way. With reflection, the **.class** file is unavailable at compile time; it is opened and examined by the runtime environment.

A Class Method Extractor

Normally you won't use the reflection tools directly, but they can be helpful to create more dynamic code. Reflection is in the language to

support other Java features, such as object serialization (see the

Appendix: Object Serialization). However, there are times when it's useful to dynamically extract information about a class.

Consider a class method extractor. Looking at a class definition's

source code or JDK documentation shows only the methods defined or

overridden *within that class definition*. But there might be dozens

more available to you that have come from base classes. To locate

these is both tedious and time consuming. 1 Fortunately, reflection provides a way to write a simple tool to automatically show you the

entire interface:

```
// typeinfo/ShowMethods.java

// Using reflection to show all the methods of a class,

// even if the methods are defined in the base class

// {java ShowMethods ShowMethods}

import java.lang.reflect.*;

import java.util.regex.*;

public class ShowMethods {

private static String usage =

"usage:\n" +

"ShowMethods qualified.class.name\n" +

"To show all methods in class or:\n" +
```

```
"ShowMethods qualified.class.name word\n" +
"To search for methods involving 'word'";
private static Pattern p = Pattern.compile("\\w+\\.");
public static void main(String[] args) {
if(args.length < 1) {
System.out.println(usage);
System.exit(0);
}
int lines = 0;
try {
Class<?> c = Class.forName(args[0]);
Method[] methods = c.getMethods();
Constructor[] ctors = c.getConstructors();
if(args.length == 1) {
for(Method method : methods)
System.out.println(
p.matcher(
method.toString()).replaceAll(""));
for(Constructor ctor : ctors)
System.out.println(
```

```
p.matcher(ctor.toString()).replaceAll(""));
lines = methods.length + ctors.length;
} else {
for(Method method : methods)
if(method.toString().contains(args[1])) {
System.out.println(p.matcher(
method.toString()).replaceAll(""));
lines++;
}
for(Constructor ctor : ctors)
if(ctor.toString().contains(args[1])) {
System.out.println(p.matcher(
ctor.toString()).replaceAll(""));
lines++;
}
}
} catch(ClassNotFoundException e) {
System.out.println("No such class: " + e);
}
}
```

```
}
/* Output:
public static void main(String[])
public final void wait() throws InterruptedException
public final void wait(long,int) throws
InterruptedException
public final native void wait(long) throws
InterruptedException
public boolean equals(Object)
public String toString()
public native int hashCode()
public final native Class getClass()
public final native void notify()
public final native void notifyAll()
public ShowMethods()
*/
```

The **Class** methods **getMethods()** and **getConstructors()** return an array of **Method** and array of **Constructor**, respectively. Each of these classes has further methods to dissect the names, arguments, and return values of the methods they represent. But you

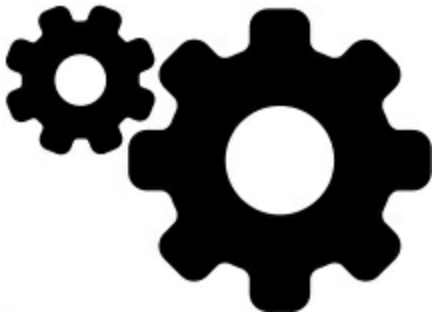
can also just use **toString()**, as is done here, to produce a **String** with the entire method signature. The rest of the code extracts the command-line information, determines if a particular signature matches your target **String** (using **indexOf()**), and strips off the name qualifiers using regular expressions (introduced in the Strings chapter).

The result produced by **Class.forName()** cannot be known at compile time, and therefore all the method signature information is extracted at run time. If you investigate the JDK reflection documentation, you'll see there is enough support to actually set up and make a method call on an object that's totally unknown at compile time (there are examples of this later in this book). Although initially this is something you might not think you'll ever need, the value of full reflection can be surprising.

The output above is produced from the command line:

```
java ShowMethods ShowMethods
```

The output includes a **public** no-arg constructor, even though no constructor was defined. The constructor you see is the one that's automatically synthesized by the compiler. If you then make **ShowMethods** a non-**public** class (that is, package access), the



synthesized no-arg constructor no longer shows up in the output. The synthesized no-arg constructor is automatically given the same access as the class.

Try running **java ShowMethods java.lang.String** with an extra argument of **char**, **int**, **String**, etc.

This tool can be a real time-saver while you're programming, when you can't remember if a class has a particular method and you don't want to hunt through the index or class hierarchy in the JDK documentation, or if you don't know whether that class can do anything with, for example, **Color** objects.

Dynamic Proxies

Proxy is one of the basic design patterns. It is an object you insert in place of the "real" object to provide additional or different operations —these usually involve communication with a "real" object, so a proxy typically acts as a go-between. Here's a trivial example to show the structure of a proxy:

```
// typeinfo/SimpleProxyDemo.java
interface Interface {
void doSomething();
void somethingElse(String arg);
}
class RealObject implements Interface {
@Override
public void doSomething() {
System.out.println("doSomething");
}
@Override
public void somethingElse(String arg) {
System.out.println("somethingElse " + arg);
}
}
class SimpleProxy implements Interface {
private Interface proxied;
SimpleProxy(Interface proxied) {
this.proxied = proxied;
}
```

```
@Override
public void doSomething() {
System.out.println("SimpleProxy doSomething");
proxied.doSomething();
}
@Override
public void somethingElse(String arg) {
System.out.println(
"SimpleProxy somethingElse " + arg);
proxied.somethingElse(arg);
}
}
class SimpleProxyDemo {
public static void consumer(Interface iface) {
iface.doSomething();
iface.somethingElse("bonobo");
}
public static void main(String[] args) {
consumer(new RealObject());
consumer(new SimpleProxy(new RealObject()));
```

```
}
}
/* Output:
doSomething
somethingElse bonobo
SimpleProxy doSomething
doSomething
SimpleProxy somethingElse bonobo
somethingElse bonobo
*/
```

Because **consumer()** accepts an **Interface**, it can't know if it's getting a **RealObject** or a **SimpleProxy**, because both implement **Interface**. But the **SimpleProxy** inserted between the client and the **RealObject** performs operations, then calls the identical method on a **RealObject**.

A proxy can be helpful anytime you'd like to separate extra operations into a different place than the "real object," and especially when you want to easily change from not using the extra operations to using them, and vice versa (the point of design patterns is to encapsulate change—so you must be changing things to justify the pattern). For example, what if you wanted to track calls to the methods in

RealObject, or to measure the overhead of such calls? This is not code you want incorporated in your application, and a proxy enables adding and removing it easily.

Java's *dynamic proxy* takes the idea of a proxy one step further, by both creating the proxy object dynamically and handling calls to the proxied methods dynamically. All calls made on a dynamic proxy are redirected to a single *invocation handler*, which has the job of discovering what the call is and deciding what to do about it. Here's **SimpleProxyDemo.java** rewritten to use a dynamic proxy:

```
// typeinfo/SimpleDynamicProxy.java
import java.lang.reflect.*;
class DynamicProxyHandler implements InvocationHandler {
private Object proxied;
DynamicProxyHandler(Object proxied) {
this.proxied = proxied;
}
@Override
public Object
invoke(Object proxy, Method method, Object[] args)
throws Throwable {
```

```
System.out.println(
"**** proxy: " + proxy.getClass() +
", method: " + method + ", args: " + args);
if(args != null)
for(Object arg : args)
System.out.println(" " + arg);
return method.invoke(proxied, args);
}
}
class SimpleDynamicProxy {
public static void consumer(Interface iface) {
iface.doSomething();
iface.somethingElse("bonobo");
}
public static void main(String[] args) {
RealObject real = new RealObject();
consumer(real);
// Insert a proxy and call again:
Interface proxy = (Interface)Proxy.newProxyInstance(
Interface.class.getClassLoader(),
```

```
new Class[]{ Interface.class },
new DynamicProxyHandler(real));
consumer(proxy);
}
}
/* Output:
doSomething
somethingElse bonobo
**** proxy: class $Proxy0, method: public abstract void
Interface.doSomething(), args: null
doSomething
**** proxy: class $Proxy0, method: public abstract void
Interface.somethingElse(java.lang.String), args:
[Ljava.lang.Object;@6bc7c054
bonobo
somethingElse bonobo
*/
```

You create a dynamic proxy by calling the **static** method **Proxy.newProxyInstance()**, which requires a class loader (you can generally just hand it a class loader from an object that has already

been loaded), a list of interfaces (not classes or abstract classes) you wish the proxy to implement, and an implementation of the interface **InvocationHandler**. The dynamic proxy will redirect all calls to the invocation handler, so the constructor for the invocation handler is usually given the reference to the "real" object so it can forward requests once it performs its intermediary task.

The **invoke()** method is handed the proxy object, in case you must distinguish where the request came from—but in many cases you won't care. However, be careful when calling methods on the proxy inside **invoke()**, because calls through the interface are redirected through the proxy.

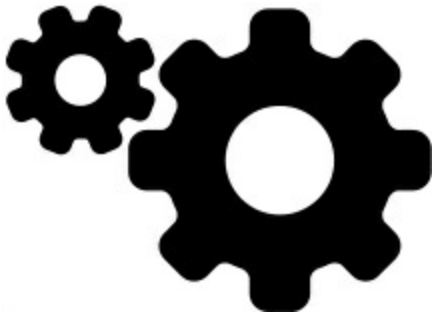
In general you perform the proxied operation, then use **Method.invoke()** to forward the request to the proxied object, passing the necessary arguments. This can initially seem limiting, as if you can only perform generic operations. However, you can filter for certain method calls, while passing others through:

```
// typeinfo/SelectingMethods.java
// Looking for particular methods in a dynamic proxy
import java.lang.reflect.*;
class MethodSelector implements InvocationHandler {
```

```
private Object proxied;
MethodSelector(Object proxied) {
this.proxied = proxied;
}
@Override
public Object
invoke(Object proxy, Method method, Object[] args)
throws Throwable {
if(method.getName().equals("interesting"))
System.out.println(
"Proxy detected the interesting method");
return method.invoke(proxied, args);
}
}
interface SomeMethods {
void boring1();
void boring2();
void interesting(String arg);
void boring3();
}
```

```
class Implementation implements SomeMethods {
@Override
public void boring1() {
System.out.println("boring1");
}
@Override
public void boring2() {
System.out.println("boring2");
}
@Override
public void interesting(String arg) {
System.out.println("interesting " + arg);
}
@Override
public void boring3() {
System.out.println("boring3");
}
}
class SelectingMethods {
public static void main(String[] args) {
```

```
SomeMethods proxy =
(SomeMethods)Proxy.newProxyInstance(
SomeMethods.class.getClassLoader(),
new Class[]{ SomeMethods.class },
new MethodSelector(new Implementation()));
proxy.boring1();
proxy.boring2();
proxy.interesting("bonobo");
proxy.boring3();
}
}
/* Output:
boring1
boring2
Proxy detected the interesting method
interesting bonobo
boring3
*/
```



Here, we are just looking for method names, but you can also look for other aspects of the method signature, and you can even search for particular argument values.

The dynamic proxy is not a tool that you'll use every day, but it can solve certain types of problems very nicely. You can learn more about *Proxy* and other design patterns in *Design Patterns*, by Erich Gamma et al. (Addison-Wesley, 1995), and in the Patterns chapter.

Using Optional

When you use the built-in **null** to indicate the absence of an object, to be completely safe you must test a reference for **null**-ness every time you use it. This can get very tedious and produce ponderous code. The problem is that **null** has no behavior of its own except for producing a **NullPointerException** if you try to do anything with it. **java.util.Optional**, which you first saw in the Functional Programming chapter, creates a thin proxy to shield potentially null values. **Optional** objects prevent your code from

directly causing a **NullPointerException**.

Although **Optional**s were introduced in Java 8 to support **Stream**s, they are a general-purpose tool. We will demonstrate that in this section by applying them to ordinary classes. The topic is included in this chapter because it involves run-time detection.

In practice it doesn't make sense to use **Optional**s everywhere—sometimes checking for **null** is fine, and sometimes you can reasonably assume you won't encounter **null**, and sometimes even detecting aberrations via **NullPointerException** is acceptable.

The place where **Optional**s seem most useful is "closer to the data," with objects that represent entities in the problem space. As a simple example, many systems have a **Person** class, and there are situations in the code where you don't have an actual person (or perhaps you do, but you don't have all the information about that person yet), so traditionally you'd use a **null** reference and test for it. Instead, we can use **Optional**:

```
// typeinfo/Person.java
// Using Optional with regular classes
import onjava.*;
import java.util.*;
```

```
class Person {
public final Optional<String> first;
public final Optional<String> last;
public final Optional<String> address;
// etc.
public final boolean empty;
Person(String first, String last, String address) {
this.first = Optional.ofNullable(first);
this.last = Optional.ofNullable(last);
this.address = Optional.ofNullable(address);
empty = ! this.first.isPresent()
&& ! this.last.isPresent()
&& ! this.address.isPresent();
}
Person(String first, String last) {
this(first, last, null);
}
Person(String last) { this(null, last, null); }
Person() { this(null, null, null); }
@Override
```

```
public String toString() {
if(empty)
return "<Empty>";
return (first.orElse("") +
" " + last.orElse("") +
" " + address.orElse("")).trim();
}
public static void main(String[] args) {
System.out.println(new Person());
System.out.println(new Person("Smith"));
System.out.println(new Person("Bob", "Smith"));
System.out.println(new Person("Bob", "Smith",
"11 Degree Lane, Frostbite Falls, MN"));
}
}
/* Output:
<Empty>
Smith
Bob Smith
Bob Smith 11 Degree Lane, Frostbite Falls, MN
```

*/

The design of **Person** is sometimes called a “data-transfer object.” Notice that all the fields are **public** and **final**, so there are no getter and setter methods. That is, **Person** is *immutable*—you can only set the values with the constructor, then read those values, but you can’t modify them (**String**s themselves are inherently immutable, so you can’t modify the contents of the **String**s nor can you re-assign to the fields). To change a **Person**, you can only replace it with a new **Person** object. The **empty** field is set during construction to easily check to see whether this **Person** represents an empty object.

Anyone using a **Person** is forced to use the **Optional** interface when accessing the **String** fields, and so cannot accidentally trigger a **NullPointerException**.

Now suppose you’ve been given a big pile of venture funding for your Amazing Idea. You’re ready to staff up, but while you’re waiting for positions to be filled, you can use **Person Optional**s as placeholders for each **Position**:

```
// typeinfo/Position.java
import java.util.*;
```

```
class EmptyTitleException extends RuntimeException {}
class Position {
private String title;
private Person person;
Position(String jobTitle, Person employee) {
setTitle(jobTitle);
setPerson(employee);
}
Position(String jobTitle) {
this(jobTitle, null);
}
public String getTitle() { return title; }
public void setTitle(String newTitle) {
// Throws EmptyTitleException if newTitle is null:
title = Optional.ofNullable(newTitle)
.orElseThrow(EmptyTitleException::new);
}
public Person getPerson() { return person; }
public void setPerson(Person newPerson) {
// Uses empty Person if newPerson is null:
```

```
person = Optional.ofNullable(newPerson)
.orElse(new Person());
}
@Override
public String toString() {
return "Position: " + title +
", Employee: " + person;
}
public static void main(String[] args) {
System.out.println(new Position("CEO"));
System.out.println(new Position("Programmer",
new Person("Arthur", "Fonzarelli")));
try {
new Position(null);
} catch(Exception e) {
System.out.println("caught " + e);
}
}
}
/* Output:
```

Position: CEO, Employee: <Empty>

Position: Programmer, Employee: Arthur Fonzarelli

caught EmptyTitleException

*/

This uses **Optional** in a different way. Notice that **title** and **person** are ordinary fields, unprotected by **Optional**. However, the only way to modify those fields is via **setTitle()** and **setPerson()**, both of which use the functionality of **Optional** to impose restrictions on the fields.

We want to guarantee that **title** is never set to **null**. In **setTitle()**, we could check the **newTitle** argument ourselves.

But a big part of functional programming is the ability to reuse tried-and-tested functionality, often even if it's small, to reduce the kinds of little programming errors you make when you code everything by hand. So we take **newTitle** and turn it into an **Optional** using **ofNullable()**, which means that if it's **null** it will produce an **Optional.empty()**. We then immediately take that **Optional** result and apply **orElseThrow()**, so if **newTitle** was **null**, you'll get an exception. We never store the field as an **Optional**, but we apply the **Optional** functionality to enforce our desired

constraint on the **title** field.

EmptyTitleException is a **RuntimeException** because it represents a programmer error. You still get an exception with this scheme, but you get it at the point the error is made—when the **null** is passed to **setTitle()**—and not at some other point in the program which will force you to debug until you find the problem. Also, the use of **EmptyTitleException** further helps localize the bug.

The **person** field has a different constraint: if you try to set it to **null**, it should automatically get set to an empty **Person** object instead. We use the same approach as before of turning it into an **Option**, but in this case when we extract the result we use **orElse(new Person())** to insert the empty **Person** for the **null**.

With **Position**, we don't make an "empty" flag or method because the existence of an empty **Person** in the **person** field implies an available **Position**. Later, you might discover you must add something explicit here, but YAGNI (*You Aren't Going to Need It*)[2] says to "try the simplest thing that could possibly work" for your first draft, and to wait until some aspect of the program requires you to add in the extra feature, rather than assuming it's necessary.

Notice that the **Staff** class blithely ignores the existence of the **Optional**s, although you know they are there, protecting you from **NullPointerException**s:

```
// typeinfo/Staff.java
import java.util.*;
public class Staff extends ArrayList<Position> {
public void add(String title, Person person) {
add(new Position(title, person));
}
public void add(String... titles) {
for(String title : titles)
add(new Position(title));
}
public Staff(String... titles) { add(titles); }
public boolean positionAvailable(String title) {
for(Position position : this)
if(position.getTitle().equals(title) &&
position.getPerson().empty)
return true;
return false;
```

```
}
public void fillPosition(String title, Person hire) {
for(Position position : this)
if(position.getTitle().equals(title) &&
position.getPerson().empty) {
position.setPerson(hire);
return;
}
throw new RuntimeException(
"Position " + title + " not available");
}
public static void main(String[] args) {
Staff staff = new Staff("President", "CTO",
"Marketing Manager", "Product Manager",
"Project Lead", "Software Engineer",
"Software Engineer", "Software Engineer",
"Software Engineer", "Test Engineer",
"Technical Writer");
staff.fillPosition("President",
new Person("Me", "Last", "The Top, Lonely At"));
```

```
staff.fillPosition("Project Lead",
new Person("Janet", "Planner", "The Burbs"));
if(staff.positionAvailable("Software Engineer"))
staff.fillPosition("Software Engineer",
new Person(
"Bob", "Coder", "Bright Light City"));
System.out.println(staff);
}
}
/* Output:
[Position: President, Employee: Me Last The Top, Lonely
At, Position: CTO, Employee: <Empty>, Position:
Marketing Manager, Employee: <Empty>, Position: Product
Manager, Employee: <Empty>, Position: Project Lead,
Employee: Janet Planner The Burbs, Position: Software
Engineer, Employee: Bob Coder Bright Light City,
Position: Software Engineer, Employee: <Empty>,
Position: Software Engineer, Employee: <Empty>,
Position: Software Engineer, Employee: <Empty>,
Position: Test Engineer, Employee: <Empty>, Position:
```

Technical Writer, Employee: <Empty>]

*/

Notice you might still need to test for **Optional**s in some places, which is not that different from checking for **null**, but in other places (such as **toString()** conversions, in this case), you don't perform extra tests; you can just assume that all object references are valid.

Tagging Interfaces

Sometimes it's more convenient to use a *tagging interface* to indicate null-ness. A tagging interface has no elements; you just use its name as a tag:

// onjava/Null.java

package onjava;

public interface Null {}

If you work with interfaces instead of concrete classes, you can use a **DynamicProxy** to automatically create the **Null**s. Suppose we have a **Robot** interface that defines a name, model, and a **List<Operation>** that describes what the **Robot** does:

```
// typeinfo/Robot.java
import onjava.*;
import java.util.*;
public interface Robot {
String name();
String model();
List<Operation> operations();
static void test(Robot r) {
if(r instanceof Null)
System.out.println("[Null Robot]");
System.out.println("Robot name: " + r.name());
System.out.println("Robot model: " + r.model());
for(Operation operation : r.operations()) {
System.out.println(operation.description.get());
operation.command.run();
}
}
}
```

You access a **Robot**s services by calling **operations()**. **Robot** also incorporates a **static** method to perform tests.

Operation contains a description and a command (it's a type of *Command* pattern). These are defined as references to functional interfaces so you can pass lambda expressions or method references to the **Operation** constructor:

```
// typeinfo/Operation.java
import java.util.function.*;
public class Operation {
public final Supplier<String> description;
public final Runnable command;
public
Operation(Supplier<String> descr, Runnable cmd) {
description = descr;
command = cmd;
}
}
```

We can now create a **Robot** that removes snow:

```
// typeinfo/SnowRemovalRobot.java
import java.util.*;
public class SnowRemovalRobot implements Robot {
private String name;
```

```
public SnowRemovalRobot(String name) {
this.name = name;
}
@Override
public String name() { return name; }
@Override
public String model() { return "SnowBot Series 11"; }
private List<Operation> ops = Arrays.asList(
new Operation(
() -> name + " can shovel snow",
() -> System.out.println(
name + " shoveling snow")),
new Operation(
() -> name + " can chip ice",
() -> System.out.println(name + " chipping ice")),
new Operation(
() -> name + " can clear the roof",
() -> System.out.println(
name + " clearing roof")));
public List<Operation> operations() { return ops; }
```

```
public static void main(String[] args) {
Robot.test(new SnowRemovalRobot("Slusher"));
}
}
/* Output:
Robot name: Slusher
Robot model: SnowBot Series 11
Slusher can shovel snow
Slusher shoveling snow
Slusher can chip ice
Slusher chipping ice
Slusher can clear the roof
Slusher clearing roof
*/
```

There will presumably be many different types of **Robot**, and we'd like each **Null** to do something special for each **Robot** type—here, incorporate information about the exact type of **Robot** the **Null** represents. This information is captured by the dynamic proxy:

```
// typeinfo/NullRobot.java
// Using a dynamic proxy to create an Optional
```

```
import java.lang.reflect.*;
import java.util.*;
import java.util.stream.*;
import onjava.*;
class NullRobotProxyHandler
implements InvocationHandler {
private String nullName;
private Robot proxied = new NRobot();
NullRobotProxyHandler(Class<? extends Robot> type) {
nullName = type.getSimpleName() + " NullRobot";
}
private class NRobot implements Null, Robot {
@Override
public String name() { return nullName; }
@Override
public String model() { return nullName; }
@Override
public List<Operation> operations() {
return Collections.emptyList();
}
```

```
}
@Override
public Object
invoke(Object proxy, Method method, Object[] args)
throws Throwable {
return method.invoke(proxied, args);
}
}
public class NullRobot {
public static Robot
newNullRobot(Class<? extends Robot> type) {
return (Robot)Proxy.newProxyInstance(
NullRobot.class.getClassLoader(),
new Class[]{ Null.class, Robot.class },
new NullRobotProxyHandler(type));
}
public static void main(String[] args) {
Stream.of(
new SnowRemovalRobot("SnowBee"),
newNullRobot(SnowRemovalRobot.class)
```

).forEach(Robot::test);

}

}

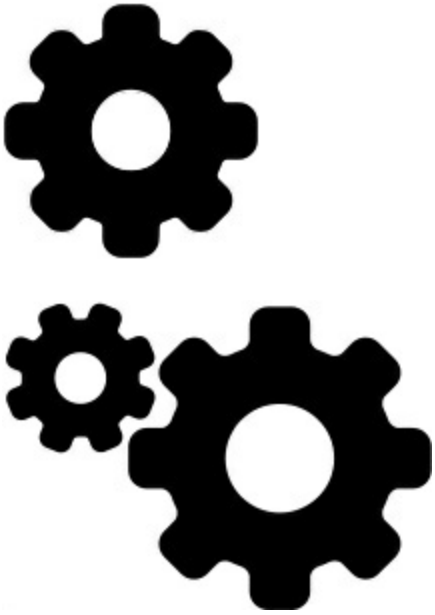
/ Output:*

Robot name: SnowBee

Robot model: SnowBot Series 11

SnowBee can shovel snow

SnowBee shoveling snow



SnowBee can chip ice

SnowBee chipping ice

SnowBee can clear the roof

SnowBee clearing roof

[Null Robot]

Robot name: SnowRemovalRobot NullRobot

Robot model: SnowRemovalRobot NullRobot

*/

Whenever you need a null **Robot** object, you just call **newNullRobot()**, passing your desired type of **Robot**, and it returns a proxy. The proxy fulfills the requirements of the **Robot** and **Null** interfaces, and provides the specific name of the type it proxies.

Mock Objects & Stubs

Logical variations of **Optional** are *Mock Objects* and *Stubs*. Both of these are proxies for the "real" object used in the finished program. Both Mock Object and Stub pretend to be real objects that deliver real information, rather than a hiding objects including potential **null**s, as **Optional** does.

The distinction between Mock Object and Stub is one of degree. Mock Objects tend to be lightweight and self-testing, and usually many of them are created to handle various testing situations. Stubs just return stubbed data, are typically heavyweight and are often reused between tests. Stubs can be configured to change depending on how they are called. So a Stub is a sophisticated object that does lots of things, whereas you usually create lots of small, simple Mock Objects if you

must do many things.

Interfaces and Type

Information

An important goal of the **interface** keyword is to allow the programmer to isolate components, and thus reduce coupling. If you write to interfaces, you accomplish this, but with type information it's possible to get around that—interfaces are not airtight guarantees of decoupling. If we start with an interface:

```
// typeinfo/interfacea/A.java
package typeinfo.interfacea;
public interface A {
void f();
}
```

This interface is then implemented, and here's how you sneak around to the actual implementation type:

```
// typeinfo/InterfaceViolation.java
// Sneaking around an interface
import typeinfo.interfacea.*;
class B implements A {
public void f() {}
```

```
public void g() {}
}
public class InterfaceViolation {
public static void main(String[] args) {
A a = new B();
a.f();
// a.g(); // Compile error
System.out.println(a.getClass().getName());
if(a instanceof B) {
B b = (B)a;
b.g();
}
}
}
/* Output:
B
*/
```

Using RTTI, we discover that **a** is implemented as a **B**. By casting to **B**, we can call a method that's not in **A**.

This is perfectly legal and acceptable, but you might not want client

programmers to do this, because it gives them an opportunity to

couple more closely to your code than you'd like. That is, you might think the **interface** keyword is protecting you, but it isn't, and the fact that you're using **B** to implement **A** here is effectively a matter of public record. 3

One solution is to simply say that programmers are on their own if they decide to use the actual class rather than the interface. This is probably reasonable in many cases, but if "probably" isn't enough, you might apply more stringent controls.

The easiest approach is to use package access for the implementation, so clients outside the package cannot see it:

```
// typeinfo/packageaccess/HiddenC.java
package typeinfo.packageaccess;
import typeinfo.interfacea.*;
class C implements A {
@Override
public void f() {
System.out.println("public C.f()");
}
public void g() {
System.out.println("public C.g()");
```

```
}
void u() {
System.out.println("package C.u()");
}
protected void v() {
System.out.println("protected C.v()");
}
private void w() {
System.out.println("private C.w()");
}
}
public class HiddenC {
public static A makeA() { return new C(); }
}
```

The only **public** part of this package, **HiddenC**, produces an **A** interface when you call it. Even if you were to return a **C** from **makeA()**, you still couldn’t use anything but an **A** from outside the package, since you cannot name **C** outside the package.

Now if you try to downcast to **C**, you can’t do it because there is no **C** type available outside the package:

```
// typeinfo/HiddenImplementation.java
// Sneaking around package hiding
import typeinfo.interfacea.*;
import typeinfo.packageaccess.*;
import java.lang.reflect.*;
public class HiddenImplementation {
public static void
main(String[] args) throws Exception {
A a = HiddenC.makeA();
a.f();
System.out.println(a.getClass().getName());
// Compile error: cannot find symbol 'C':
/* if(a instanceof C) {
C c = (C)a;
c.g();
} */
// Oops! Reflection still allows us to call g():
callHiddenMethod(a, "g");
// And even less accessible methods!
callHiddenMethod(a, "u");
```

```
callHiddenMethod(a, "v");
callHiddenMethod(a, "w");
}
static void
callHiddenMethod(Object a, String methodName)
throws Exception {
Method g =
a.getClass().getDeclaredMethod(methodName);
g.setAccessible(true);
g.invoke(a);
}
}
/* Output:
public C.f()
typeinfo.packageaccess.C
public C.g()
package C.u()
protected C.v()
private C.w()
*/
```

It’s still possible to reach in and call *all* methods using reflection, even **private** methods! If you know the name of the method, you can call **setAccessible(true)** on the **Method** object to make it callable, as seen in **callHiddenMethod()**.

You might think you can prevent this by only distributing compiled code, but that’s no solution. All you must do is run **javap**, which is the decompiler that comes with the JDK. Here’s the command line:

javap -**private** C

The **-private** flag indicates that all members should be displayed, even private ones. Here’s the output:

class typeinfo.packageaccess.C **extends**
java.lang.Object **implements** typeinfo.interfacea.A {
typeinfo.packageaccess.C();
public void f();
public void g();
void u();
protected void v();
private void w();
}

So anyone can get the names and signatures of your most private

methods, and call them.

What if you implement the interface as a **private** inner class? Here's what it looks like:

```
// typeinfo/InnerImplementation.java
// Private inner classes can't hide from reflection
import typeinfo.interfacea.*;
class InnerA {
private static class C implements A {
public void f() {
System.out.println("public C.f()");
}
public void g() {
System.out.println("public C.g()");
}
void u() {
System.out.println("package C.u()");
}
protected void v() {
System.out.println("protected C.v()");
}
```

```
private void w() {
System.out.println("private C.w()");
}
}
public static A makeA() { return new C(); }
}
public class InnerImplementation {
public static void
main(String[] args) throws Exception {
A a = InnerA.makeA();
a.f();
System.out.println(a.getClass().getName());
// Reflection still gets into the private class:
HiddenImplementation.callHiddenMethod(a, "g");
HiddenImplementation.callHiddenMethod(a, "u");
HiddenImplementation.callHiddenMethod(a, "v");
HiddenImplementation.callHiddenMethod(a, "w");
}
}
/* Output:
```

public C.f()

InnerA$C

public C.g()

package C.u()

protected C.v()

private C.w()

**/*

That didn’t hide anything from reflection. What about an anonymous class?

```
// typeinfo/AnonymousImplementation.java
// Anonymous inner classes can't hide from reflection
import typeinfo.interfacea.*;
class AnonymousA {
public static A makeA() {
return new A() {
public void f() {
System.out.println("public C.f()");
}
public void g() {
System.out.println("public C.g()");
```

```
}
void u() {
System.out.println("package C.u()");
}
protected void v() {
System.out.println("protected C.v()");
}
private void w() {
System.out.println("private C.w()");
}
};
}
}
public class AnonymousImplementation {
public static void
main(String[] args) throws Exception {
A a = AnonymousA.makeA();
a.f();
System.out.println(a.getClass().getName());
// Reflection still gets into the anonymous class:
```

```
HiddenImplementation.callHiddenMethod(a, "g");
HiddenImplementation.callHiddenMethod(a, "u");
HiddenImplementation.callHiddenMethod(a, "v");
HiddenImplementation.callHiddenMethod(a, "w");
}
}
/* Output:
public C.f()
AnonymousA$1
public C.g()
package C.u()
protected C.v()
private C.w()
*/
```

There doesn’t seem to be any way to prevent reflection from reaching in and calling methods that have non-public access. This is also true for fields, even **private** fields:

```
// typeinfo/ModifyingPrivateFields.java
import java.lang.reflect.*;
class WithPrivateFinalField {
```

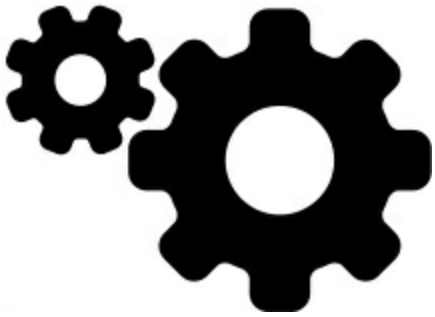
```
private int i = 1;
private final String s = "I'm totally safe";
private String s2 = "Am I safe?";
@Override
public String toString() {
return "i = " + i + ", " + s + ", " + s2;
}
}
public class ModifyingPrivateFields {
public static void
main(String[] args) throws Exception {
WithPrivateFinalField pf =
new WithPrivateFinalField();
System.out.println(pf);
Field f = pf.getClass().getDeclaredField("i");
f.setAccessible(true);
System.out.println(
"f.getInt(pf): " + f.getInt(pf));
f.setInt(pf, 47);
System.out.println(pf);
```

```
f = pf.getClass().getDeclaredField("s");
f.setAccessible(true);
System.out.println("f.get(pf): " + f.get(pf));
f.set(pf, "No, you're not!");
System.out.println(pf);
f = pf.getClass().getDeclaredField("s2");
f.setAccessible(true);
System.out.println("f.get(pf): " + f.get(pf));
f.set(pf, "No, you're not!");
System.out.println(pf);
}
}
/* Output:
i = 1, I'm totally safe, Am I safe?
f.getInt(pf): 1
i = 47, I'm totally safe, Am I safe?
f.get(pf): I'm totally safe
i = 47, I'm totally safe, Am I safe?
f.get(pf): Am I safe?
i = 47, I'm totally safe, No, you're not!
```

*/

However, **final** fields are actually safe from change. The runtime system accepts any attempts at change without complaint, but nothing actually happens.

In general, all these access violations are not the worst thing in the world. If someone uses such a technique to call methods you marked with **private** or package access (meaning, they should not be



called), then it’s difficult for them to complain if you change some aspect of those methods. On the other hand, the fact you always have a back door into a class can allow you to solve certain types of problems that could otherwise be difficult or impossible, and the benefits of reflection in general are undeniable.

Programmers often become overconfident about the access control afforded by the language, going so far as to believe that Java is somehow superior in its safety than other languages that provide (apparently) less stringent access control4. As you can see, it’s not.

Summary

RTTI discovers type information from an anonymous base-class reference. Thus, it's ripe for misuse by the novice, since it might make sense before polymorphic method calls do. For people coming from a procedural background, it's difficult not to organize programs into sets of **switch** statements. You can accomplish this with RTTI and thus lose the important value of polymorphism in code development and maintenance. The intent of OO programming is to use polymorphic method calls everywhere you can, and RTTI only when you must. However, using polymorphic method calls as they are intended requires you have control of the base-class definition, because at some point in the extension of your program you might discover that the base class doesn't include the method you need. If the base class comes from someone else's library, one solution is RTTI: You can inherit a new type and add your extra method. Elsewhere in the code you can detect your particular type and call that special method. This doesn't destroy the polymorphism and extensibility of the program, because adding a new type will not require you to hunt for **switch** statements in your program. However, when you add code that requires your new feature, you must use RTTI to detect your particular

type.

Putting a feature in a base class might mean that, for the benefit of one particular class, the interface becomes less sensible. For example, consider a class hierarchy representing musical instruments. Suppose you want to clear the spit valves of all the appropriate instruments in your orchestra. One option is to put a **clearSpitValve()** method in the base class **Instrument**, but this is confusing because it implies that **Percussion**, **Stringed** and **Electronic** instruments also have spit valves. RTTI provides a reasonable solution because you can place the method in the specific class where it's appropriate (**Wind**, in this case). At the same time, you might discover there's a more sensible solution—here, a **prepareInstrument()** method in the base class. However, you might not see such a solution when you're first solving the problem and could mistakenly assume you must use RTTI.

Finally, RTTI will sometimes solve efficiency problems. Suppose your code uses polymorphism, but one of your objects reacts to this general-purpose code in a horribly inefficient way. You can pick out that type using RTTI and write case-specific code to improve the efficiency. Be wary, however, of programming for efficiency too soon.

It’s a seductive trap. It’s best to get the program working *first*, then decide if it’s running fast enough, and only then should you attack efficiency issues—with a profiler.

We’ve also seen that reflection opens up a new world of programming possibilities by allowing a much more dynamic style of programming. There are some for whom this dynamic nature of reflection is disturbing. The fact you can do things that can only be checked at run time and reported with exceptions seems, to a mind grown comfortable with the security of static type checking, to be the wrong direction. Some people go so far as to say that introducing the possibility of a runtime exception is a clear indicator that such code should be avoided. I find this sense of security is an illusion—there are always things that can happen at run time and throw exceptions, even in a program that contains no **try** blocks or exception specifications. Instead, I think the existence of a consistent error-reporting model *empowers* us to write dynamic code using reflection. It’s worth trying to write code that can be statically checked … when you can. But I believe that dynamic code is one of the important facilities that separate Java from languages like C++.

1. Especially in the past. However, great improvements in the HTML

Java documentation makes it easier to see base-class methods. ↩

2. A tenet of *Extreme Programming* (XP), as is “Try the simplest thing that could possibly work.” ↩

3. The most famous case of this is the Windows operating system, which had a published API you were supposed to write to, and an unpublished but visible set of functions you could discover and call. To solve problems, programmers used the hidden API functions, which forced Microsoft to maintain them as if they were part of the public API. This became a source of great cost and effort for the company. ↩

4. In Python, for example, you put a double underscore __ in front of any element you want hidden, and the runtime complains if you try to access it outside the class or package↩

Generics

Ordinary classes and methods work with specific types: either primitives or class types. If you write code to use across more types, this rigidity can be

overconstraining.

Polymorphism is an object-oriented generalization tool. You write a method that takes a base class object as an argument, then use that method with any class derived from the base class—including classes that haven't been created yet. Now your method is more general, and useful in more places. The same is true within classes—anyplace you use a specific type, a base type provides more flexibility. Anything but a **final** class (or a class with all **private** constructors) can be extended, so this flexibility is automatic much of the time.

A single hierarchy can be too limiting because you must inherit *from that hierarchy* to produce an object that fits your method argument. If a method argument is an interface instead of a class, the limitations are loosened to include anything that implements the interface. This gives the client programmer the option of implementing an interface in combination with an existing class—that is, to adapt an existing class to fit your method. Interfaces cut across class hierarchies, as long as you have the option to implement those interfaces to fit.

Sometimes even an interface is too restrictive. An interface still requires that your code work with that particular interface. You can write even more general code if you can say that your code works with

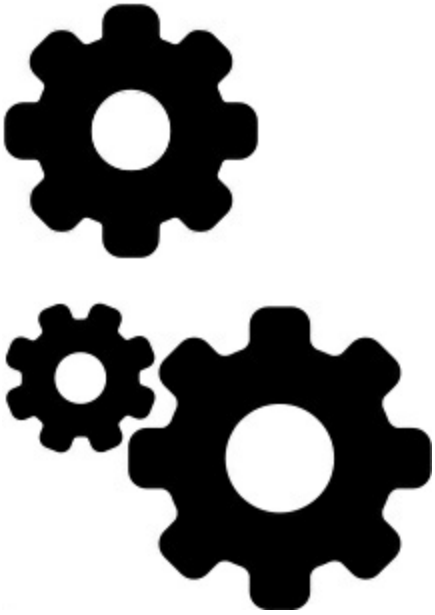
“some unspecified type,” rather than a specific interface or class. This is the concept of generics, one of the more significant changes in Java 5. Generics produce *parameterized types*, so you can create components (most notably collections) that are easy to use with multiple types. The term “generic” means “pertaining or appropriate to large groups of classes.” The original intent of generics in programming languages was to allow the programmer the greatest amount of expressiveness possible when writing classes or methods, by loosening type constraints on those classes or methods. As you will see in this chapter, the Java implementation of generics is not that broad—indeed, you might question whether the term “generic” is even appropriate for this feature.

If you’ve never seen any kind of parameterized type mechanism before, Java generics probably seem like a convenient addition to the language. When you create an instance of a parameterized type, casts are automatic and type correctness is ensured at compile time. This is an improvement.

However, if you’ve had experience with parameterized types, for example in C++, you’ll find you can’t do everything you might expect when using Java generics. While using someone else’s generic type is

usually easy, creating your own produces numerous surprises.

This is not to say that Java generics are useless. In many cases they make code more straightforward and even elegant. But if you're coming from a language that has implemented a more pure version of generics, you might be frustrated. In this chapter, we will examine strengths and limitations of Java generics. I try to explain how the feature came to be as it is, so you can use generics more effectively.1



Comparison with C++

The Java designers stated that much of the inspiration for the language came as a reaction to C++. Despite this, it is possible to teach Java largely without reference to C++.

Generics require comparison with C++ for two reasons. First, understanding certain aspects of C++ *templates* (the main inspiration

for generics, including the basic syntax) illuminates the foundations of the concept, as well as—and this is very important—the limitations of Java generics and why those limitations exist. The ultimate goal is a clear understanding of the boundaries, making you a more powerful programmer. Knowing what you can't do, you make better use of what you *can* do (partly because you don't waste time bumping against walls).

The second reason is there is significant misunderstanding in the Java community about C++ templates, and this misunderstanding can further confuse you about the intent of generics.

Thus, I introduce a few C++ template examples in this chapter, but only when they improve your depth of understanding.

Simple Generics

One of the most compelling initial motivations for generics is to create *collection classes*, which you saw in the Collections chapter. A collection is an object that holds other objects, while you're working with them. This is also true of arrays, but collections tend to be more flexible and have different characteristics than simple arrays. Virtually all programs require you hold a group of objects while you use them, so collections are one of the most reusable of class libraries.

Let’s look at a class that holds a single object. The class can specify the exact type of the object, like this:

```
// generics/Holder1.java
class Automobile {}
public class Holder1 {
private Automobile a;
public Holder1(Automobile a) { this.a = a; }
Automobile get() { return a; }
}
```

This is not a very reusable tool, since it can’t be used to hold anything else. We would prefer not to write a new one of these for every type we encounter.

Before Java 5, we would simply make it hold an **Object**:

```
// generics/ObjectHolder.java
public class ObjectHolder {
private Object a;
public ObjectHolder(Object a) { this.a = a; }
public void set(Object a) { this.a = a; }
public Object get() { return a; }
public static void main(String[] args) {
```

```
ObjectHolder h2 =
new ObjectHolder(new Automobile());
Automobile a = (Automobile)h2.get();
h2.set("Not an Automobile");
String s = (String)h2.get();
h2.set(1); // Autoboxes to Integer
Integer x = (Integer)h2.get();
}
}
```

Now an **ObjectHolder** can hold anything—and in this example, a single **ObjectHolder** holds three different types of objects.

In rare cases, you'll want a collection to hold multiple types of objects, but typically you only put one type of object into a particular collection object. One of the primary motivations for generics is to specify the type of object a collection holds, and to enforce that specification via the compiler.

So instead of **Object**, we'd like to give a type placeholder, to be decided at a later time. To do this, you put a *type parameter* inside angle brackets after the class name, then substitute an actual type when you use the class. For the "holder" class, it looks like this, where **T** is the type parameter:

```
// generics/GenericHolder.java
public class GenericHolder<T> {
private T a;
public GenericHolder() {}
public void set(T a) { this.a = a; }
public T get() { return a; }
public static void main(String[] args) {
GenericHolder<Automobile> h3 =
new GenericHolder<Automobile>();
h3.set(new Automobile()); // type checked
Automobile a = h3.get(); // No cast needed
//- h3.set("Not an Automobile"); // Error
//- h3.set(1); // Error
}
}
```

When creating a **GenericHolder**, you specify the type it holds using the same angle-bracket syntax, as you see in **main()**. You are only allowed to put objects of that type (or a subtype, since the substitution principle still works with generics) into the holder. When you call **get()** to produce a value, it is automatically the right type.

That’s the core idea of Java generics: You tell it what type to use, and it takes care of the details.

You’ll note that the definition of **h3** is rather wordy and redundant. On

the left side of the equals sign, you say **GenericHolder<Automobile>** , then you say the same thing again on the right side of the equals sign. When Java 5 came out, this noise was explained away as “necessary,” but by Java 7 the designers had fixed the problem (and this new simplicity then became a touted feature). So now you can use the simpler form:

```
// generics/Diamond.java
class Bob {}
public class Diamond<T> {
public static void main(String[] args) {
GenericHolder<Bob> h3 = new GenericHolder<>();
h3.set(new Bob());
}
}
```

Notice that the right-hand side of the definition of **h3** now uses the empty “diamond” syntax rather than duplicating the type information from the left. You’ll see this used throughout the rest of the book.

In general, you can treat generics as if they are any other type—they just happen to have type parameters. To use a generic definition, you just name it along with its type argument list.

A Tuple Library

You’ll often return multiple objects from a method call. The **return** statement only returns a single object, so the solution is to create an object that holds multiple objects, and return that object. You can write a special class every time you encounter the situation, but with generics it’s possible to solve the problem once and save yourself the effort in the future. At the same time, you are ensuring compile-time type safety.

This concept is called a *tuple*, and it is a group of objects wrapped together into a single object. The recipient of the object is allowed to read the elements but not put new ones in. (This concept is also called a *Data Transfer Object* or *Messenger*.)

Tuples can typically be any length, and each object in the tuple can be of a different type. However, we specify the type of each object and ensure that, when the recipient reads the value, they get the right type.

To deal with the problem of multiple lengths, we create multiple different tuples. Here's one that holds two objects:

```
// onjava/Tuple2.java
package onjava;
public class Tuple2<A, B> {
public final A a1;
public final B a2;
public Tuple2(A a, B b) { a1 = a; a2 = b; }
public String rep() { return a1 + ", " + a2; }
@Override
public String toString() {
return "(" + rep() + ")";
}
}
```

The constructor captures the object to be stored. The tuple implicitly keeps its elements in order. Notice that we use the fact that an identifier can start with an underscore to create numbered identifiers. Upon first reading, you might think this violates common safety principles of Java programming. Shouldn't **a1** and **a2** be **private**, and only accessed with methods named **getFirst()** and

getSecond()? Consider the “safety” that produces: Clients could still read the objects and do whatever they want with them, but they could not assign **a1** or **a2** to anything else. The **final** declaration buys you the same safety, but the above form is shorter and simpler.

Another design observation is that you might *want* to allow a client programmer to point **a1** or **a2** to another object. However, it’s safer to leave it in the above form, and just force the user to create a new **Tuple2** if they want one that has different elements.

The longer-length tuples can be created with inheritance. Adding more type parameters is a simple matter:

```
// onjava/Tuple3.java
package onjava;
public class Tuple3<A, B, C> extends Tuple2<A, B> {
public final C a3;
public Tuple3(A a, B b, C c) {
super(a, b);
a3 = c;
}
@Override
public String rep() {
return super.rep() + ", " + a3;
```

```
}
}
// onjava/Tuple4.java
package onjava;
public class Tuple4<A, B, C, D>
extends Tuple3<A, B, C> {
public final D a4;
public Tuple4(A a, B b, C c, D d) {
super(a, b, c);
a4 = d;
}
@Override
public String rep() {
return super.rep() + ", " + a4;
}
}
// onjava/Tuple5.java
package onjava;
public class Tuple5<A, B, C, D, E>
extends Tuple4<A, B, C, D> {
```

```
public final E a5;
public Tuple5(A a, B b, C c, D d, E e) {
super(a, b, c, d);
a5 = e;
}
@Override
public String rep() {
return super.rep() + ", " + a5;
}
}
```

For tuple experiments, we'll define a couple of classes:

```
// generics/Amphibian.java
public class Amphibian {}
// generics/Vehicle.java
public class Vehicle {}
```

To use a tuple, you define the appropriate-length tuple as the return value for your function, then create and return it. Notice the return type declarations for the method definitions:

```
// generics/TupleTest.java
import onjava.*;
```

```
public class TupleTest {
static Tuple2<String, Integer> f() {
// Autoboxing converts the int to Integer:
return new Tuple2<>("hi", 47);
}
static Tuple3<Amphibian, String, Integer> g() {
return new Tuple3<>(new Amphibian(), "hi", 47);
}
static
```

```
Tuple4<Vehicle, Amphibian, String, Integer> h() {
return
new Tuple4<>(
new Vehicle(), new Amphibian(), "hi", 47);
}
static
Tuple5<Vehicle, Amphibian,
String, Integer, Double> k() {
```

```
return new
Tuple5<>(
new Vehicle(), new Amphibian(), "hi", 47, 11.1);
}
public static void main(String[] args) {
Tuple2<String, Integer> ttsi = f();
System.out.println(ttsi);
// ttsi.a1 = "there"; // Compile error: final
System.out.println(g());
System.out.println(h());
System.out.println(k());
}
}
/* Output:
(hi, 47)
(Amphibian@1540e19d, hi, 47)
(Vehicle@7f31245a, Amphibian@6d6f6e28, hi, 47)
(Vehicle@330bedb4, Amphibian@2503dbd3, hi, 47, 11.1)
*/
```

With generics, you can easily create any tuple to return any group of

types, just by writing the expression.

The **final** specification on the public fields prevents them from reassignment after construction, as shown in the failure of the statement **ttsi.a1 = "there"** .

The **new** expressions are a little verbose. Later in this chapter you'll see how to simplify them using *generic methods*.

A Stack Class

Let's look at something slightly more complicated: the traditional pushdown stack. In the Collections chapter, you saw this implemented using a **LinkedList** as the **onjava.Stack** class. That example showed that a **LinkedList** already has the necessary methods to create a stack. The **Stack** was constructed by composing one generic class (**Stack<T>**) with another generic class (**LinkedList<T>**). In that example, notice that (with a few differences we look at later) a generic type is just another type.

Instead of using **LinkedList**, we can implement our own internal linked storage mechanism.

```
// generics/LinkedStack.java
// A stack implemented with an internal linked structure
public class LinkedStack<T> {
private static class Node<U> {
```

```
U item;
Node<U> next;
Node() { item = null; next = null; }
Node(U item, Node<U> next) {
this.item = item;
this.next = next;
}
boolean end() {
return item == null && next == null;
}
}
private Node<T> top = new Node<>(); // End sentinel
public void push(T item) {
top = new Node<>(item, top);
}
public T pop() {
T result = top.item;
if(!top.end())
top = top.next;
return result;
```

```
}

public static void main(String[] args) {
```

```
LinkedStack<String> lss = new LinkedStack<>();

for(String s : "Phasers on stun!".split(" "))

lss.push(s);

String s;

while((s = lss.pop()) != null)

System.out.println(s);

}

}

/* Output:

stun!

on

Phasers

*/
```

The inner class **Node** is also generic, and has its own type parameter.

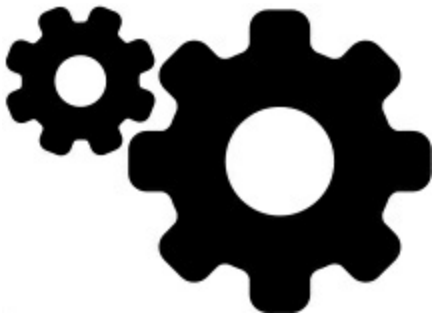
This example makes use of an *end sentinel* to determine when the

stack is empty. The end sentinel is created when the **LinkedStack** is constructed, and each time you call **push()** a new **Node<T>** is created and linked to the previous **Node<T>** . When you call **pop()**, you always return the **top.item**, then you discard the current **Node<T>** and move to the next one—except when you hit the end sentinel, when you don't move. That way, if the client keeps calling **pop()**, they keep getting **null** back to indicate the stack is empty.

RandomList

For another example of a holder, suppose you'd like a special type of list that randomly selects one of its elements each time you call **select()**. To build a tool that works with all objects, use generics:

```
// generics/RandomList.java
import java.util.*;
import java.util.stream.*;
```



```
public class RandomList<T> extends ArrayList<T> {
private Random rand = new Random(47);
```

```
public T select() {
return get(rand.nextInt(size()));
}
public static void main(String[] args) {
RandomList<String> rs = new RandomList<>();
Arrays.stream(
("The quick brown fox jumped over " +
"the lazy brown dog").split(" "))
.forEach(rs::add);
IntStream.range(0, 11).forEach(i ->
System.out.print(rs.select() + " "));
}
}
/* Output:
brown over fox quick quick dog brown The brown lazy
brown
*/
```

By because it inherits **ArrayList**, **RandomList** has all the baked-in behaviors from **ArrayList**. We've only added the **select()** method.

Generic Interfaces

Generics also work with interfaces. For example, a *generator* is a class that creates objects. The generator actually a specialization of the *Factory Method* design pattern, but when you ask a generator for new object, you don't pass it any arguments, whereas you typically do pass arguments to a Factory Method. The generator knows how to create new objects without any extra information.

Typically, a generator just defines one method, the method that produces new objects. The **java.util.function** library defines a generator as **Supplier**, and the producer method is called **get()**.

The return type of **get()** is parameterized to **T**.

To create a **Supplier**, we'll need some classes. Here's a coffee hierarchy:

```
// generics/coffee/Coffee.java
package generics.coffee;
public class Coffee {
private static long counter = 0;
private final long id = counter++;
@Override
public String toString() {
```

return getClass().getSimpleName() + " " + id;

}

}

// generics/coffee/Latte.java

package generics.coffee;

public class Latte **extends** Coffee {}

// generics/coffee/Mocha.java

package generics.coffee;

public class Mocha **extends** Coffee {}

// generics/coffee/Cappuccino.java

package generics.coffee;

public class Cappuccino **extends** Coffee {}

// generics/coffee/Americano.java

package generics.coffee;

public class Americano **extends** Coffee {}

// generics/coffee/Breve.java

package generics.coffee;

public class Breve **extends** Coffee {}

Now we can implement a **Supplier<Coffee>** that produces

random different types of **Coffee** objects:

```
// generics/coffee/CoffeeSupplier.java
// {java generics.coffee.CoffeeSupplier}
package generics.coffee;
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
public class CoffeeSupplier
implements Supplier<Coffee>, Iterable<Coffee> {
private Class<?>[] types = { Latte.class, Mocha.class,
Cappuccino.class, Americano.class, Breve.class, };
private static Random rand = new Random(47);
public CoffeeSupplier() {}
// For iteration:
private int size = 0;
public CoffeeSupplier(int sz) { size = sz; }
@Override
public Coffee get() {
try {
return (Coffee)
types[rand.nextInt(types.length)].newInstance();
```

```
// Report programmer errors at run time:
} catch(InstantiationException |
IllegalAccessException e) {
throw new RuntimeException(e);
}
}
class CoffeeIterator implements Iterator<Coffee> {
int count = size;
@Override
public boolean hasNext() { return count > 0; }
@Override
public Coffee next() {
count--;
return CoffeeSupplier.this.get();
}
@Override
public void remove() { // Not implemented
throw new UnsupportedOperationException();
}
}
```

```
@Override
public Iterator<Coffee> iterator() {
return new CoffeeIterator();
}
public static void main(String[] args) {
Stream.generate(new CoffeeSupplier())
.limit(5)
.forEach(System.out::println);
for(Coffee c : new CoffeeSupplier(5))
System.out.println(c);
}
}
/* Output:
Americano 0
Latte 1
Americano 2
Mocha 3
Mocha 4
Breve 5
Americano 6
```

Latte 7

Cappuccino 8

Cappuccino 9

/

The parameterized **Supplier** interface ensures that **get()** returns the parameter type. **CoffeeSupplier** also implements the **Iterable** interface, so it can be used in a *for-in* statement. However, it must know when to stop, and this is provided by the second constructor.

Here's a second implementation of **Supplier<T>** , this time to produce Fibonacci numbers:

```
// generics/Fibonacci.java
// Generate a Fibonacci sequence
import java.util.function.*;
import java.util.stream.*;
public class Fibonacci implements Supplier<Integer> {
private int count = 0;
@Override
public Integer get() { return fib(count++); }
private int fib(int n) {
```

```
if(n < 2) return 1;
return fib(n-2) + fib(n-1);
}
public static void main(String[] args) {
Stream.generate(new Fibonacci())
.limit(18)
.map(n -> n + " ")
.forEach(System.out::print);
}
}
/* Output:
1 1 2 3 5 8 13 21 34 55 89 144 233 377 610 987 1597
2584
*/
```

Although we are working with **int**s both inside and outside the class, the type parameter is **Integer**. This brings up one of the limitations of Java generics: You cannot use primitives as type parameters. However, Java 5 autoboxing and autounboxing converts from primitive types to wrapper types and back. You see the effect here because **int**s are seamlessly used and produced by the class.

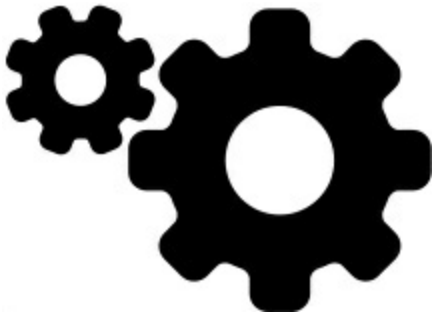
We can go one step further and make an **Iterable** Fibonacci generator. One option is to reimplement the class and add the **Iterable** interface, but you don't always have control of the original code, and you don't rewrite unless you must. Instead, we can create an *Adapter* to produce the desired interface—this design pattern was introduced earlier in the book.

Adapters can be implemented in multiple ways. For example, inheritance can generate the adapted class:

```
// generics/IterableFibonacci.java
// Adapt the Fibonacci class to make it Iterable
import java.util.*;
public class IterableFibonacci
extends Fibonacci implements Iterable<Integer> {
private int n;
public IterableFibonacci(int count) { n = count; }
@Override
public Iterator<Integer> iterator() {
return new Iterator<Integer>() {
@Override
public boolean hasNext() { return n > 0; }
```

```
@Override
public Integer next() {
n--;
return IterableFibonacci.this.get();
}
@Override
public void remove() { // Not implemented
throw new UnsupportedOperationException();
}
};
}
public static void main(String[] args) {
for(int i : new IterableFibonacci(18))
System.out.print(i + " ");
}
}
/* Output:
1 1 2 3 5 8 13 21 34 55 89 144 233 377 610 987 1597
2584
*/
```

To use **IterableFibonacci** in a *for-in* statement, you give the



constructor a boundary so **hasNext()** can know when to return **false**.

Generic Methods

So far we've looked at parameterizing entire classes. You can also parameterize methods within a class. The class itself might or might not be generic—this is independent of whether you have a generic method.

A generic method varies the method independently of the class. As a guideline, use generic methods "whenever you can." Making a single method generic rather than the entire class is generally clearer.

If a method is **static**, it has no access to the generic type parameters of the class, so if it uses genericity it must be a generic method.

To define a generic method, place the generic parameter list before the return value, like this:

// generics/GenericMethods.java

```
public class GenericMethods {
public <T> void f(T x) {
System.out.println(x.getClass().getName());
}
public static void main(String[] args) {
GenericMethods gm = new GenericMethods();
gm.f("");
gm.f(1);
gm.f(1.0);
gm.f(1.0F);
gm.f('c');
gm.f(gm);
}
}
/* Output:
```

```
java.lang.String
java.lang.Integer
```

java.lang.Double

java.lang.Float

java.lang.Character

GenericMethods

*/

The class **GenericMethods** is not parameterized, although both a class and its methods can be parameterized at the same time. But here, only the method **f()** has a type parameter, indicated by the parameter list before the method's return type.

With a generic class, you must specify the type parameters when you instantiate the class. With a generic method, you don't usually specify the parameter types, because the compiler figures that out for you. This is called *type argument inference*. So calls to **f()** look like normal method calls, and it appears that **f()** is infinitely overloaded. It will even take an argument of the type **GenericMethods**.

For the calls to **f()** that use primitive types, autoboxing comes into play, automatically wrapping the primitive types in their associated objects.

Varargs and Generic Methods

Generic methods and variable argument lists coexist nicely:

```
// generics/GenericVarargs.java
import java.util.*;
public class GenericVarargs {
@SafeVarargs
public static <T> List<T> makeList(T... args) {
List<T> result = new ArrayList<>();
for(T item : args)
```

```
result.add(item);
return result;
}
public static void main(String[] args) {
List<String> ls = makeList("A");
System.out.println(ls);
ls = makeList("A", "B", "C");
System.out.println(ls);
ls = makeList(
"ABCDEFFHIJKLMNOPQRSTUVWXYZ".split(""));
```

```
System.out.println(ls);
}
}
/* Output:
[A]
[A, B, C]
[A, B, C, D, E, F, F, H, I, J, K, L, M, N, O, P, Q, R,
S, T, U, V, W, X, Y, Z]
*/
```

The **makeList()** method shown here produces the same functionality as the standard library's **java.util.Arrays.asList()** method.

The **@SafeVarargs** annotation promises we are not making any modifications to the variable argument list, which is true because we only read from it. Without the annotation the compiler can't know and issues a warning.

A General-Purpose Supplier

Here's a class that produces a **Supplier** for any class that has a no-arg constructor. To reduce typing, it also includes a generic method to produce a **BasicSupplier**:

```
// onjava/BasicSupplier.java
// Supplier from a class with a no-arg constructor
package onjava;
import java.util.function.*;
public class BasicSupplier<T> implements Supplier<T> {
private Class<T> type;
public BasicSupplier(Class<T> type) {
this.type = type;
}
@Override
public T get() {
try {
// Assumes type is a public class:
return type.newInstance();
} catch(InstantiationException |
IllegalAccessException e) {
throw new RuntimeException(e);
}
}
// Produce a default Supplier from a type token:
```

public static <T> Supplier<T> create(Class<T> type) {

return new BasicSupplier<>(type);

}

}

This class provides a basic implementation to produce objects of a class that:

1. Is **public**. Because **BasicSupplier** is in a separate package, the class in question must have **public** and not just package access.
2. Has a no-arg constructor. To create one of these **BasicSupplier** objects, you call the **create()** method and pass it the type token for the type you want generated. The generic **create()** method provides the syntax **BasicSupplier.create(MyType.class)** instead of the more awkward **new BasicSupplier<MyType>(MyType.class)**.

For example, here's a simple class that has a no-arg constructor:

// generics/CountedObject.java

public class CountedObject {

private static long counter = 0;

```
private final long id = counter++;
public long id() { return id; }
@Override
public String toString() {
return "CountedObject " + id;
}
}
```

The **CountedObject** class keeps track of how many instances of itself are created, and reports these via **toString()**.

BasicSupplier easily creates a **Supplier** for **CountedObject**:

```
// generics/BasicSupplierDemo.java
import onjava.*;
import java.util.stream.*;
public class BasicSupplierDemo {
public static void main(String[] args) {
Stream.generate(
BasicSupplier.create(CountedObject.class))
.limit(5)
.forEach(System.out::println);
```

```
}
}
/* Output:
CountedObject 0
CountedObject 1
CountedObject 2
CountedObject 3
CountedObject 4
*/
```

The generic method reduces the amount of typing necessary to

produce the **Supplier** object. Java generics force you to pass in the **Class** object, so you might as well use it for type inference in the **create()** method.

Simplifying Tuple Use

With type argument inference and **static** imports, we'll rewrite the earlier tuples into a more general-purpose library. Here, we create tuples using an overloaded **static** method:

```
// onjava/Tuple.java
// Tuple library using type argument inference
package onjava;
public class Tuple {
public static <A, B> Tuple2<A, B> tuple(A a, B b) {
return new Tuple2<>(a, b);
}
public static <A, B, C> Tuple3<A, B, C>
tuple(A a, B b, C c) {
return new Tuple3<>(a, b, c);
}
public static <A, B, C, D> Tuple4<A, B, C, D>
tuple(A a, B b, C c, D d) {
return new Tuple4<>(a, b, c, d);
}
public static <A, B, C, D, E>
Tuple5<A, B, C, D, E> tuple(A a, B b, C c, D d, E e) {
return new Tuple5<>(a, b, c, d, e);
}
}
```

We modify **TupleTest.java** to test **Tuple.java**:

```
// generics/TupleTest2.java
import onjava.*;
import static onjava.Tuple.*;
public class TupleTest2 {
static Tuple2<String, Integer> f() {
return tuple("hi", 47);
}
static Tuple2 f2() { return tuple("hi", 47); }
static Tuple3<Amphibian, String, Integer> g() {
return tuple(new Amphibian(), "hi", 47);
}
static
Tuple4<Vehicle, Amphibian, String, Integer> h() {
return tuple(
new Vehicle(), new Amphibian(), "hi", 47);
}
static
Tuple5<Vehicle, Amphibian,
String, Integer, Double> k() {
```

```
return tuple(new Vehicle(), new Amphibian(),
"hi", 47, 11.1);
}
public static void main(String[] args) {
Tuple2<String, Integer> ttsi = f();
System.out.println(ttsi);
System.out.println(f2());
System.out.println(g());
System.out.println(h());
System.out.println(k());
}
}
/* Output:
(hi, 47)
(hi, 47)
(Amphibian@14ae5a5, hi, 47)
(Vehicle@135fbaa4, Amphibian@45ee12a7, hi, 47)
(Vehicle@4b67cf4d, Amphibian@7ea987ac, hi, 47, 11.1)
*/
```

Notice that **f()** returns a parameterized **Tuple2** object, while **f2()**

returns an unparameterized **Tuple2** object. The compiler doesn't warn about **f2()** here because the return value is not used in a parameterized fashion; in a sense, it is "upcast" to an unparameterized

Tuple2. However, if you were to try to capture the result of **f2()** into a parameterized **Tuple2**, the compiler would issue a warning.

A Set Utility

For another example of generic methods, consider the mathematical relationships expressed by **Set**s. These are conveniently defined as generic methods for use with all different types:

```
// onjava/Sets.java
package onjava;
import java.util.*;
public class Sets {
public static <T> Set<T> union(Set<T> a, Set<T> b) {
Set<T> result = new HashSet<>(a);
result.addAll(b);
return result;
```

```
}
public static <T>
Set<T> intersection(Set<T> a, Set<T> b) {
Set<T> result = new HashSet<>(a);
result.retainAll(b);
return result;
}
// Subtract subset from superset:
public static <T> Set<T>
difference(Set<T> superset, Set<T> subset) {
Set<T> result = new HashSet<>(superset);
result.removeAll(subset);
return result;
}
// Reflexive--everything not in the intersection:
public static
<T> Set<T> complement(Set<T> a, Set<T> b) {
return difference(union(a, b), intersection(a, b));
}
}
```

The first three methods duplicate the first argument by copying its references into a new **HashSet** object, so the argument **Set**s are not directly modified. The return value is thus a new **Set** object.

The four methods represent mathematical set operations: **union()** returns a **Set** containing the combination of the two arguments, **intersection()** returns a **Set** containing the common elements between the two arguments, **difference()** performs a subtraction of the **subset** elements from the **superset**, and **complement()** returns a **Set** of all the elements not in the intersection. As part of a simple example showing the effects of these methods, here's an **enum** containing different names of watercolors:

```
// generics/watercolors/Watercolors.java
package generics.watercolors;
public enum Watercolors {
ZINC, LEMON_YELLOW, MEDIUM_YELLOW, DEEP_YELLOW,
ORANGE, BRILLIANT_RED, CRIMSON, MAGENTA,
ROSE_MADDER, VIOLET, CERULEAN_BLUE_HUE,
PHTHALO_BLUE, ULTRAMARINE, COBALT_BLUE_HUE,
PERMANENT_GREEN, VIRIDIAN_HUE, SAP_GREEN,
YELLOW_OCHRE, BURNT_SIENNA, RAW_UMBER,
```

BURNT_UMBER, PAYNES_GRAY, IVORY_BLACK

}

For convenience (so all the names don't have to be qualified), this is imported statically into the following example. This example uses the **EnumSet** for easy creation of **Set**s from **enum**s. (You'll learn more about **EnumSet** in the Enumerations chapter.) Here, the **static** method **EnumSet.range()** is given the first and last elements of the range to create in the resulting **Set**:

```
// generics/WatercolorSets.java

import generics.watercolors.*;

import java.util.*;

import static onjava.Sets.*;

import static generics.watercolors.Watercolors.*;

public class WatercolorSets {

public static void main(String[] args) {

Set<Watercolors> set1 =

EnumSet.range(BRILLIANT_RED, VIRIDIAN_HUE);

Set<Watercolors> set2 =

EnumSet.range(CERULEAN_BLUE_HUE, BURNT_UMBER);

System.out.println("set1: " + set1);

System.out.println("set2: " + set2);
```

```
System.out.println(
"union(set1, set2): " + union(set1, set2));
Set<Watercolors> subset = intersection(set1, set2);
System.out.println(
"intersection(set1, set2): " + subset);
System.out.println("difference(set1, subset): " +
difference(set1, subset));
System.out.println("difference(set2, subset): " +
difference(set2, subset));
System.out.println("complement(set1, set2): " +
complement(set1, set2));
}
}
/* Output:
set1: [BRILLIANT_RED, CRIMSON, MAGENTA, ROSE_MADDER,
VIOLET, CERULEAN_BLUE_HUE, PHTHALO_BLUE, ULTRAMARINE,
COBALT_BLUE_HUE, PERMANENT_GREEN, VIRIDIAN_HUE]
set2: [CERULEAN_BLUE_HUE, PHTHALO_BLUE, ULTRAMARINE,
COBALT_BLUE_HUE, PERMANENT_GREEN, VIRIDIAN_HUE,
SAP_GREEN, YELLOW_OCHRE, BURNT_SIENNA, RAW_UMBER,
```

BURNT_UMBER]

union(set1, set2): [BURNT_SIENNA, BRILLIANT_RED,

YELLOW_OCHRE, MAGENTA, SAP_GREEN, CERULEAN_BLUE_HUE,

ULTRAMARINE, VIRIDIAN_HUE, VIOLET, RAW_UMBER,

ROSE_MADDER, PERMANENT_GREEN, BURNT_UMBER,

PHTHALO_BLUE, CRIMSON, COBALT_BLUE_HUE]

intersection(set1, set2): [PERMANENT_GREEN,

CERULEAN_BLUE_HUE, ULTRAMARINE, VIRIDIAN_HUE,

PHTHALO_BLUE, COBALT_BLUE_HUE]

difference(set1, subset): [BRILLIANT_RED, MAGENTA,

VIOLET, CRIMSON, ROSE_MADDER]

difference(set2, subset): [BURNT_SIENNA, YELLOW_OCHRE,

BURNT_UMBER, SAP_GREEN, RAW_UMBER]

complement(set1, set2): [BURNT_SIENNA, BRILLIANT_RED,

YELLOW_OCHRE, MAGENTA, SAP_GREEN, VIOLET, RAW_UMBER,

ROSE_MADDER, BURNT_UMBER, CRIMSON]

**/*

The following example uses **Sets.difference()** to show the

method differences between various **Collection** and **Map** classes in

java.util:

```
// onjava/CollectionMethodDifferences.java
// {java onjava.CollectionMethodDifferences}
package onjava;
import java.lang.reflect.*;
import java.util.*;
import java.util.stream.*;
public class CollectionMethodDifferences {
static Set<String> methodSet(Class<?> type) {
return Arrays.stream(type.getMethods())
.map(Method::getName)
.collect(Collectors.toCollection(TreeSet::new));
}
static void interfaces(Class<?> type) {
System.out.print("Interfaces in " +
type.getSimpleName() + ": ");
System.out.println(
Arrays.stream(type.getInterfaces())
.map(Class::getSimpleName)
.collect(Collectors.toList()));
}
```

```
static Set<String> object = methodSet(Object.class);
static { object.add("clone"); }
static void
difference(Class<?> superset, Class<?> subset) {
System.out.print(superset.getSimpleName() +
" extends " + subset.getSimpleName() +
", adds: ");
Set<String> comp = Sets.difference(
methodSet(superset), methodSet(subset));
comp.removeAll(object); // Ignore 'Object' methods
System.out.println(comp);
interfaces(superset);
}
public static void main(String[] args) {
System.out.println("Collection: " +
methodSet(Collection.class));
interfaces(Collection.class);
difference(Set.class, Collection.class);
difference(HashSet.class, Set.class);
difference(LinkedHashSet.class, HashSet.class);
```

```
difference(TreeSet.class, Set.class);
difference(List.class, Collection.class);
difference(ArrayList.class, List.class);
difference(LinkedList.class, List.class);
difference(Queue.class, Collection.class);
difference(PriorityQueue.class, Queue.class);
System.out.println("Map: " + methodSet(Map.class));
difference(HashMap.class, Map.class);
difference(LinkedHashMap.class, HashMap.class);
difference(SortedMap.class, Map.class);
difference(TreeMap.class, Map.class);
}
}
/* Output:
Collection: [add, addAll, clear, contains, containsAll,
equals, forEach, hashCode, isEmpty, iterator,
parallelStream, remove, removeAll, removeIf, retainAll,
size, spliterator, stream, toArray]
Interfaces in Collection: [Iterable]
Set extends Collection, adds: []
```

Interfaces in Set: [Collection]

HashSet extends Set, adds: []

Interfaces in HashSet: [Set, Cloneable, Serializable]

LinkedHashSet extends HashSet, adds: []

Interfaces in LinkedHashSet: [Set, Cloneable,

Serializable]

TreeSet extends Set, adds: [headSet,

descendingIterator, descendingSet, pollLast, subSet,

floor, tailSet, ceiling, last, lower, comparator,

pollFirst, first, higher]

Interfaces in TreeSet: [NavigableSet, Cloneable,

Serializable]

List extends Collection, adds: [replaceAll, get,

indexOf, subList, set, sort, lastIndexOf, listIterator]

Interfaces in List: [Collection]

ArrayList extends List, adds: [trimToSize,

ensureCapacity]

Interfaces in ArrayList: [List, RandomAccess,

Cloneable, Serializable]

LinkedList extends List, adds: [offerFirst, poll,

getLast, offer, getFirst, removeFirst, element,

removeLastOccurrence, peekFirst, peekLast, push,

pollFirst, removeFirstOccurrence, descendingIterator,

pollLast, removeLast, pop, addLast, peek, offerLast,

addFirst]

Interfaces in LinkedList: [List, Deque, Cloneable,

Serializable]

Queue extends Collection, adds: [poll, peek, offer,

element]

Interfaces in Queue: [Collection]

PriorityQueue extends Queue, adds: [comparator]

Interfaces in PriorityQueue: [Serializable]

Map: [clear, compute, computeIfAbsent,

computeIfPresent, containsKey, containsValue, entrySet,

equals, forEach, get, getOrDefault, hashCode, isEmpty,

keySet, merge, put, putAll, putIfAbsent, remove,

replace, replaceAll, size, values]

HashMap extends Map, adds: []

Interfaces in HashMap: [Map, Cloneable, Serializable]

LinkedHashMap extends HashMap, adds: []

Interfaces in LinkedHashMap: [Map]

SortedMap extends Map, adds: [lastKey, subMap,

comparator, firstKey, headMap, tailMap]

Interfaces in SortedMap: [Map]

TreeMap extends Map, adds: [descendingKeySet,

navigableKeySet, higherEntry, higherKey, floorKey,

subMap, ceilingKey, pollLastEntry, firstKey, lowerKey,

headMap, tailMap, lowerEntry, ceilingEntry,

descendingMap, pollFirstEntry, lastKey, firstEntry,

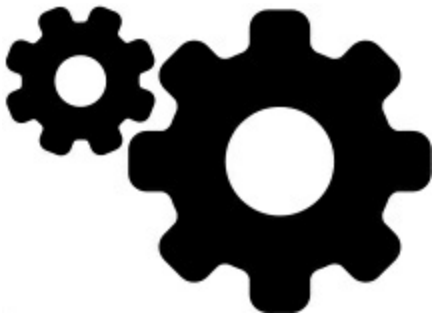
floorEntry, comparator, lastEntry]

Interfaces in TreeMap: [NavigableMap, Cloneable,

Serializable]

**/*

The output of this program was used in the “Summary” section of the



Collections chapter.

Building Complex

Models

An important benefit of generics is the ability to simply and safely create complex models. For example, we can easily create a **List** of tuples:

```
// generics/TupleList.java
// Combining generic types to make complex generic types
import java.util.*;
import onjava.*;
import java.util.stream.*;
public class TupleList<A, B, C, D>
extends ArrayList<Tuple4<A, B, C, D>> {
public static void main(String[] args) {
TupleList<Vehicle, Amphibian, String, Integer> tl =
new TupleList<>();
tl.add(TupleTest2.h());
tl.add(TupleTest2.h());
tl.forEach(System.out::println);
}
}
/* Output:
```

(Vehicle@7cca494b, Amphibian@7ba4f24f, hi, 47)

(Vehicle@3b9a45b3, Amphibian@7699a589, hi, 47)

/

This produces a fairly powerful data structure without too much code. Here's a second example. Even though each class is a building block, the total has many parts. Here, the model is a retail store with aisles, shelves and products:

```
// generics/Store.java
// Building a complex model using generic collections
import java.util.*;
import java.util.function.*;
import onjava.*;
class Product {
private final int id;
private String description;
private double price;
Product(int idNumber, String descr, double price) {
id = idNumber;
description = descr;
this.price = price;
```

```
System.out.println(toString());
}
@Override
public String toString() {
return id + ": " + description +
", price: $" + price;
}
public void priceChange(double change) {
price += change;
}
public static Supplier<Product> generator =
new Supplier<Product>() {
private Random rand = new Random(47);
@Override
public Product get() {
return new Product(rand.nextInt(1000), "Test",
Math.round(
rand.nextDouble() * 1000.0) + 0.99);
}
};
```

```
}
class Shelf extends ArrayList<Product> {
Shelf(int nProducts) {
Suppliers.fill(this, Product.generator, nProducts);
}
}
class Aisle extends ArrayList<Shelf> {
Aisle(int nShelves, int nProducts) {
for(int i = 0; i < nShelves; i++)
add(new Shelf(nProducts));
}
}
class CheckoutStand {}
class Office {}
public class Store extends ArrayList<Aisle> {
private ArrayList<CheckoutStand> checkouts =
new ArrayList<>();
private Office office = new Office();
public Store(
int nAisles, int nShelves, int nProducts) {
```

```
for(int i = 0; i < nAisles; i++)
add(new Aisle(nShelves, nProducts));
}
@Override
public String toString() {
StringBuilder result = new StringBuilder();
for(Aisle a : this)
for(Shelf s : a)
for(Product p : s) {
result.append(p);
result.append("\n");
}
return result.toString();
}
public static void main(String[] args) {
System.out.println(new Store(5, 4, 3));
}
}
/* Output: (First 8 Lines)
258: Test, price: $400.99
```

861: Test, price: $160.99

868: Test, price: $417.99

207: Test, price: $268.99

551: Test, price: $114.99

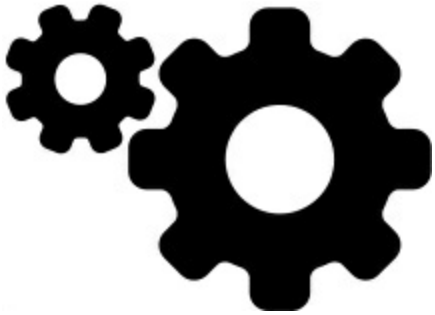
278: Test, price: $804.99

520: Test, price: $554.99

140: Test, price: $530.99

...

*/



Store.toString() shows the result: many layers of collections that are nonetheless type-safe and manageable. What's impressive is it is not intellectually prohibitive to assemble such a model.

Shelf uses **Suppliers.fill()**, a utility that takes a **Collection** (the first argument) and fills it using a **Supplier** (the second argument) with a number **n** (the third argument) of elements. The methods in the **Suppliers** class all perform some variation of

filling, and are used in other examples in this chapter. The class is defined at the end of the chapter.

The Mystery of Erasure

As you begin to delve more deeply into generics, there are a number of issues that won't initially make sense. For example, although you can say **ArrayList.class**, you cannot say **ArrayList<Integer>.class**. And consider the following:

```
// generics/ErasedTypeEquivalence.java
import java.util.*;
public class ErasedTypeEquivalence {
public static void main(String[] args) {
Class c1 = new ArrayList<String>().getClass();
Class c2 = new ArrayList<Integer>().getClass();
System.out.println(c1 == c2);
}
}
/* Output:
true
*/
```

ArrayList<String> and **ArrayList<Integer>** should be distinct types. Different types behave differently. If you try, for

example, to put an **Integer** into an **ArrayList<String>** , you

get different behavior (it fails) than if you put an **Integer** into an

ArrayList<Integer> (it succeeds). And yet the above program

suggests they are the same type.

Here's an example that adds to this puzzle:

```
// generics/LostInformation.java

import java.util.*;

class Frob {}

class Fnorkle {}

class Quark<Q> {}

class Particle<POSITION, MOMENTUM> {}

public class LostInformation {

public static void main(String[] args) {

List<Frob> list = new ArrayList<>();

Map<Frob, Fnorkle> map = new HashMap<>();

Quark<Fnorkle> quark = new Quark<>();

Particle<Long, Double> p = new Particle<>();

System.out.println(Arrays.toString(

list.getClass().getTypeParameters()));
```

```
System.out.println(Arrays.toString(
map.getClass().getTypeParameters()));
System.out.println(Arrays.toString(
quark.getClass().getTypeParameters()));
System.out.println(Arrays.toString(
p.getClass().getTypeParameters()));
}
}
/* Output:
[E]
[K, V]
[Q]
[POSITION, MOMENTUM]
*/
```

According to the JDK documentation,

Class.getTypeParameters() “returns an array of

TypeVariable objects that represent the type variables declared by

the generic declaration…" This suggests you can discover the parameter types. However, as the output shows, you only find out about identifiers used as the parameter placeholders—not so interesting.

The cold truth is:

There's no information about generic parameter types available inside generic code.

Thus, you can know things like the identifier of the type parameter and the bounds of the generic type—you just can't know the actual type parameter(s) used to create a particular instance. This fact, especially frustrating if you're coming from C++, is the most fundamental issue you must deal with when working with Java generics.

Java generics are implemented using *erasure*. This means any specific type information is erased when you use a generic. Inside the generic, the only thing you know is that you're using an object. So **List<String>** and **List<Integer>** *are*, in fact, the same type at run time. Both forms are "erased" to their *raw type*, **List**.

Understanding erasure and how you must deal with it is one of the biggest hurdles you face when learning Java generics. We explore erasure in this section.

The C++ Approach

Here's a C++ example which uses *templates*. The syntax for parameterized types is similar because Java took inspiration from C++:

```
// generics/Templates.cpp
#include <iostream>
using namespace std;
template< class T> class Manipulator {
T obj;
public:
Manipulator(T x) { obj = x; }
void manipulate() { obj.f(); }
};
class HasF {
public:
void f() { cout << "HasF::f()" << endl; }
};
int main() {
HasF hf;
Manipulator<HasF> manipulator(hf);
```

```
manipulator.manipulate();
}
/* Output:
HasF::f()
*/
```

The **Manipulator** class stores an object of type **T**. The **manipulate()** method calls a method **f()** on **obj**. How can it know that the **f()** method exists for the type parameter **T**? The C++ compiler checks when you instantiate the template, so at the point of instantiation of **Manipulator<HasF>** , it sees that **HasF** has a method **f()**. If it were not the case, you'd get a compile-time error, preserving type safety.

Writing this kind of code in C++ is straightforward because when a template is instantiated, the template code knows the type of its template parameters. Java generics are different. Here's the translation of **HasF**:

```
// generics/HasF.java
public class HasF {
public void f() {
System.out.println("HasF.f()");
```

```
}
}
```

If we take the rest of the example and translate it to Java, it won't compile:

```
// generics/Manipulation.java
// {WillNotCompile}
class Manipulator<T> {
private T obj;
Manipulator(T x) { obj = x; }
// Error: cannot find symbol: method f():
public void manipulate() { obj.f(); }
}
public class Manipulation {
public static void main(String[] args) {
HasF hf = new HasF();
Manipulator<HasF> manipulator =
new Manipulator<>(hf);
manipulator.manipulate();
}
}
```

Because of erasure, the Java compiler can't map the requirement that **manipulate()** must call **f()** on **obj** to the fact that **HasF** has a method **f()**. To call **f()**, we must assist the generic class by giving it a *bound* that tells the compiler to only accept types that conform to that bound. This reuses the **extends** keyword. Because of the bound, the following compiles:

```
// generics/Manipulator2.java
class Manipulator2<T extends HasF> {
private T obj;
Manipulator2(T x) { obj = x; }
public void manipulate() { obj.f(); }
}
```

The bound **<T extends HasF>** says that **T** must be of type **HasF** or something derived from **HasF**. If this is true, it is safe to call **f()** on **obj**.

We say that a generic type parameter *erases to its first bound* (multiple bounds are possible, as you shall see later). We also talk about *erasure of the type parameter*. The compiler actually replaces the type parameter with its erasure, so in the above case, **T** erases to **HasF**, which is the same as replacing **T** with **HasF** in the class body.

You might correctly observe that in **Manipulator2.java**, generics do not contribute anything. You can just as easily perform the erasure yourself and produce a class without generics:

```
// generics/Manipulator3.java
class Manipulator3 {
private HasF obj;
Manipulator3(HasF x) { obj = x; }
public void manipulate() { obj.f(); }
}
```

This brings up an important point: Generics are only useful for type parameters more “generic” than a specific type (and all its subtypes)—that is, when you want code to work across multiple classes. As a result, the type parameters and their application in useful generic code will usually be more complex than simple class replacement. However, you can’t just say that anything of the form **<T extends HasF>** is therefore flawed. For example, if a class has a method that returns **T**, generics are helpful, because they will then return the exact type:

```
// generics/ReturnGenericType.java
```

```
class ReturnGenericType<T extends HasF> {
private T obj;
ReturnGenericType(T x) { obj = x; }
public T get() { return obj; }
}
```

You must look at all your code and determine whether it is “complex enough” to warrant generics.

We’ll look at bounds in more detail later in the chapter.

Migration Compatibility

To allay any potential confusion about erasure, you must clearly understand that it is *not* a language feature. It is a compromise in the implementation of Java generics, necessary because generics were not made part of the language from the beginning. This compromise will cause you pain, so get used to it early and understand why it’s there.

If generics had been part of Java 1.0, the feature would not have been implemented using erasure—it would have used *reification* to retain the type parameters as first-class entities, so you would perform type-

based language and reflective operations on type parameters. You'll see later in this chapter that erasure reduces the "genericity" of generics. Generics are still useful in Java, just not as useful as they could be, and the reason is erasure.

In an erasure-based implementation, generic types are treated as second-class types that cannot be used in some important contexts. The generic types are present only during static type checking, after which every generic type in the program is erased by replacing it with a non-generic upper bound. For example, type annotations such as **List<T>** are erased to **List**, and ordinary type variables are erased to **Object** unless a bound is specified.

The core motivation for erasure is that you can use generified clients

with non-generified libraries, and vice versa. This is often called *migration compatibility*. In the ideal world, everything would be generified on some designated day. In reality, even if programmers are only writing generic code, they must deal with non-generic libraries written before Java 5. The authors of those libraries might never have

the incentive to generify their code, or they might just take their time in getting to it.

So Java generics must not only support *backward compatibility*—existing code and class files are still legal, and continue to mean what they meant before—but must also support migration compatibility, so libraries can become generic at their own pace, and when a library does become generic, it doesn't break code and applications that depend upon it. After deciding this was the goal, the Java designers and the various groups working on the problem decided that erasure was the only feasible solution. Erasure enables this migration towards generics by allowing non-generic code to coexist with generic code. For example, suppose an application uses two libraries, **X** and **Y**, and **Y** uses library **Z**. With the advent of Java 5, the creators of this application and these libraries will probably, eventually, migrate to generics. Each of them, however, will have different motivations and constraints as to when that migration happens. To achieve migration compatibility, each library and application must be independent of all the others in terms of whether generics are used. Thus, they cannot detect whether other libraries are or are not using generics. Ergo, the evidence that a particular library is using generics must be "erased."

Without some kind of migration path, all the libraries that had been built up over time stood the chance of being cut off from the developers that chose to move to Java generics. Libraries are arguably the part of a programming language that has the greatest productivity impact, so this was not an acceptable cost. Whether or not erasure was the best or only migration path is something that only time will tell.

The Problem with Erasure

So the primary justification for erasure is the transition process from non-generified code to generified code, and to incorporate generics into the language without breaking existing libraries. Erasure allows you to continue using existing non-generic client code unchanged, until clients are ready to rewrite code for generics. This is a noble motivation, because it doesn't suddenly break all existing code.

The cost of erasure is significant. Generic types cannot be used in operations that explicitly refer to runtime types, such as casts, **instanceof** operations, and **new** expressions. Because all type information about parameters is lost, when writing generic code you must constantly remind yourself it only *appears* you have type information about a parameter.

Consider a piece of code like this:

```
class Foo<T> {
T var;
}
```

It appears that when you create an instance of **Foo**:

```
Foo<Cat> f = new Foo<>();
```

the code in **class Foo** ought to know it is now working with a **Cat**.

The syntax strongly suggests that the type **T** is substituted everywhere throughout the class, as it is in C++. But it isn't, and you must remind yourself, "No, it's just an **Object**," whenever you're writing the code for the class.

In addition, erasure and migration compatibility mean that using generics is not enforced when you might want it to be:

```
// generics/ErasureAndInheritance.java
class GenericBase<T> {
private T element;
public void set(T arg) { element = arg; }
public T get() { return element; }
}
class Derived1<T> extends GenericBase<T> {}
class Derived2 extends GenericBase {} // No warning
```

```
// class Derived3 extends GenericBase<?> {}
// Strange error:
// unexpected type
// required: class or interface without bounds
public class ErasureAndInheritance {
@SuppressWarnings("unchecked")
public static void main(String[] args) {
Derived2 d2 = new Derived2();
Object obj = d2.get();
d2.set(obj); // Warning here!
}
}
```

Derived2 inherits from **GenericBase** with no generic parameters, and the compiler doesn't issue a warning. The warning doesn't occur until **set()** is called.

To turn off the warning, Java provides an annotation, the one you see in the listing:

```
@SuppressWarnings("unchecked")
```

This is placed on the method that generates the warning, rather than the entire class. It's best to be as "focused" as possible when you turn

off a warning, so you don’t accidentally cloak a real problem by turning off warnings too broadly.

Presumably, the error produced by **Derived3** means the compiler expects a raw base class.

Add to this the extra effort of managing bounds when you treat your

type parameter as more than just an **Object**, and you have far more effort for much less payoff than you get in parameterized types with languages like C++, Ada or Eiffel. This is not to say that those languages in general buy you more than Java does for the majority of programming problems, but rather that their parameterized type mechanisms are more flexible and powerful than Java’s.

The Action at the Boundaries

Because of erasure, I find the most confusing aspect of generics is that you can represent things that have no meaning. For example:

```
// generics/ArrayMaker.java
import java.lang.reflect.*;
import java.util.*;
```

```
public class ArrayMaker<T> {
private Class<T> kind;
public ArrayMaker(Class<T> kind) { this.kind = kind; }
@SuppressWarnings("unchecked")
T[] create(int size) {
return (T[])Array.newInstance(kind, size);
}
public static void main(String[] args) {
ArrayMaker<String> stringMaker =
new ArrayMaker<>(String.class);
String[] stringArray = stringMaker.create(9);
System.out.println(Arrays.toString(stringArray));
}
}
/* Output:
[null, null, null, null, null, null, null, null, null]
*/
```

Even though **kind** is stored as **Class<T>** , erasure means it is actually just stored as a **Class**, with no parameter. So, when you do something with it, as in creating an array, **Array.newInstance()**

doesn’t actually have the type information that’s implied in **kind**. It cannot produce the specific result, which must therefore be cast, which

produces a warning you cannot satisfy.

Note that using **Array.newInstance()** is the recommended

approach for creating arrays in generics.

It’s different if we create a collection instead of an array:

// generics/ListMaker.java

import java.util.*;

public class ListMaker<T> {

List<T> create() { **return new** ArrayList<>(); }

public static void main(String[] args) {

ListMaker<String> stringMaker = **new** ListMaker<>();

List<String> stringList = stringMaker.create();

}

}

The compiler gives no warnings, even though we know (from erasure)

that the **<T>** in **new ArrayList<>()** inside **create()** is

removed—at runtime there’s no **<T>** inside the class, so it seems

meaningless. But if you follow this idea and change the expression to

new ArrayList(), the compiler gives a warning.

Is it really meaningless here? What if you were to put some objects in

the **List** while creating it, like this:

```
// generics/FilledList.java
import java.util.*;
import java.util.function.*;
import onjava.*;
public class FilledList<T> extends ArrayList<T> {
FilledList(Supplier<T> gen, int size) {
Suppliers.fill(this, gen, size);
}
public FilledList(T t, int size) {
for(int i = 0; i < size; i++)
this.add(t);
}
public static void main(String[] args) {
List<String> list = new FilledList<>("Hello", 4);
System.out.println(list);
// Supplier version:
List<Integer> ilist = new FilledList<>(() -> 47, 4);
System.out.println(ilist);
}
```

}

/ *Output:*

[Hello, Hello, Hello, Hello]

[47, 47, 47, 47]

**/*

Even though the compiler is unable to know anything about **T** inside **add()**, it can still ensure—at compile time—that what you put into the **FilledList** is of type **T**. Thus, even though erasure removes the information about the actual type inside a method or class, the compiler can still ensure internal consistency in the way that the type is used within the method or class.

Because erasure removes type information in the body of a method, what matters at run time is the *boundaries*: the points where objects enter and leave a method. These are the points at which the compiler performs type checks at compile time, and inserts casting code.

Consider the following non-generic example:

// generics/SimpleHolder.java

public class SimpleHolder {

private Object obj;

public void set(Object obj) { **this**.obj = obj; }

public Object get() { **return** obj; }

public static void main(String[] args) {

SimpleHolder holder = **new** SimpleHolder();

holder.set("Item");

String s = (String)holder.get();

}

}

If we decompile the result with **javap -c SimpleHolder**, we get

(after editing):

public void set(java.lang.Object);

0: aload_0

1: aload_1

2: putfield #2; *//Field obj:Object;*

5: **return**

public java.lang.Object get();

0: aload_0

1: getfield #2; *//Field obj:Object;*

4: areturn

public static void main(java.lang.String[]);

0: **new** #3; *//class SimpleHolder*

3: dup

4: invokespecial #4; *//Method "<init>":()V*

7: astore_1

8: aload_1

9: ldc #5; *//String Item*

11: invokevirtual #6; *//Method set:(Object;)V*

14: aload_1

15: invokevirtual #7; *//Method get:()Object;*

18: checkcast #8; *//class java/lang/String*

21: astore_2

22: **return**

The **set()** and **get()** methods store and produce the value, and the cast is checked at the point of the call to **get()**.

Now incorporate generics into the above code:

```
// generics/GenericHolder2.java
public class GenericHolder2<T> {
private T obj;
public void set(T obj) { this.obj = obj; }
public T get() { return obj; }
public static void main(String[] args) {
```

GenericHolder2<String> holder =

new GenericHolder2<>();

holder.set("Item");

String s = holder.get();

}

}

The need for the cast from **get()** has disappeared, but we also know that the value passed to **set()** is type-checked at compile time. Here are the relevant bytecodes:

public void set(java.lang.Object);

0: aload_0

1: aload_1

2: putfield #2; *//Field obj:Object;*

5: **return**

public java.lang.Object get();

0: aload_0

1: getfield #2; *//Field obj:Object;*

4: areturn

public static void main(java.lang.String[]);

0: **new** #3; *//class GenericHolder2*

3: dup

4: invokespecial #4; *//Method "<init>":()V*

7: astore_1

8: aload_1

9: ldc #5; *//String Item*

11: invokevirtual #6; *//Method set:(Object;)V*

14: aload_1

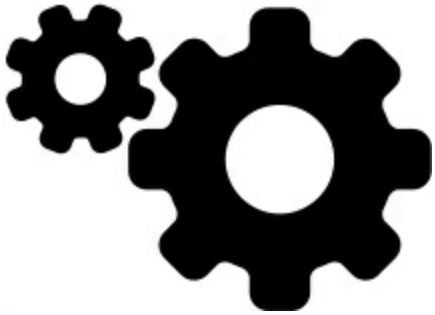
15: invokevirtual #7; *//Method get:()Object;*

18: checkcast #8; *//class java/lang/String*

21: astore_2

22: **return**

The resulting code is identical. The extra work of checking the incoming type in **set()** is free, because it is performed by the



compiler. And the cast for the outgoing value of **get()** is still there, but it’s no less than you’d do yourself—and it’s automatically inserted by the compiler, so the code you write (and read) is less noisy.

Since **get()** and **set()** produce the same bytecodes, this tells us that all the action in generics happens at the boundaries—the extra compile-time check for incoming values, and the inserted cast for outgoing values. It helps to counter the confusion of erasure to remember that "the boundaries are where the action takes place."

Compensating for Erasure

With erasure, we lose the ability to perform certain operations in generic code. Anything that requires knowing the exact type at run time won't work:

```
// generics/Erased.java
// {WillNotCompile}
public class Erased<T> {
private final int SIZE = 100;
public void f(Object arg) {
// error: illegal generic type for instanceof
if(arg instanceof T) {}
// error: unexpected type
T var = new T();
// error: generic array creation
```

```
T[] array = new T[SIZE];
// warning: [unchecked] unchecked cast
T[] array = (T[])new Object[SIZE];
}
}
```

Occasionally you can program around these issues, but sometimes you must compensate for erasure by introducing a *type tag*. This means explicitly passing a **Class** object for your type to use it in type expressions.

For example, the attempt to use **instanceof** in the previous program fails because the type information was erased. A type tag enables a dynamic **isInstance()**:

```
// generics/ClassTypeCapture.java
class Building {}
class House extends Building {}
public class ClassTypeCapture<T> {
Class<T> kind;
public ClassTypeCapture(Class<T> kind) {
this.kind = kind;
}
```

```
public boolean f(Object arg) {
return kind.isInstance(arg);
}
public static void main(String[] args) {
ClassTypeCapture<Building> ctt1 =
new ClassTypeCapture<>(Building.class);
System.out.println(ctt1.f(new Building()));
System.out.println(ctt1.f(new House()));
ClassTypeCapture<House> ctt2 =
new ClassTypeCapture<>(House.class);
System.out.println(ctt2.f(new Building()));
System.out.println(ctt2.f(new House()));
}
}
/* Output:
true
true
false
```

true

**/*

The compiler ensures that the type tag matches the generic argument.

Creating Instances of Types

The attempt to create a **new T()** in **Erased.java** won't work, partly because of erasure, and partly because the compiler cannot verify that **T** has a default (no-arg) constructor. But in C++ this operation is natural, straightforward, and safe (it's checked at compile time):

```
// generics/InstantiateGenericType.cpp
// C++, not Java!
template< class T> class Foo {
T x; // Create a field of type T
T* y; // Pointer to T
public:
// Initialize the pointer:
Foo() { y = new T(); }
```

```
};
class Bar {};
int main() {
Foo<Bar> fb;
Foo<int> fi; // ... and it works with primitives
}
```

The solution in Java is to pass in a factory object, and use that to make the new instance. A convenient factory object is just the **Class** object, so if you use a type tag, you can use **newInstance()** to create a new object of that type:

```
// generics/InstantiateGenericType.java
import java.util.function.*;
class ClassAsFactory<T> implements Supplier<T> {
Class<T> kind;
ClassAsFactory(Class<T> kind) {
this.kind = kind;
}
@Override
public T get() {
try {
```

```
return kind.newInstance();
} catch(InstantiationException |
IllegalAccessException e) {
throw new RuntimeException(e);
}
}
}
class Employee {
@Override
public String toString() { return "Employee"; }
}
public class InstantiateGenericType {
public static void main(String[] args) {
ClassAsFactory<Employee> fe =
new ClassAsFactory<>(Employee.class);
System.out.println(fe.get());
ClassAsFactory<Integer> fi =
new ClassAsFactory<>(Integer.class);
try {
System.out.println(fi.get());
```

} **catch**(Exception e) {

System.out.println(e.getMessage());

}

}

}

/ *Output:*

Employee

java.lang.InstantiationException: java.lang.Integer

**/*

This compiles, but fails with **ClassAsFactory<Integer>**

because **Integer** doesn't have a no-arg constructor. Because the error is not caught at compile time, this approach is frowned upon by the language creators. They suggest instead that you use an explicit factory (**Supplier**) and constrain the type so it only takes a class that implements this factory. Here are two different ways to create the factory:

// generics/FactoryConstraint.java

import java.util.*;

import java.util.function.*;

import onjava.*;

```
class IntegerFactory implements Supplier<Integer> {
private int i = 0;
@Override
public Integer get() {
return ++i;
}
}
class Widget {
private int id;
Widget(int n) { id = n; }
@Override
public String toString() {
return "Widget " + id;
}
public static
class Factory implements Supplier<Widget> {
private int i = 0;
@Override
public Widget get() { return new Widget(++i); }
}
```

```
}
class Fudge {
private static int count = 1;
private int n = count++;
@Override
public String toString() { return "Fudge " + n; }
}
class Foo2<T> {
private List<T> x = new ArrayList<>();
Foo2(Supplier<T> factory) {
Suppliers.fill(x, factory, 5);
}
@Override
public String toString() { return x.toString(); }
}
public class FactoryConstraint {
public static void main(String[] args) {
System.out.println(
new Foo2<>(new IntegerFactory()));
System.out.println(
```

```
new Foo2<>(new Widget.Factory()));
System.out.println(
new Foo2<>(Fudge::new));
}
}
/* Output:
[1, 2, 3, 4, 5]
[Widget 1, Widget 2, Widget 3, Widget 4, Widget 5]
[Fudge 1, Fudge 2, Fudge 3, Fudge 4, Fudge 5]
*/
```

IntegerFactory is itself a factory by implementing **Supplier<Integer>** . **Widget** contains an inner class which is a factory. And notice that **Fudge** does not do anything factory-like, and yet passing **Fudge::new** still produces factory behavior, because the compiler translates a call to the functional method **::new** into a call to **get()**.

Another approach is the *Template Method* design pattern. In the following example, **create()** is the Template Method, overridden in the subclass to produce an object of that type:

```
// generics/CreatorGeneric.java
abstract class GenericWithCreate<T> {
final T element;
GenericWithCreate() { element = create(); }
abstract T create();
}
class X {}
class XCreator extends GenericWithCreate<X> {
@Override
X create() { return new X(); }
void f() {
System.out.println(
element.getClass().getSimpleName());
}
}
public class CreatorGeneric {
public static void main(String[] args) {
```

```
XCreator xc = new XCreator();
xc.f();
}
}
/* Output:
X
*/
```

GenericWithCreate contains the **element** field, and forces its initialization via the no-arg constructor, which in turn calls the **abstract create()** method. This way creation can be defined in the subclass, at the same time the type of **T** is established.

Arrays of Generics

As you saw in **Erased.java**, you can't create arrays of generics. The general solution is to use an **ArrayList** anywhere you are tempted to create an array of generics:

```
// generics/ListOfGenerics.java
import java.util.*;
public class ListOfGenerics<T> {
private List<T> array = new ArrayList<>();
public void add(T item) { array.add(item); }
```

```
public T get(int index) { return array.get(index); }
}
```

Here you get the behavior of an array but the compile-time type safety afforded by generics.

At times, you still create an array of generic types (the **ArrayList**, for example, uses arrays internally). You can define a generic *reference* to an array in a way that makes the compiler happy:

```
// generics/ArrayOfGenericReference.java
class Generic<T> {}
public class ArrayOfGenericReference {
static Generic<Integer>[] gia;
}
```

The compiler accepts this without producing warnings. But you can never create an array of that exact type (including the type parameters), so it's a little confusing. Since all arrays have the same structure (size of each array slot and array layout) regardless of the type they hold, it seems like you can create an array of **Object** and cast that to the desired array type. This does in fact compile, but it produces a **ClassCastException**:

```
// generics/ArrayOfGeneric.java
```

```
public class ArrayOfGeneric {
static final int SIZE = 100;
static Generic<Integer>[] gia;
@SuppressWarnings("unchecked")
public static void main(String[] args) {
try {
gia = (Generic<Integer>[])new Object[SIZE];
} catch(ClassCastException e) {
System.out.println(e.getMessage());
}
// Runtime type is the raw (erased) type:
gia = (Generic<Integer>[])new Generic[SIZE];
System.out.println(gia.getClass().getSimpleName());
gia[0] = new Generic<>();
//- gia[1] = new Object(); // Compile-time error
// Discovers type mismatch at compile time:
//- gia[2] = new Generic<Double>();
}
}
/* Output:
```

[Ljava.lang.Object; cannot be cast to [LGeneric;

Generic[]

**/*

The problem is that arrays keep track of their actual type, and that type is established at the point of creation of the array. So even though **gia** is cast to a **Generic<Integer>[]**, that information only exists at compile time (and without the **@SuppressWarnings** annotation, you'd get a warning for that cast). At run time, it's still an array of **Object**, and that causes problems. The only way to successfully create an array of a generic type is to create a new array of the erased type, and cast that.

Let's look at a slightly more sophisticated example. Consider a simple generic wrapper around an array:

```
// generics/GenericArray.java
public class GenericArray<T> {
private T[] array;
@SuppressWarnings("unchecked")
public GenericArray(int sz) {
array = (T[])new Object[sz];
}
```

```
public void put(int index, T item) {
array[index] = item;
}
public T get(int index) { return array[index]; }
// Method that exposes the underlying representation:
public T[] rep() { return array; }
public static void main(String[] args) {
GenericArray<Integer> gai = new GenericArray<>(10);
try {
Integer[] ia = gai.rep();
} catch(ClassCastException e) {
System.out.println(e.getMessage());
}
// This is OK:
Object[] oa = gai.rep();
}
}
/* Output:
[Ljava.lang.Object; cannot be cast to
[Ljava.lang.Integer;
```

*/

As before, we can't say **T[] array = new T[sz]**, so we create an array of objects and cast it.

The **rep()** method returns a **T[]**, which in **main()** should be an **Integer[]** for **gai**, but if you call it and try to capture the result as an **Integer[]** reference, you get a **ClassCastException**, again because the actual runtime type is **Object[]**.

If you compile **GenericArray.java** after commenting out the **@SuppressWarnings** annotation, the compiler produces a warning:

GenericArray.java uses unchecked or unsafe operations.

Recompile with -Xlint:unchecked **for** details.

Here, we've gotten a single warning, and we believe it's about the cast.

But to really make sure, compile with **-Xlint:unchecked**:

GenericArray.java:7: warning: [unchecked] unchecked cast

array = (T[])**new** Object[sz];

^

required: T[]

found: Object[]

where T is a type-variable:

T **extends** Object declared in **class** GenericArray

1 warning

It is indeed complaining about that cast. Because warnings become noise, the best we can possibly do, once we verify that a particular warning is expected, is to turn it off using **@SuppressWarnings**. That way, when a warning does appear, we'll actually investigate it. Because of erasure, the runtime type of the array can only be **Object[]**. If we immediately cast it to **T[]**, then at compile-time the actual type of the array is lost, and the compiler can miss out on some potential error checks. Because of this, it's better to use an **Object[]** inside the collection, and add a cast to **T** when you use an array element. Let's see how that would look with the **GenericArray.java** example:

```
// generics/GenericArray2.java
public class GenericArray2<T> {
private Object[] array;
public GenericArray2(int sz) {
array = new Object[sz];
}
public void put(int index, T item) {
```

```
array[index] = item;
}
@SuppressWarnings("unchecked")
public T get(int index) { return (T)array[index]; }
@SuppressWarnings("unchecked")
public T[] rep() {
return (T[])array; // Unchecked cast
}
public static void main(String[] args) {
GenericArray2<Integer> gai =
new GenericArray2<>(10);
for(int i = 0; i < 10; i ++)
gai.put(i, i);
for(int i = 0; i < 10; i ++)
System.out.print(gai.get(i) + " ");
System.out.println();
try {
Integer[] ia = gai.rep();
} catch(Exception e) {
System.out.println(e);
```

```
}
}
}
/* Output:
0 1 2 3 4 5 6 7 8 9
java.lang.ClassCastException: [Ljava.lang.Object;
cannot be cast to [Ljava.lang.Integer;
*/
```

Initially, this doesn't look very different, just that the cast has moved. Without the **@SuppressWarnings** annotations, you still get "unchecked" warnings. However, the internal representation is now **Object[]** rather than **T[]**. When **get()** is called, it casts the object to **T**, which is in fact the correct type, so that is safe. However, if you call **rep()**, it again attempts to cast the **Object[]** to a **T[]**, still incorrect, and produces a warning at compile time and an exception at run time. Thus there's no way to subvert the type of the underlying array, which can only be **Object[]**. The advantage of treating **array** internally as **Object[]** instead of **T[]** is it's less likely you'll forget the runtime type of the array and accidentally introduce a bug (although the majority, and perhaps all, of such bugs would be rapidly detected at run time).

For new code, pass in a type token. In that case, the **GenericArray** looks like this:

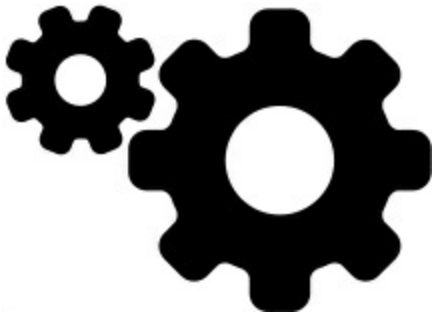
```
// generics/GenericArrayWithTypeToken.java
import java.lang.reflect.*;
public class GenericArrayWithTypeToken<T> {
private T[] array;
@SuppressWarnings("unchecked")
public
GenericArrayWithTypeToken(Class<T> type, int sz) {
array = (T[])Array.newInstance(type, sz);
}
public void put(int index, T item) {
array[index] = item;
}
public T get(int index) { return array[index]; }
// Expose the underlying representation:
public T[] rep() { return array; }
public static void main(String[] args) {
GenericArrayWithTypeToken<Integer> gai =
new GenericArrayWithTypeToken<>(
```

```
Integer.class, 10);
// This now works:
Integer[] ia = gai.rep();
}
}
```

The type token **Class<T>** is passed into the constructor to recover from the erasure, so we can create the actual type of array we need, although the warning from the cast must be suppressed with **@SuppressWarnings**. Once we get the actual type, we can return it and produce the desired results, as you see in **main()**. The runtime type of the array is the exact type **T[]**.

Unfortunately, if you look at the source code in the Java standard libraries, you'll see there are casts from **Object** arrays to parameterized types everywhere. For example, here's the copy-**ArrayList**-from-**Collection** constructor, after cleaning up and simplifying:

```
public ArrayList(Collection c) {
```



```
size = c.size();
elementData = (E[])new Object[size];
c.toArray(elementData);
}
```

If you look through **ArrayList.java**, you'll find plenty of these casts. And what happens when we compile it?

```
Note: ArrayList.java uses unchecked or unsafe operations
Note: Recompile with -Xlint:unchecked for details.
```

Sure enough, the standard libraries produce lots of warnings. If you've worked with C, especially pre-ANSI C, you remember a particular effect of warnings: When you discover you can ignore them, you do. For that reason, it's best to not issue any kind of message from the compiler unless the programmer must do something about it.

In his weblog,[2] Neal Gafter (one of the lead developers for Java 5) points out that he was lazy when rewriting the Java libraries, and that we should not do what he did. Neal also points out that he could not

fix some of the Java library code without breaking the existing interface. So even if certain idioms appear in the Java library sources, that's not necessarily the right way to do it. When you look at library code, you cannot assume it's an example to follow in your own code.

Note that the type token technique is recommended in the Java literature, such as Gilad Bracha's paper *Generics in the Java Programming Language*,[3] where he notes, "It's an idiom that's used extensively in the new APIs for manipulating annotations, for example." However, I've discovered some inconsistency in people's comfort level with this technique; some people strongly prefer the factory approach, which was presented earlier in this chapter.

Bounds

Bounds were briefly introduced earlier in the chapter. Bounds allow you to place constraints on parameter types used with generics. Although this can enforce rules about types to which your generics are applied, a potentially more important effect is that you can call methods in your bound types.

Because erasure removes type information, the only methods you can call for an unbounded generic parameter are those available for **Object**. If, however, you are able to constrain that parameter to a subset of types, you can call the methods in that subset. To apply

constraints, Java generics reuse the **extends** keyword.

It’s important to understand that **extends** has a significantly different meaning in the context of generic bounds than it does ordinarily. This example shows the basics of bounds:

```
// generics/BasicBounds.java
interface HasColor { java.awt.Color getColor(); }
class WithColor<T extends HasColor> {
T item;
WithColor(T item) { this.item = item; }
T getItem() { return item; }
// The bound allows you to call a method:
java.awt.Color color() { return item.getColor(); }
}
class Coord { public int x, y, z; }
// This fails. Class must be first, then interfaces:
// class WithColorCoord<T extends HasColor & Coord> {
// Multiple bounds:
class WithColorCoord<T extends Coord & HasColor> {
T item;
WithColorCoord(T item) { this.item = item; }
```

```
T getItem() { return item; }

java.awt.Color color() { return item.getColor(); }

int getX() { return item.x; }
```

```
int getY() { return item.y; }
int getZ() { return item.z; }
}
interface Weight { int weight(); }
// As with inheritance, you can have only one
// concrete class but multiple interfaces:
class Solid<T extends Coord & HasColor & Weight> {
T item;
Solid(T item) { this.item = item; }
T getItem() { return item; }
java.awt.Color color() { return item.getColor(); }
int getX() { return item.x; }
int getY() { return item.y; }
int getZ() { return item.z; }
int weight() { return item.weight(); }
}
class Bounded
extends Coord implements HasColor, Weight {
@Override
public java.awt.Color getColor() { return null; }
```

```
@Override
public int weight() { return 0; }
}
public class BasicBounds {
public static void main(String[] args) {
Solid<Bounded> solid =
new Solid<>(new Bounded());
solid.color();
solid.getY();
solid.weight();
}
}
```

You might observe that **BasicBounds.java** seems to contain redundancies that could be eliminated through inheritance. Here, each level of inheritance also adds bounds constraints:

```
// generics/InheritBounds.java
class HoldItem<T> {
T item;
HoldItem(T item) { this.item = item; }
T getItem() { return item; }
```

```
}
class WithColor2<T extends HasColor>
extends HoldItem<T> {
WithColor2(T item) { super(item); }
java.awt.Color color() { return item.getColor(); }
}
class WithColorCoord2<T extends Coord & HasColor>
extends WithColor2<T> {
WithColorCoord2(T item) { super(item); }
int getX() { return item.x; }
int getY() { return item.y; }
int getZ() { return item.z; }
}
class Solid2<T extends Coord & HasColor & Weight>
extends WithColorCoord2<T> {
Solid2(T item) { super(item); }
int weight() { return item.weight(); }
}
public class InheritBounds {
public static void main(String[] args) {
```

```
Solid2<Bounded> solid2 =
new Solid2<>(new Bounded());
solid2.color();
solid2.getY();
solid2.weight();
}
}
```

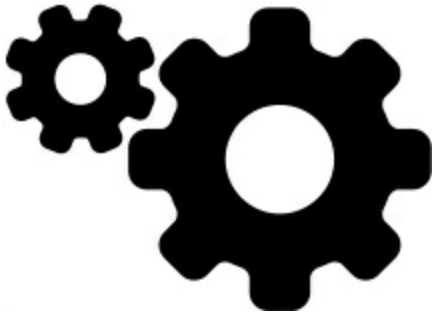
HoldItem holds an object, so this behavior is inherited into **WithColor2**, which also requires its parameter conforms to **HasColor**. **WithColorCoord2** and **Solid2** further extend the hierarchy and add bounds at each level. Now the methods are inherited and they're not repeated in each class.

Here's an example with more layers:

```
// generics/EpicBattle.java
// Bounds in Java generics
import java.util.*;
interface SuperPower {}
interface XRayVision extends SuperPower {
void seeThroughWalls();
}
```

```
interface SuperHearing extends SuperPower {
void hearSubtleNoises();
}
interface SuperSmell extends SuperPower {
void trackBySmell();
}
class SuperHero<POWER extends SuperPower> {
POWER power;
SuperHero(POWER power) { this.power = power; }
POWER getPower() { return power; }
}
class SuperSleuth<POWER extends XRayVision>
extends SuperHero<POWER> {
SuperSleuth(POWER power) { super(power); }
void see() { power.seeThroughWalls(); }
}
class
CanineHero<POWER extends SuperHearing & SuperSmell>
extends SuperHero<POWER> {
CanineHero(POWER power) { super(power); }
```

```
void hear() { power.hearSubtleNoises(); }
void smell() { power.trackBySmell(); }
}
class SuperHearSmell
implements SuperHearing, SuperSmell {
@Override
```



```
public void hearSubtleNoises() {}
@Override
public void trackBySmell() {}
}
class DogPerson extends CanineHero<SuperHearSmell> {
DogPerson() { super(new SuperHearSmell()); }
}
public class EpicBattle {
// Bounds in generic methods:
static <POWER extends SuperHearing>
```

```
void useSuperHearing(SuperHero<POWER> hero) {
hero.getPower().hearSubtleNoises();
}
static <POWER extends SuperHearing & SuperSmell>
void superFind(SuperHero<POWER> hero) {
hero.getPower().hearSubtleNoises();
hero.getPower().trackBySmell();
}
public static void main(String[] args) {
DogPerson dogPerson = new DogPerson();
useSuperHearing(dogPerson);
superFind(dogPerson);
// You can do this:
List<? extends SuperHearing> audioPeople;
// But you can't do this:
// List<? extends SuperHearing & SuperSmell> dogPs;
}
}
```

Wildcards, which we shall investigate next, are limited to a single bound.

Wildcards

You've already seen some simple uses of *wildcards*—question marks in

generic argument expressions—in the Collections chapter and more in the Type Information chapter. This section will explore the feature

more deeply.

We'll start with an example that shows a particular behavior of arrays:

You can assign an array of a derived type to an array reference of the

base type:

```
// generics/CovariantArrays.java

class Fruit {}

class Apple extends Fruit {}

class Jonathan extends Apple {}

class Orange extends Fruit {}

public class CovariantArrays {

public static void main(String[] args) {

Fruit[] fruit = new Apple[10];

fruit[0] = new Apple(); // OK

fruit[1] = new Jonathan(); // OK

// Runtime type is Apple[], not Fruit[] or Orange[]:

try {

// Compiler allows you to add Fruit:
```

```
fruit[0] = new Fruit(); // ArrayStoreException
} catch(Exception e) { System.out.println(e); }
try {
// Compiler allows you to add Oranges:
fruit[0] = new Orange(); // ArrayStoreException
} catch(Exception e) { System.out.println(e); }
}
}
/* Output:
java.lang.ArrayStoreException: Fruit
java.lang.ArrayStoreException: Orange
*/
```

The first line in **main()** creates an array of **Apple** and assigns it to a reference to an array of **Fruit**. This makes sense—an **Apple** is a kind of **Fruit**, so an array of **Apple** should also be an array of **Fruit**.

However, if the actual array type is **Apple[]**, you can place an **Apple** or a subtype of **Apple** into the array, which in fact works at both compile time and run time. But you can also place a **Fruit** object into the array. This makes sense to the compiler, because it has

a **Fruit[]** reference—why shouldn't it allow a **Fruit** object, or anything descended from **Fruit**, such as **Orange**, to be placed into the array? So at compile time, this is allowed. The runtime array mechanism, however, knows it's dealing with an **Apple[]** and throws an exception when a foreign type is placed into the array.

"Upcast" is a misnomer here. What you're really doing is assigning one array to another. The array behavior is to hold other objects, but because we are able to upcast, it's clear that the array objects can preserve the rules about the type of objects they contain. It's as if the arrays are conscious of what they are holding, so between the compile-time checks and the runtime checks, you can't abuse them.

This arrangement for arrays is not so terrible, because you *do* find out at run time that you've inserted an improper type. But one of the primary goals of generics is to move such error detection to compile time. So what happens when we try to use generic collections instead of arrays?

```
// generics/NonCovariantGenerics.java
// {WillNotCompile}
import java.util.*;
public class NonCovariantGenerics {
```

```
// Compile Error: incompatible types:
List<Fruit> flist = new ArrayList<Apple>();
}
```

Although you might at first read this as saying, “You can’t assign a collection of **Apple** to a collection of **Fruit**,” remember that generics are not just about collections. What it’s really saying is, “You can’t assign a generic *involving* **Apple**s to a generic *involving* **Fruit**.” If, as in the case of arrays, the compiler knew enough about the code to determine that collections were involved, perhaps it could give some leeway. But it doesn’t know anything like that, so it refuses to allow the “upcast.” But it really isn’t an “upcast” anyway—a **List** of **Apple** is not a **List** of **Fruit**. A **List** of **Apple** will hold **Apple**s and subtypes of **Apple**, and a **List** of **Fruit** will hold any kind of **Fruit**. Yes, including **Apple**s, but that doesn’t make it a **List** of **Apple**; it’s still a **List** of **Fruit**. A **List** of **Apple** is not type-equivalent to a **List** of **Fruit**, even if an **Apple** is a type of **Fruit**.

The real issue is that we are talking about the type of the collection, rather than the type that the collection is holding. Unlike arrays, generics do not have built-in covariance. This is because arrays are completely defined in the language and can thus have both compile-time and runtime checks built in, but with generics, the compiler and

runtime system cannot know what to do with your types and what the rules should be.

Sometimes, however, you'd like to establish some kind of upcasting relationship between the two. Wildcards produce this relationship.

```
// generics/GenericsAndCovariance.java
import java.util.*;
public class GenericsAndCovariance {
public static void main(String[] args) {
// Wildcards allow covariance:
List<? extends Fruit> flist = new ArrayList<>();
// Compile Error: can't add any type of object:
// flist.add(new Apple());
// flist.add(new Fruit());
// flist.add(new Object());
flist.add(null); // Legal but uninteresting
// We know it returns at least Fruit:
Fruit f = flist.get(0);
}
}
```

The type of **flist** is now **List<? extends Fruit>** , which you can read as “a list of any type that’s inherited from **Fruit**.” This doesn’t actually mean that the **List** will hold any type of **Fruit**, however. The wildcard refers to a definite type, so it means “some specific type which the **flist** reference doesn’t specify.” So the **List** that’s assigned must hold some specified type such as **Fruit** or **Apple**, but to upcast to **flist**, that type is a “don’t actually care.”

The **List** must hold a specific **Fruit** or subtype of **Fruit**, but if you don’t actually care what it is, what can you do with such a **List**? If you don’t know what type the **List** is holding, how can you safely add an object? Just as with the “upcast” array in **CovariantArrays.java**, you can’t, except that the compiler prevents it from happening rather than the runtime system. You discover the problem sooner.

You might argue that things have gone a bit overboard, because now you can’t even add an **Apple** to a **List** you just said would hold **Apple**s. Yes, but the compiler doesn’t know that. A **List<?**

extends Fruit> could legally point to a **List<Orange>** . Once you do this kind of “upcast,” you lose the ability to pass anything in, even an **Object**.

On the other hand, if you call a method that returns **Fruit**, that’s safe because you know that anything in the **List** must at least be of type **Fruit**, so the compiler allows it.

How Smart is the Compiler?

Now, you might guess you are prevented from calling any methods that take arguments, but consider this:

```
// generics/CompilerIntelligence.java
import java.util.*;
public class CompilerIntelligence {
public static void main(String[] args) {
List<? extends Fruit> flist =
Arrays.asList(new Apple());
Apple a = (Apple)flist.get(0); // No warning
flist.contains(new Apple()); // Argument is 'Object'
flist.indexOf(new Apple()); // Argument is 'Object'
}
}
```

Here, calls to **contains()** and **indexOf()** take **Apple** objects as arguments, and those are just fine. Does this mean that the compiler actually examines the code to see if a particular method modifies its object?

By looking at the documentation for **ArrayList**, we find that the compiler is not that smart. While **add()** takes an argument of the generic parameter type, **contains()** and **indexOf()** take arguments of type **Object**. So when you specify an **ArrayList<? extends Fruit>** , the argument for **add()** becomes **? extends Fruit**. From that description, the compiler cannot know which specific subtype of **Fruit** is required there, so it won't accept any type of **Fruit**. It doesn't matter if you upcast the **Apple** to a **Fruit** first —the compiler simply refuses to call a method (such as **add()**) if a wildcard is involved in the argument list.

With **contains()** and **indexOf()**, the arguments are of type **Object**, so there are no wildcards involved and the compiler allows the call. This means it's up to the generic class designer to decide which calls are "safe," and to use **Object** types for their arguments. To disallow a call when the type is used with wildcards, use the type parameter in the argument list.

A very simple **Holder** class will demonstrate:

```
// generics/Holder.java
import java.util.Objects;
public class Holder<T> {
private T value;
public Holder() {}
public Holder(T val) { value = val; }
public void set(T val) { value = val; }
public T get() { return value; }
@Override
public boolean equals(Object o) {
return o instanceof Holder &&
Objects.equals(value, ((Holder)o).value);
}
@Override
public int hashCode() {
return Objects.hashCode(value);
}
public static void main(String[] args) {
Holder<Apple> apple = new Holder<>(new Apple());
```

```
Apple d = apple.get();
apple.set(d);
// Holder<Fruit> Fruit = apple; // Cannot upcast
Holder<? extends Fruit> fruit = apple; // OK
Fruit p = fruit.get();
d = (Apple)fruit.get(); // Returns 'Object'
try {
Orange c = (Orange)fruit.get(); // No warning
} catch(Exception e) { System.out.println(e); }
// fruit.set(new Apple()); // Cannot call set()
// fruit.set(new Fruit()); // Cannot call set()
System.out.println(fruit.equals(d)); // OK
}
}
/* Output:
java.lang.ClassCastException: Apple cannot be cast to
Orange
```

false

*/

Holder has a **set()** which takes a **T**, a **get()** which returns a **T**, and an **equals()** that takes an **Object**. As you've already seen, if

you create a **Holder<Apple>** , you cannot upcast it to a

Holder<Fruit> , but you can upcast to a **Holder<? extends**

Fruit> . If you call **get()**, it only returns a **Fruit**—that's as much as it knows given the "anything that extends **Fruit**" bound. If you

know more about what's there, you can cast to a specific type of

Fruit and there won't be any warning about it, but you risk a

ClassCastException. The **set()** method won't work with either

an **Apple** or a **Fruit**, because the **set()** argument is also "**?**

Extends Fruit," which means it can be anything and the compiler

can't verify type safety for "anything."

However, the **equals()** method works fine because it takes an

Object instead of a **T** as an argument. Thus, the compiler is only

paying attention to the types of objects that are passed and returned. It

is not analyzing the code to see if you perform any actual writes or

reads.

Java 7 introduced the **java.util.Objects** library for the

purpose, among other things, of making it easier to create **equals()**

and **hashCode()** methods. The canonical form of **equals()** shown here is described in the Appendix: Understanding **equals()** and **hashCode()**.

Contravariance

It's also possible to go the other way, and use *supertype wildcards*. Here, you say that the wildcard is bounded by any base class of a particular class, by specifying **<? super MyClass>** or even using a type parameter: **<? super T>** (although you cannot give a generic parameter a supertype bound; that is, you cannot say **<T super MyClass>**). This safely passes a typed object into a generic type. Thus, with supertype wildcards you can write into a **Collection**:

```
// generics/SuperTypeWildcards.java
import java.util.*;
public class SuperTypeWildcards {
static void writeTo(List<? super Apple> apples) {
apples.add(new Apple());
apples.add(new Jonathan());
// apples.add(new Fruit()); // Error
}
}
```

The argument **apples** is a **List** of some type that is the base type of **Apple**; thus you know it is safe to add an **Apple** or a subtype of **Apple**. Since the *lower bound* is **Apple**, however, you don't know it is safe to add **Fruit** to such a **List**, because that would allow the **List** to be opened up to the addition of non-**Apple** types, which would violate static type safety.

This example provides a review of covariance and wildcards:

```
// generics/GenericReading.java
import java.util.*;
public class GenericReading {
static List<Apple> apples =
Arrays.asList(new Apple());
static List<Fruit> fruit = Arrays.asList(new Fruit());
static <T> T readExact(List<T> list) {
return list.get(0);
}
// A static method adapts to each call:
static void f1() {
Apple a = readExact(apples);
Fruit f = readExact(fruit);
```

```
f = readExact(apples);
}
// A class type is established
// when the class is instantiated:
static class Reader<T> {
T readExact(List<T> list) { return list.get(0); }
}
static void f2() {
Reader<Fruit> fruitReader = new Reader<>();
Fruit f = fruitReader.readExact(fruit);
//- Fruit a = fruitReader.readExact(apples);
// error: incompatible types: List<Apple>
// cannot be converted to List<Fruit>
}
static class CovariantReader<T> {
T readCovariant(List<? extends T> list) {
return list.get(0);
}
}
static void f3() {
```

```
CovariantReader<Fruit> fruitReader =
new CovariantReader<>();
Fruit f = fruitReader.readCovariant(fruit);
Fruit a = fruitReader.readCovariant(apples);
}
public static void main(String[] args) {
f1(); f2(); f3();
}
}
```

readExact() uses the precise type. If you use the precise type with no wildcards, you can both write and read that precise type into and out of a **List**. In addition, for the return value, the **static** generic method **readExact()** effectively "adapts" to each method call, and returns an **Apple** from a **List<Apple>** and a **Fruit** from a

List<Fruit> , as you see in **f1()**. Thus, if you can get away with a **static** generic method, you don't necessarily need covariance if you're just reading.

With a generic class, however, the parameter is established for the class when you make an instance of that class. As shown in **f2()**, the **fruitReader** instance can read a piece of **Fruit** from a **List<Fruit>** , since that is its exact type. But a **List<Apple>** should also produce **Fruit** objects, and the **fruitReader** doesn't allow this.

To fix the problem, the **CovariantReader.readCovariant()** method takes a **List<? extends T>** . It's safe to read a **T** from that list because you know that everything in that list is at least a **T**, and possibly something derived from a **T**. In **f3()** you see it's now possible to read a **Fruit** from a **List<Apple>** .

Unbounded Wildcards

The *unbounded wildcard* **<?>** appears to mean "anything," and so using an unbounded wildcard looks equivalent to using a raw type. Indeed, the compiler seems at first to agree with this assessment:

```
// generics/UnboundedWildcards1.java
import java.util.*;
public class UnboundedWildcards1 {
static List list1;
static List<?> list2;
```

```
static List<? extends Object> list3;
static void assign1(List list) {
list1 = list;
list2 = list;
//- list3 = list;
// warning: [unchecked] unchecked conversion
// list3 = list;
// ^
// required: List<? extends Object>
// found: List
}
static void assign2(List<?> list) {
list1 = list;
list2 = list;
list3 = list;
}
static void assign3(List<? extends Object> list) {
list1 = list;
list2 = list;
list3 = list;
```

```
}
public static void main(String[] args) {
assign1(new ArrayList());
assign2(new ArrayList());
//- assign3(new ArrayList());
// warning: [unchecked] unchecked method invocation:
// method assign3 in class UnboundedWildcards1
// is applied to given types
// assign3(new ArrayList());
// ^
// required: List<? extends Object>
// found: ArrayList
// warning: [unchecked] unchecked conversion
// assign3(new ArrayList());
// ^
// required: List<? extends Object>
// found: ArrayList
// 2 warnings
assign1(new ArrayList<>());
assign2(new ArrayList<>());
```

```
assign3(new ArrayList<>());
// Both forms are acceptable as List<?>:
List<?> wildList = new ArrayList();
wildList = new ArrayList<>();
assign1(wildList);
assign2(wildList);
assign3(wildList);
}
}
```

There are many cases like the ones you see here where the compiler could care less whether you use a raw type or **<?>** . In those cases, **<?>** can be thought of as a decoration; and yet it is valuable because, in effect, it says, “I wrote this code with Java generics in mind, and I don’t mean here I’m using a raw type, but that in this case the generic parameter can hold any type.”

A second example shows an important use of unbounded wildcards. When you are dealing with multiple generic parameters, it’s sometimes necessary to allow one parameter to be any type while establishing a particular type for the other parameter:

```
// generics/UnboundedWildcards2.java
import java.util.*;
```

```
public class UnboundedWildcards2 {
static Map map1;
static Map<?,?> map2;
static Map<String,?> map3;
static void assign1(Map map) { map1 = map; }
static void assign2(Map<?,?> map) { map2 = map; }
static void assign3(Map<String,?> map) { map3 = map; }
public static void main(String[] args) {
assign1(new HashMap());
assign2(new HashMap());
//- assign3(new HashMap());
// warning: [unchecked] unchecked method invocation:
// method assign3 in class UnboundedWildcards2
// is applied to given types
// assign3(new HashMap());
// ^
// required: Map<String,?>
// found: HashMap
// warning: [unchecked] unchecked conversion
// assign3(new HashMap());
```

```
// ^
// required: Map<String,?>
// found: HashMap
// 2 warnings
assign1(new HashMap<>());
assign2(new HashMap<>());
assign3(new HashMap<>());
}
}
```

But again, when you have all unbounded wildcards, as seen in **Map<?,?>** , the compiler doesn't seem to distinguish it from a raw **Map**. In addition, **UnboundedWildcards1.java** shows that the compiler treats **List<?>** and **List<? extends Object>** differently.

What's confusing is that the compiler doesn't always care about differences between, for example, **List** and **List<?>** , so they can seem like the same thing. Indeed, since a generic argument erases to its first bound, **List<?>** would seem equivalent to **List<Object>** , and **List** is effectively **List<Object>** as well—except neither of those statements is exactly true. **List** actually means "a raw **List** that holds any **Object** type," whereas **List<?>** means "a non-raw

List of *some specific type*, but we just don’t know what that type is.” When does the compiler actually care about differences between raw types and types involving unbounded wildcards? The following example uses the previously defined **Holder<T>** class. It contains methods that take **Holder** as an argument, but in various forms: as a raw type, with a specific type parameter, and with an unbounded wildcard parameter:

```
// generics/Wildcards.java
// Exploring the meaning of wildcards
public class Wildcards {
// Raw argument:
static void rawArgs(Holder holder, Object arg) {
//- holder.set(arg);
// warning: [unchecked] unchecked call to set(T)
// as a member of the raw type Holder
// holder.set(arg);
// ^
// where T is a type-variable:
// T extends Object declared in class Holder
// 1 warning
```

```
// Can't do this; don't have any 'T':
// T t = holder.get();
// OK, but type information is lost:
Object obj = holder.get();
}
// Like rawArgs(), but errors instead of warnings:
static void
unboundedArg(Holder<?> holder, Object arg) {
//- holder.set(arg);
// error: method set in class Holder<T>
// cannot be applied to given types;
// holder.set(arg);
// ^
// required: CAP#1
// found: Object
// reason: argument mismatch;
// Object cannot be converted to CAP#1
// where T is a type-variable:
// T extends Object declared in class Holder
// where CAP#1 is a fresh type-variable:
```

```
// CAP#1 extends Object from capture of ?
// 1 error
// Can't do this; don't have any 'T':
// T t = holder.get();
// OK, but type information is lost:
Object obj = holder.get();
}
static <T> T exact1(Holder<T> holder) {
return holder.get();
}
static <T> T exact2(Holder<T> holder, T arg) {
holder.set(arg);
return holder.get();
}
static <T>
T wildSubtype(Holder<? extends T> holder, T arg) {
//- holder.set(arg);
// error: method set in class Holder<T#2>
// cannot be applied to given types;
// holder.set(arg);
```

```
// ^
// required: CAP#1
// found: T#1
// reason: argument mismatch;
// T#1 cannot be converted to CAP#1
// where T#1,T#2 are type-variables:
// T#1 extends Object declared in method
// <T#1>wildSubtype(Holder<? extends T#1>,T#1)
// T#2 extends Object declared in class Holder
// where CAP#1 is a fresh type-variable:
// CAP#1 extends T#1 from
// capture of ? extends T#1
// 1 error
return holder.get();
}
static <T>
void wildSupertype(Holder<? super T> holder, T arg) {
holder.set(arg);
//- T t = holder.get();
// error: incompatible types:
```

```
// CAP#1 cannot be converted to T
// T t = holder.get();
// ^
// where T is a type-variable:
// T extends Object declared in method
// <T>wildSupertype(Holder<? super T>,T)
// where CAP#1 is a fresh type-variable:
// CAP#1 extends Object super:
// T from capture of ? super T
// 1 error
// OK, but type information is lost:
Object obj = holder.get();
}
public static void main(String[] args) {
Holder raw = new Holder<>();
// Or:
raw = new Holder();
Holder<Long> qualified = new Holder<>();
Holder<?> unbounded = new Holder<>();
Holder<? extends Long> bounded = new Holder<>();
```

```
Long lng = 1L;
rawArgs(raw, lng);
rawArgs(qualified, lng);
rawArgs(unbounded, lng);
rawArgs(bounded, lng);
unboundedArg(raw, lng);
unboundedArg(qualified, lng);
unboundedArg(unbounded, lng);
unboundedArg(bounded, lng);
//- Object r1 = exact1(raw);
// warning: [unchecked] unchecked method invocation:
// method exact1 in class Wildcards is applied
// to given types
// Object r1 = exact1(raw);
// ^
// required: Holder<T>
// found: Holder
// where T is a type-variable:
// T extends Object declared in
// method <T>exact1(Holder<T>)
```

// warning: [unchecked] unchecked conversion

// Object r1 = exact1(raw);

// ^

// required: Holder<T>

// found: Holder

// where T is a type-variable:

// T extends Object declared in

// method <T>exact1(Holder<T>)

// 2 warnings

Long r2 = exact1(qualified);

Object r3 = exact1(unbounded); *// Must return Object*

Long r4 = exact1(bounded);

//- Long r5 = exact2(raw, lng);

// warning: [unchecked] unchecked method invocation:

// method exact2 in class Wildcards is

// applied to given types

// Long r5 = exact2(raw, lng);

// ^

// required: Holder<T>,T

// found: Holder,Long

// where T is a type-variable:

// T extends Object declared in

// method <T>exact2(Holder<T>,T)

// warning: [unchecked] unchecked conversion

// Long r5 = exact2(raw, lng);

// ^

// required: Holder<T>

// found: Holder

// where T is a type-variable:

// T extends Object declared in

// method <T>exact2(Holder<T>,T)

// 2 warnings

Long r6 = exact2(qualified, lng);

//- Long r7 = exact2(unbounded, lng);

// error: method exact2 in class Wildcards

// cannot be applied to given types;

// Long r7 = exact2(unbounded, lng);

// ^

// required: Holder<T>,T

// found: Holder<CAP#1>,Long

// reason: inference variable T has

// incompatible bounds

// equality constraints: CAP#1

// lower bounds: Long

// where T is a type-variable:

// T extends Object declared in

// method <T>exact2(Holder<T>,T)

// where CAP#1 is a fresh type-variable:

// CAP#1 extends Object from capture of ?

// 1 error

//- Long r8 = exact2(bounded, lng);

// error: method exact2 in class Wildcards

// cannot be applied to given types;

// Long r8 = exact2(bounded, lng);

// ^

// required: Holder<T>,T

// found: Holder<CAP#1>,Long

// reason: inference variable T

// has incompatible bounds

// equality constraints: CAP#1

// lower bounds: Long

// where T is a type-variable:

// T extends Object declared in

// method <T>exact2(Holder<T>,T)

// where CAP#1 is a fresh type-variable:

// CAP#1 extends Long from

// capture of ? extends Long

// 1 error

//- Long r9 = wildSubtype(raw, lng);

// warning: [unchecked] unchecked method invocation:

// method wildSubtype in class Wildcards

// is applied to given types

// Long r9 = wildSubtype(raw, lng);

// ^

// required: Holder<? extends T>,T

// found: Holder,Long

// where T is a type-variable:

// T extends Object declared in

// method <T>wildSubtype(Holder<? extends T>,T)

// warning: [unchecked] unchecked conversion

// Long r9 = wildSubtype(raw, lng);

// ^

// required: Holder<? extends T>

// found: Holder

// where T is a type-variable:

// T extends Object declared in

// method <T>wildSubtype(Holder<? extends T>,T)

// 2 warnings

Long r10 = wildSubtype(qualified, lng);

// OK, but can only return Object:

Object r11 = wildSubtype(unbounded, lng);

Long r12 = wildSubtype(bounded, lng);

//- wildSupertype(raw, lng);

// warning: [unchecked] unchecked method invocation:

// method wildSupertype in class Wildcards

// is applied to given types

// wildSupertype(raw, lng);

// ^

// required: Holder<? super T>,T

// found: Holder,Long

```
// where T is a type-variable:
// T extends Object declared in
// method <T>wildSupertype(Holder<? super T>,T)
// warning: [unchecked] unchecked conversion
// wildSupertype(raw, lng);
// ^
// required: Holder<? super T>
// found: Holder
// where T is a type-variable:
// T extends Object declared in
// method <T>wildSupertype(Holder<? super T>,T)
// 2 warnings
wildSupertype(qualified, lng);
//- wildSupertype(unbounded, lng);
// error: method wildSupertype in class Wildcards
// cannot be applied to given types;
// wildSupertype(unbounded, lng);
// ^
// required: Holder<? super T>,T
// found: Holder<CAP#1>,Long
```

// reason: cannot infer type-variable(s) T

// (argument mismatch; Holder<CAP#1>

// cannot be converted to Holder<? super T>)

// where T is a type-variable:

// T extends Object declared in

// method <T>wildSupertype(Holder<? super T>,T)

// where CAP#1 is a fresh type-variable:

// CAP#1 extends Object from capture of ?

// 1 error

//- wildSupertype(bounded, lng);

// error: method wildSupertype in class Wildcards

// cannot be applied to given types;

// wildSupertype(bounded, lng);

// ^

// required: Holder<? super T>,T

// found: Holder<CAP#1>,Long

// reason: cannot infer type-variable(s) T

// (argument mismatch; Holder<CAP#1>

// cannot be converted to Holder<? super T>)

// where T is a type-variable:

// T extends Object declared in

// method <T>wildSupertype(Holder<? super T>,T)

// where CAP#1 is a fresh type-variable:

// CAP#1 extends Long from capture of

// ? extends Long

// 1 error

}

}

In **rawArgs()**, the compiler knows that **Holder** is a generic type, so even though it is expressed as a raw type here, the compiler knows that passing an **Object** to **set()** is unsafe. Since it's a raw type, you can pass an object of any type into **set()**, and that object is upcast to **Object**. So anytime you have a raw type, you give up compile-time checking. The call to **get()** shows the same issue: There's no **T**, so the result can only be an **Object**.

It's easy to start thinking that a raw **Holder** and a **Holder<?>** are roughly the same thing. But **unboundedArg()** emphasizes that they are different—it discovers the same kind of problems, but reports them as errors rather than warnings, because the raw **Holder** will hold a combination of any types, whereas a **Holder<?>** holds a

homogeneous collection of *some specific type*, and thus you can't just pass in an **Object**.

In **exact1()** and **exact2()**, you see the exact generic parameters used—no wildcards. You'll see that **exact2()** has different limitations than **exact1()**, because of the extra argument.

In **wildSubtype()**, the constraints on the type of **Holder** are relaxed to include a **Holder** of anything that **extends T**. Again, this means **T** could be **Fruit**, while **holder** could legitimately be a **Holder<Apple>** . To prevent putting an **Orange** in a **Holder<Apple>** , the call to **set()** (or any method that takes an argument of the type parameter) is disallowed. However, you still know that anything that comes out of a **Holder<? extends Fruit>** will at least be **Fruit**, so **get()** (or any method that produces a return value of the type parameter) is allowed.

Supertype wildcards are shown in **wildSupertype()**, which shows the opposite behavior of **wildSubtype()**: **holder** can be a collection that holds any type that's a base class of **T**. Thus, **set()** can accept a **T**, since anything that works with a base type will polymorphically work with a derived type (thus a **T**). However, trying to call **get()** is not helpful, because the type held by **holder** can be

any supertype at all, so the only safe one is **Object**.

This example also shows the limitations on what you can and can't do with an unbounded parameter in **unbounded()**: You can't **get()** or **set()** a **T** because you don't have a **T**.

In **main()** you see which of these methods can accept which types of arguments without errors and warnings. For migration compatibility, **rawArgs()** will take all the different variations of **Holder** without producing warnings. The **unboundedArg()** method is equally accepting of all types, although, as previously noted, it handles them

differently inside the body of the method.

If you pass a raw **Holder** reference into a method that takes an "exact" generic type (no wildcards), you get a warning because the exact argument is expecting information that doesn't exist in the raw type. And if you pass an unbounded reference to **exact1()**, there's no type information to establish the return type.

exact2() has the most constraints, since it wants exactly a **Holder<T>** and an argument of type **T**, and because of this it

generates errors or warnings unless you give it the exact arguments. Sometimes this is OK, but if it's overconstraining, you can use wildcards, depending on whether you get typed return values from your generic argument (as seen in **wildSubtype()**) or you pass typed arguments to your generic argument (as seen in **wildSupertype()**).

The benefit of using exact types instead of wildcard types is that you can do more with the generic parameters. But wildcards accepts a broader range of parameterized types as arguments. You must decide which trade-off is more appropriate for your needs on a case-by-case basis.

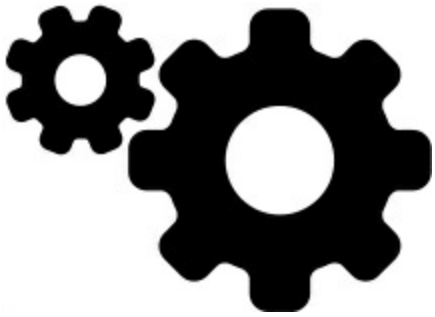
Capture Conversion

One situation in particular *requires* **<?>** rather than a raw type. If you pass a raw type to a method that uses **<?>** , it's possible for the compiler to infer the actual type parameter, so the method can turn around and call another method that uses the exact type. The following example demonstrates this technique, called *capture conversion* because the unspecified wildcard type is captured and converted to an exact type. Here, the comments about warnings only take effect when the **@SuppressWarnings** annotation is removed:

// generics/CaptureConversion.java

```
public class CaptureConversion {
static <T> void f1(Holder<T> holder) {
T t = holder.get();
System.out.println(t.getClass().getSimpleName());
}
static void f2(Holder<?> holder) {
f1(holder); // Call with captured type
}
@SuppressWarnings("unchecked")
public static void main(String[] args) {
Holder raw = new Holder<>(1);
f1(raw);
// warning: [unchecked] unchecked method invocation:
// method f1 in class CaptureConversion
// is applied to given types
// f1(raw);
// ^
// required: Holder<T>
// found: Holder
// where T is a type-variable:
```

```
// T extends Object declared in
// method <T>f1(Holder<T>)
// warning: [unchecked] unchecked conversion
// f1(raw);
// ^
// required: Holder<T>
// found: Holder
// where T is a type-variable:
// T extends Object declared in
// method <T>f1(Holder<T>)
// 2 warnings
f2(raw); // No warnings
Holder rawBasic = new Holder();
rawBasic.set(new Object());
// warning: [unchecked] unchecked call to set(T)
// as a member of the raw type Holder
// rawBasic.set(new Object());
// ^
```



// where T is a type-variable:

// T extends Object declared in class Holder

// 1 warning

f2(rawBasic); *// No warnings*

// Upcast to Holder<?>, still figures it out:

Holder<?> wildcarded = **new** Holder<>(1.0);

f2(wildcarded);

}

}

/ Output:*

Integer

Integer

Object

Double

**/*

The type parameters in **f1()** are all exact, without wildcards or

bounds. In **f2()**, the **Holder** parameter is an unbounded wildcard, so it would seem to be effectively unknown. However, within **f2()**, **f1()** is called and **f1()** requires a known parameter. What's happening is that the parameter type is captured in the process of calling **f2()**, and used in the call to **f1()**.

You might wonder if this technique could be used for writing, but that would require you to pass a specific type along with the **Holder<?>** . Capture conversion only works in situations where, within the method, you must work with the exact type. Notice you can't return **T** from **f2()**, because **T** is unknown for **f2()**. Capture conversion is interesting, but limited.

Issues

This section addresses an assorted set of issues that appear when you use Java generics.

No Primitives as Type Parameters

As mentioned earlier in this chapter, one of the limitations in Java

generics is you cannot use primitives as type parameters. So you cannot, for example, create an **ArrayList<int>** .

The solution is to use the primitive wrapper classes in conjunction with autoboxing. If you create an **ArrayList<Integer>** and use primitive **int**s with this collection, you'll discover that autoboxing does the conversion to and from **Integer** automatically—so it's almost as if you have an **ArrayList<int>** :

```
// generics/ListOfInt.java
// Autoboxing compensates for the inability
// to use primitives in generics
import java.util.*;
import java.util.stream.*;
public class ListOfInt {
public static void main(String[] args) {
List<Integer> li = IntStream.range(38, 48)
.boxed() // Converts ints to Integers
.collect(Collectors.toList());
System.out.println(li);
}
}
```

```
/* Output:
[38, 39, 40, 41, 42, 43, 44, 45, 46, 47]
*/
```

In general this solution works fine—you're able to successfully store and retrieve **int**s, and autoboxing hides the conversions. However, if performance is a problem, you can use a specialized version of the collections adapted for primitive types; one open-source version of this is **org.apache.commons.collections.primitives**.

Here's another approach, which creates a **Set** of **Byte**s:

```
// generics/ByteSet.java
import java.util.*;
public class ByteSet {
Byte[] possibles = { 1,2,3,4,5,6,7,8,9 };
Set<Byte> mySet =
new HashSet<>(Arrays.asList(possibles));
// But you can't do this:
// Set<Byte> mySet2 = new HashSet<>(
// Arrays.<Byte>asList(1,2,3,4,5,6,7,8,9));
}
```

Autoboxing solves some problems, but not all.

In the following example, the **FillArray interface** contains generic methods that use **Supplier**s to fill arrays with objects (making the *class* generic wouldn't work here because the method is **static**). The **Supplier** implementations come from the Arrays chapter, and in **main()** you see **FillArray.fill()** used to fill arrays with objects:

```
// generics/PrimitiveGenericTest.java
import onjava.*;
import java.util.*;
import java.util.function.*;
// Fill an array using a generator:
interface FillArray {
static <T> T[] fill(T[] a, Supplier<T> gen) {
Arrays.setAll(a, n -> gen.get());
return a;
}
static int[] fill(int[] a, IntSupplier gen) {
Arrays.setAll(a, n -> gen.getAsInt());
return a;
```

```
}
static long[] fill(long[] a, LongSupplier gen) {
Arrays.setAll(a, n -> gen.getAsLong());
return a;
}
static double[] fill(double[] a, DoubleSupplier gen) {
Arrays.setAll(a, n -> gen.getAsDouble());
return a;
}
}
public class PrimitiveGenericTest {
public static void main(String[] args) {
String[] strings = FillArray.fill(
new String[5], new Rand.String(9));
System.out.println(Arrays.toString(strings));
int[] integers = FillArray.fill(
new int[9], new Rand.Pint());
```

```
System.out.println(Arrays.toString(integers));
}
}
/* Output:
[btpenpccu, xszgvgmei, nneeloztd, vewcippcy, gpoalkljl]
[635, 8737, 3941, 4720, 6177, 8479, 6656, 3768, 4948]
*/
```

Autoboxing doesn't apply to arrays, so we have to create overloaded versions of **FillArray.fill()**, or create generators that produced the Wrapped output.

FillArray is only slightly more useful than **java.util.Arrays.setAll()** because it returns the filled array.

Implementing Parameterized Interfaces

A class cannot implement two variants of the same generic interface. Because of erasure, these are both the same interface. Here's a

situation where this clash occurs:

```
// generics/MultipleInterfaceVariants.java
// {WillNotCompile}
package generics;
interface Payable<T> {}
class Employee implements Payable<Employee> {}
class Hourly extends Employee
implements Payable<Hourly> {}
```

Hourly won’t compile because erasure reduces **Payable<Employee>** and **Payable<Hourly>** to the same class, **Payable**, and the above code would mean that you’d be implementing the same interface twice. If you remove the generic parameters from both uses of **Payable**—as the compiler does during erasure—the code compiles.

This issue becomes annoying when working with some of the more fundamental Java interfaces, such as **Comparable<T>** , as you’ll see a little later in this section.

Casting and Warnings

Using a cast or **instanceof** with a generic type parameter doesn’t have any effect. The following collection stores values internally as

Objects and casts them back to **T** when you fetch them:

```
// generics/GenericCast.java
import java.util.*;
import java.util.stream.*;
class FixedSizeStack<T> {
private final int size;
private Object[] storage;
private int index = 0;
FixedSizeStack(int size) {
this.size = size;
storage = new Object[size];
}
public void push(T item) {
if(index < size)
storage[index++] = item;
}
@SuppressWarnings("unchecked")
public T pop() {
return index == 0 ? null : (T)storage[--index];
}
```

```
@SuppressWarnings("unchecked")
Stream<T> stream() {
return (Stream<T>)Arrays.stream(storage);
}
}
public class GenericCast {
static String[] letters =
"ABCDEFGHIJKLMNOPQRS".split("");
public static void main(String[] args) {
FixedSizeStack<String> strings =
new FixedSizeStack<>(letters.length);
Arrays.stream("ABCDEFGHIJKLMNOPQRS".split(""))
.forEach(strings::push);
System.out.println(strings.pop());
strings.stream()
.map(s -> s + " ")
.forEach(System.out::print);
}
}
/* Output:
```

S

A B C D E F G H I J K L M N O P Q R S

/

Without the **@SuppressWarnings** annotations, the compiler will produce an “unchecked cast” warning for **pop()** and **stream()**. Because of erasure, it can’t know whether the cast is safe. **T** is erased to its first bound, **Object** by default, so **pop()** is actually just casting an **Object** to an **Object**.

There are times when generics do not eliminate the need to cast, and this generates a warning by the compiler which is inappropriate. For example:

```
// generics/NeedCasting.java
import java.io.*;
import java.util.*;
public class NeedCasting {
@SuppressWarnings("unchecked")
public void f(String[] args) throws Exception {
ObjectInputStream in = new ObjectInputStream(
new FileInputStream(args[0]));
List<Widget> shapes = (List<Widget>)in.readObject();
```

}

}

As you'll learn in the Appendix: Object Serialization, **readObject()** cannot know what it is reading, so it returns an **Object** that must be

cast. But when you comment out the **@SuppressWarnings**

annotation and compile the program, you get a warning:

NeedCasting.java uses unchecked or unsafe operations.

Recompile with -Xlint:unchecked **for** details.

And if you follow the instructions and recompile with **-**

Xlint:unchecked:

NeedCasting.java:10: warning: [unchecked] unchecked cast

List<Widget> shapes = (List<Widget>)in.readObject();

^

required: List<Widget>

found: Object

1 warning

You're forced to cast, and yet you're told not to. To solve the problem,

you must use a form of cast introduced in Java 5, the cast via a generic class:

```
// generics/ClassCasting.java
import java.io.*;
import java.util.*;
public class ClassCasting {
@SuppressWarnings("unchecked")
public void f(String[] args) throws Exception {
ObjectInputStream in = new ObjectInputStream(
new FileInputStream(args[0]));
// Won't Compile:
// List<Widget> lw1 =
// List<>.class.cast(in.readObject());
List<Widget> lw2 = List.class.cast(in.readObject());
}
}
```

However, you can’t cast to the actual type (**List<Widget>**). That is, you can’t say:

```
List<Widget>.class.cast(in.readObject())
```

and even if you add another cast like this:

(List<Widget>)List.class.cast(in.readObject())

you'll still get a warning.

Overloading

This won't compile, even though it seems reasonable:

```
// generics/UseList.java
// {WillNotCompile}
import java.util.*;
public class UseList<W, T> {
void f(List<T> v) {}
void f(List<W> v) {}
}
```

Overloading the method produces the identical type signature because of erasure.

Instead, you must provide distinct method names when the erased arguments do not produce a unique argument list:

```
// generics/UseList2.java
import java.util.*;
```

```
public class UseList2<W, T> {
void f1(List<T> v) {}
void f2(List<W> v) {}
}
```

Fortunately, this kind of problem is detected by the compiler.

Base Class Hijacks an Interface

Suppose you have a **Pet** class that is **Comparable** to other **Pet** objects:

```
// generics/ComparablePet.java
public class ComparablePet
implements Comparable<ComparablePet> {
@Override
public int compareTo(ComparablePet arg) {
return 0;
}
}
```

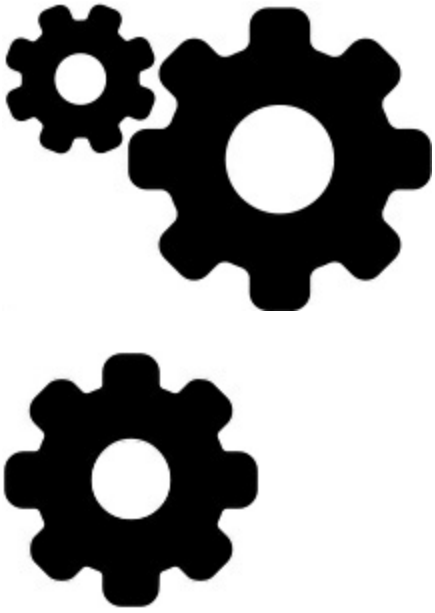
It makes sense to try to narrow the comparison type for a subclass of **ComparablePet**. For example, a **Cat** should only be **Comparable** with other **Cat**s:

```
// generics/HijackedInterface.java
// {WillNotCompile}
class Cat
extends ComparablePet implements Comparable<Cat>{
// error: Comparable cannot be inherited with
// different arguments: <Cat> and <ComparablePet>
// class Cat
// ^
// 1 error
public int compareTo(Cat arg) { return 0; }
}
```

Unfortunately, this won't work. Once the **ComparablePet** argument is established for **Comparable**, no other implementing class can ever be compared to anything but a **ComparablePet**:

```
// generics/RestrictedComparablePets.java
class Hamster extends ComparablePet
implements Comparable<ComparablePet> {
public int compareTo(ComparablePet arg) {
return 0;
}
```

```
}
// Or just:
class Gecko extends ComparablePet {
public int compareTo(ComparablePet arg) {
return 0;
}
```



```
}
```

Hamster shows it is possible to reimplement the same interface that is in **ComparablePet**, as long as it is exactly the same, including the parameter types. However, this is the same as just overriding the methods in the base class, as seen in **Gecko**.

Self-Bounded Types

There's one rather mind-bending idiom that appears periodically in

Java generics. Here’s what it looks like:

class SelfBounded<T **extends** SelfBounded<T>> { // ...

This has the dizzying effect of two mirrors pointed at each other, a kind of infinite reflection. The class **SelfBounded** takes a generic argument **T**, **T** is constrained by a bound, and that bound is **SelfBounded**, with **T** as an argument.

This is difficult to parse when you first see it, and it emphasizes that the **extends** keyword, when used with bounds, is definitely different than when it is used to create subclasses.

Curiously Recurring Generics

To understand what a self-bounded type means, let’s start with a simpler version of the idiom, without the self-bound.

You can’t inherit directly from a generic parameter. However, you *can* inherit from a class that uses that generic parameter in its own definition. That is, you can say:

// generics/CuriouslyRecurringGeneric.java

class GenericType<T> {}

public class CuriouslyRecurringGeneric

extends GenericType<CuriouslyRecurringGeneric> {}

This could be called *curiously recurring generics* (CRG) after Jim

Coplien's *Curiously Recurring Template Pattern* in C++. The "curiously recurring" part refers to the fact that your class appears, rather curiously, in its own base class.

To understand what this means, try saying it aloud: "I'm creating a new class that inherits from a generic type that takes my class name as its parameter." What can the generic base type accomplish when given the derived class name? Well, generics in Java are about arguments and return types, so it can produce a base class that uses the derived type for its arguments and return types. It can also use the derived type for field types, even though those are erased to **Object**. Here's a generic class that expresses this:

```
// generics/BasicHolder.java
public class BasicHolder<T> {
T element;
void set(T arg) { element = arg; }
T get() { return element; }
void f() {
System.out.println(
element.getClass().getSimpleName());
}
```

}

It’s an ordinary generic type with methods that both accept and produce objects of the parameter type, along with a method that operates on the stored field (although it only performs **Object** operations on that field).

We can use **BasicHolder** in a curiously recurring generic:

```
// generics/CRGWithBasicHolder.java
class Subtype extends BasicHolder<Subtype> {}
public class CRGWithBasicHolder {
public static void main(String[] args) {
Subtype
st1 = new Subtype(),
st2 = new Subtype();
st1.set(st2);
Subtype st3 = st1.get();
st1.f();
}
```

}

/ *Output:*

Subtype

**/*

Notice something important here: The new class **Subtype** takes arguments and returns values of **Subtype**, not just the base class **BasicHolder**. This is the essence of CRG: *The base class substitutes the derived class for its parameters*. This means the generic base class becomes a kind of template for common functionality for all its derived classes, but this functionality will use the derived type for all of its arguments and return values. That is, the exact type instead of the base type is used in the resulting class. So in **Subtype**, both the argument to **set()** and the return type of **get()** are exactly **Subtype**s.

Self-Bounding

The **BasicHolder** can use any type as its generic parameter, as seen here:

// generics/Unconstrained.java

class Other {}

class BasicOther **extends** BasicHolder<Other> {}

```
public class Unconstrained {
public static void main(String[] args) {
BasicOther b = new BasicOther();
BasicOther b2 = new BasicOther();
b.set(new Other());
Other other = b.get();
b.f();
}
}
/* Output:
Other
*/
```

Self-bounding takes the extra step of *forcing* the generic to be used as its own bound argument. Look at how the resulting class can and can't be used:

```
// generics/SelfBounding.java
class SelfBounded<T extends SelfBounded<T>> {
T element;
SelfBounded<T> set(T arg) {
element = arg;
```

```
return this;
}
T get() { return element; }
}
class A extends SelfBounded<A> {}
class B extends SelfBounded<A> {} // Also OK
class C extends SelfBounded<C> {
C setAndGet(C arg) { set(arg); return get(); }
}
class D {}
// Can't do this:
// class E extends SelfBounded<D> {}
// Compile error:
// Type parameter D is not within its bound
// Alas, you can do this, so you cannot force the idiom:
class F extends SelfBounded {}
public class SelfBounding {
public static void main(String[] args) {
A a = new A();
a.set(new A());
```

```
a = a.set(new A()).get();
a = a.get();
C c = new C();
c = c.setAndGet(new C());
}
}
```

What self-bounding does is require the class in an inheritance relationship:

```
class A extends SelfBounded<A> {}
```

This forces you to pass the class you are defining as a parameter to the base class.

What's the added value in self-bounding the parameter? The type parameter must be the same as the class being defined. As you see in the definition of class **B**, you can also derive from a **SelfBounded** that uses a parameter of another **SelfBounded**, although the predominant use seems to be the one you see for class **A**. The attempt to define **E** shows you cannot use a type parameter that is not a **SelfBounded**.

Unfortunately, **F** compiles without warnings, so the self-bounding idiom is not enforceable. If it's really important, it can require an

external tool to ensure that raw types are not used in place of parameterized types.

Notice you can remove the constraint and all the classes will still compile, but **E** will also compile:

```
// generics/NotSelfBounded.java
public class NotSelfBounded<T> {
T element;
NotSelfBounded<T> set(T arg) {
element = arg;
return this;
}
T get() { return element; }
}
class A2 extends NotSelfBounded<A2> {}
class B2 extends NotSelfBounded<A2> {}
class C2 extends NotSelfBounded<C2> {
C2 setAndGet(C2 arg) { set(arg); return get(); }
}
class D2 {}
// Now this is OK:
```

class E2 **extends** NotSelfBounded<D2> {}

Clearly, the self-bounding constraint serves only to force the inheritance relationship. If you use self-bounding, you know that the type parameter used by the class is the same basic type as the class that's using that parameter. It forces anyone using that class to follow that form.

It's also possible to use self-bounding for generic methods:

// generics/SelfBoundingMethods.java

public class SelfBoundingMethods {

static <T **extends** SelfBounded<T>> T f(T arg) {

return arg.set(arg).get();

}

public static void main(String[] args) {

A a = f(**new** A());

}

}

This prevents the method from being applied to anything but a self-

bounded argument of the form shown.

Argument Covariance

The value of self-bounding types is that they produce *covariant argument types*—method argument types vary to follow the subclasses.

Although self-bounding types also produce return types that are the same as the subclass type, this is not so important because *covariant return types* were introduced in Java 5:

```
// generics/CovariantReturnTypes.java
class Base {}
class Derived extends Base {}
interface OrdinaryGetter {
Base get();
}
interface DerivedGetter extends OrdinaryGetter {
// Overridden method return type can vary:
@Override
Derived get();
}
public class CovariantReturnTypes {
```

```
void test(DerivedGetter d) {
Derived d2 = d.get();
}
}
```

The **get()** method in **DerivedGetter** overrides **get()** in **OrdinaryGetter** *and* returns a type that is derived from the type returned by **OrdinaryGetter.get()**. Although this is perfectly logical—a derived type method can return a more specific type than the base type method it's overriding—it was illegal in earlier versions of Java.

A self-bounded generic does in fact produce the exact derived type as a return value, as seen here with **get()**:

```
// generics/GenericsAndReturnTypes.java
interface GenericGetter<T extends GenericGetter<T>> {
T get();
}
interface Getter extends GenericGetter<Getter> {}
public class GenericsAndReturnTypes {
void test(Getter g) {
Getter result = g.get();
```

```
GenericGetter gg = g.get(); // Also the base type
}
}
```

Notice this code would not have compiled unless covariant return types had been added in Java 5.

In non-generic code, however, the *argument* types cannot be made to vary with the subtypes:

```
// generics/OrdinaryArguments.java
class OrdinarySetter {
void set(Base base) {
System.out.println("OrdinarySetter.set(Base)");
}
}
class DerivedSetter extends OrdinarySetter {
void set(Derived derived) {
System.out.println("DerivedSetter.set(Derived)");
}
}
public class OrdinaryArguments {
public static void main(String[] args) {
```

```
Base base = new Base();
Derived derived = new Derived();
DerivedSetter ds = new DerivedSetter();
ds.set(derived);
// Compiles--overloaded, not overridden!:
ds.set(base);
}
}
/* Output:
DerivedSetter.set(Derived)
OrdinarySetter.set(Base)
*/
```

Both **set(derived)** and **set(base)** are legal, so **DerivedSetter.set()** is not overriding **OrdinarySetter.set()**, but instead it is *overloading* that method. The output shows there are two methods in **DerivedSetter**, so the base-class version is still available, thus verifying it was overloaded.

However, with self-bounding types, there is only one method in the derived class, and that method takes the derived type as its argument,

not the base type:

```
// generics/SelfBoundingAndCovariantArguments.java
interface
SelfBoundSetter<T extends SelfBoundSetter<T>> {
void set(T arg);
}
interface Setter extends SelfBoundSetter<Setter> {}
public class SelfBoundingAndCovariantArguments {
void
testA(Setter s1, Setter s2, SelfBoundSetter sbs) {
s1.set(s2);
//- s1.set(sbs);
// error: method set in interface SelfBoundSetter<T>
// cannot be applied to given types;
// s1.set(sbs);
// ^
// required: Setter
// found: SelfBoundSetter
// reason: argument mismatch;
// SelfBoundSetter cannot be converted to Setter
```

// where T is a type-variable:

// T extends SelfBoundSetter<T> declared in

// interface SelfBoundSetter

// 1 error

}

}

The compiler doesn’t recognize the attempt to pass in the base type as an argument to **set()**, because there is no method with that signature. The argument has, in effect, been overridden.

Without self-bounding, the ordinary inheritance mechanism steps in and you get overloading, just as with the non-generic case:

// generics/PlainGenericInheritance.java

class GenericSetter<T> { *// Not self-bounded*

void set(T arg) {

System.out.println("GenericSetter.set(Base)");

}

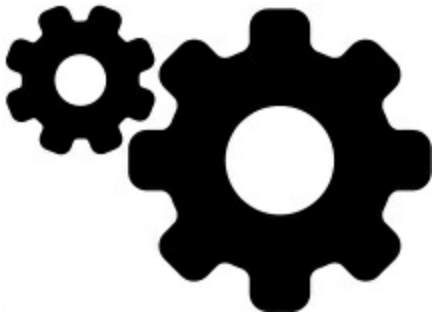
}

class DerivedGS **extends** GenericSetter<Base> {

void set(Derived derived) {

System.out.println("DerivedGS.set(Derived)");

```
}
}
public class PlainGenericInheritance {
public static void main(String[] args) {
Base base = new Base();
```



```
Derived derived = new Derived();
DerivedGS dgs = new DerivedGS();
dgs.set(derived);
dgs.set(base); // Overloaded, not overridden!
}
}
/* Output:
DerivedGS.set(Derived)
GenericSetter.set(Base)
*/
```

This code mimics **OrdinaryArguments.java**; in that example,

DerivedSetter inherits from **OrdinarySetter** which contains a **set(Base)**. Here, **DerivedGS** inherits from **GenericSetter<Base>** which also contains a **set(Base)**, created by the generic. And just like **OrdinaryArguments.java**, the output shows that **DerivedGS** contains two overloaded versions of **set()**. Without self-bounding, you overload on argument types. If you use self-bounding, you only end up with one version of a method, which takes the exact argument type.

Dynamic Type Safety

Because you can pass generic collections to pre-Java 5 code, there's still the possibility that old-style code can corrupt your collections. Java 5 added a set of utilities in **java.util.Collections** to solve the type-checking problem in this situation: the **static** methods **checkedCollection()**, **checkedList()**, **checkedMap()**, **checkedSet()**, **checkedSortedMap()** and **checkedSortedSet()**. Each of these takes the collection to dynamically check as the first argument and the type to enforce as the second argument.

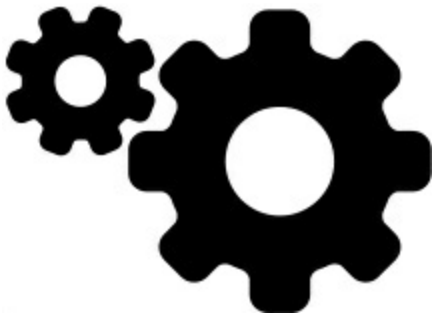
A checked collection will throw a **ClassCastException** when you try to *insert* an improper object, as opposed to a pre-generic (raw)

collection which would inform you there was a problem when you pulled the object *out*. In the latter case, you know there's a problem but you don't know who the culprit is, but with checked collections you find out who tried to insert the bad object.

Let's look at the problem of "putting a cat in a list of dogs" using a checked collection. Here, **oldStyleMethod()** represents legacy code because it takes a raw **List**, and the **@SuppressWarnings("unchecked")** annotation is necessary to silence the resulting warning:

```
// generics/CheckedList.java
// Using Collection.checkedList()
import typeinfo.pets.*;
import java.util.*;
public class CheckedList {
@SuppressWarnings("unchecked")
static void oldStyleMethod(List probablyDogs) {
probablyDogs.add(new Cat());
}
public static void main(String[] args) {
List<Dog> dogs1 = new ArrayList<>();
```

```
oldStyleMethod(dogs1); // Quietly accepts a Cat
List<Dog> dogs2 = Collections.checkedList(
new ArrayList<>(), Dog.class);
try {
oldStyleMethod(dogs2); // Throws an exception
} catch(Exception e) {
System.out.println("Expected: " + e);
}
// Derived types work fine:
List<Pet> pets = Collections.checkedList(
new ArrayList<>(), Pet.class);
pets.add(new Dog());
pets.add(new Cat());
}
```



```
}
/* Output:
```

Expected: java.lang.ClassCastException: Attempt to

insert class typeinfo.pets.Cat element into collection

with element type class typeinfo.pets.Dog

**/*

When you run the program you'll see that the insertion of a **Cat** goes unchallenged by **dogs1**, but **dogs2** immediately throws an exception upon the insertion of an incorrect type. You can also see it's fine to put derived-type objects into a checked collection that is checking for the base type.

Exceptions

Because of erasure, a **catch** clause cannot catch an exception of a generic type, because the exact type of the exception must be known at both compile time and run time. Also, a generic class can't directly or indirectly inherit from **Throwable** (this further prevents you from trying to define generic exceptions that can't be caught).

However, type parameters can be used in the **throws** clause of a method declaration. This means you can write generic code that varies with the type of a checked exception:

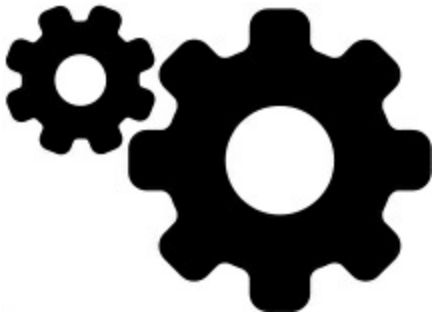
// generics/ThrowGenericException.java

import java.util.*;

```
interface Processor<T, E extends Exception> {
void process(List<T> resultCollector) throws E;
}
class ProcessRunner<T, E extends Exception>
extends ArrayList<Processor<T, E>> {
List<T> processAll() throws E {
List<T> resultCollector = new ArrayList<>();
for(Processor<T, E> processor : this)
processor.process(resultCollector);
return resultCollector;
}
}
class Failure1 extends Exception {}
class Processor1
implements Processor<String, Failure1> {
static int count = 3;
@Override
public void process(List<String> resultCollector)
throws Failure1 {
if(count-- > 1)
```

```
resultCollector.add("Hep!");
else
resultCollector.add("Ho!");
if(count < 0)
throw new Failure1();
}
}
class Failure2 extends Exception {}
class Processor2
implements Processor<Integer, Failure2> {
static int count = 2;
@Override
public void process(List<Integer> resultCollector)
throws Failure2 {
if(count-- == 0)
resultCollector.add(47);
else {
resultCollector.add(11);
}
if(count < 0)
```

```
throw new Failure2();
}
}
public class ThrowGenericException {
public static void main(String[] args) {
```



```
ProcessRunner<String, Failure1> runner =
new ProcessRunner<>();
for(int i = 0; i < 3; i++)
runner.add(new Processor1());
try {
System.out.println(runner.processAll());
} catch(Failure1 e) {
System.out.println(e);
}
ProcessRunner<Integer, Failure2> runner2 =
new ProcessRunner<>();
```

```
for(int i = 0; i < 3; i++)
runner2.add(new Processor2());
try {
System.out.println(runner2.processAll());
} catch(Failure2 e) {
System.out.println(e);
}
}
}
/* Output:
[Hep!, Hep!, Ho!]
Failure2
*/
```

A **Processor** performs a **process()** and might throw an exception of type **E**. The result of the **process()** is stored in the **List<T> resultCollector** (this is called a *collecting parameter*). A **ProcessRunner** has a **processAll()** method that executes every **Process** object it holds, and returns the **resultCollector**.

Unless you can parameterize the thrown exceptions, you can't write

this code generically because of the checked exceptions.

Mixins

The term *mixin* has acquired numerous meanings, but the fundamental concept is that of mixing capabilities from multiple classes to produce a resulting class that represents all the types of the mixins. This is often something you do at the last minute, which makes it convenient to easily assemble classes.

One value of mixins is they consistently apply characteristics and behaviors across multiple classes. As a bonus, if you change something in a mixin class, those changes are applied across all the classes where the mixin is used. Because of this, mixins have part of the flavor of *aspect-oriented programming* (AOP), and aspects are often suggested to solve the mixin problem.

Mixins in C++

One of the strongest arguments made for multiple inheritance in C++ is for mixins. A more elegant approach to mixins uses parameterized types, whereby a mixin is a class that inherits from its type parameter.

In C++, you can easily create mixins because C++ remembers the type of its template parameters.

Here's a C++ example with two mixin types: one that mixes in the property of having a time stamp, and another that mixes in a serial number for each object instance:

```
// generics/Mixins.cpp
#include <string>
#include <ctime>
#include <iostream>
using namespace std;
template< class T> class TimeStamped : public T {
long timeStamp;
public:
TimeStamped() { timeStamp = time(0); }
long getStamp() { return timeStamp; }
};
template< class T> class SerialNumbered : public T {
long serialNumber;
static long counter;
public:
```

```
SerialNumbered() { serialNumber = counter++; }
long getSerialNumber() { return serialNumber; }
};
// Define and initialize the static storage:
template< class T> long SerialNumbered<T>::counter = 1;
class Basic {
string value;
public:
void set(string val) { value = val; }
string get() { return value; }
};
int main() {
TimeStamped<SerialNumbered<Basic>> mixin1, mixin2;
mixin1.set("test string 1");
mixin2.set("test string 2");
cout << mixin1.get() << " " << mixin1.getStamp() <<
" " << mixin1.getSerialNumber() << endl;
cout << mixin2.get() << " " << mixin2.getStamp() <<
" " << mixin2.getSerialNumber() << endl;
}
```

/ *Output:*

test string 1 1452987605 1

test string 2 1452987605 2

**/*

In **main()**, the resulting type of **mixin1** and **mixin2** has all the methods of the mixed-in types. You can think of a mixin as a function that maps existing classes to new subclasses. Notice how trivial it is to create a mixin using this technique; basically, you just say, “Here’s what I want,” and it happens:

TimeStamped<SerialNumbered<Basic>> mixin1, mixin2;

Very unfortunately, Java generics don’t permit this. Erasure forgets

the base-class type, so:

A generic class cannot inherit directly

from a generic parameter.

This highlights one of the big problems I have with any number of Java language design decisions (and the marketing that went along with those features): There’s a lot of promise, but when you actually

try to do something interesting, you discover you can’t.

Mixing with Interfaces

A commonly suggested solution is to use interfaces to produce the effect of mixins, like this:

```
// generics/Mixins.java
import java.util.*;
interface TimeStamped { long getStamp(); }
class TimeStampedImp implements TimeStamped {
private final long timeStamp;
TimeStampedImp() {
timeStamp = new Date().getTime();
}
@Override
public long getStamp() { return timeStamp; }
}
interface SerialNumbered { long getSerialNumber(); }
class SerialNumberedImp implements SerialNumbered {
private static long counter = 1;
private final long serialNumber = counter++;
@Override
```

```
public long getSerialNumber() { return serialNumber; }
}
interface Basic {
void set(String val);
String get();
}
class BasicImp implements Basic {
private String value;
@Override
public void set(String val) { value = val; }
@Override
public String get() { return value; }
}
class Mixin extends BasicImp
implements TimeStamped, SerialNumbered {
private TimeStamped timeStamp = new TimeStampedImp();
private SerialNumbered serialNumber =
new SerialNumberedImp();
@Override
public long getStamp() {
```

```
return timeStamp.getStamp();
}
@Override
public long getSerialNumber() {
return serialNumber.getSerialNumber();
}
}
public class Mixins {
public static void main(String[] args) {
Mixin mixin1 = new Mixin(), mixin2 = new Mixin();
mixin1.set("test string 1");
mixin2.set("test string 2");
System.out.println(mixin1.get() + " " +
mixin1.getStamp() + " " +
mixin1.getSerialNumber());
System.out.println(mixin2.get() + " " +
mixin2.getStamp() + " " +
mixin2.getSerialNumber());
}
}
```

/ *Output:*

test string 1 1494331663026 1

test string 2 1494331663027 2

**/*

The **Mixin** class is basically using *delegation*, so each mixed-in type requires a field in **Mixin**, and you must write all the necessary methods in **Mixin** to forward calls to the appropriate object. This example uses trivial classes, but with a more complex mixin the code grows rapidly. 4

Using the Decorator Pattern

When you look at the way it is used, the concept of a mixin seems closely related to the *Decorator* design pattern. Decorators are often used when, to satisfy every possible combination, simple subclassing produces so many classes it becomes impractical.

The Decorator pattern uses layered objects to dynamically and transparently add responsibilities to individual objects. The pattern specifies that all objects that wrap around your initial object have the

same basic interface. Something is decoratable, and you layer on functionality by wrapping other classes around the decoratable. This makes the decorators transparent—there are a set of common messages you can send to an object whether or not it is decorated. A decorating class can also add methods, but as you shall see, this is limited.

Decorators are implemented using composition and formal structures (the decoratable/decorator hierarchy), whereas mixins are inheritance-based. Think of parameterized-type-based mixins as a generic decorator mechanism that does not require the inheritance structure of the Decorator design pattern.

The previous example can be recast using Decorator:

```
// generics/decorator/Decoration.java
// {java generics.decorator.Decoration}
package generics.decorator;
import java.util.*;
class Basic {
private String value;
public void set(String val) { value = val; }
public String get() { return value; }
```

```
}
class Decorator extends Basic {
protected Basic basic;
Decorator(Basic basic) { this.basic = basic; }
@Override
public void set(String val) { basic.set(val); }
@Override
public String get() { return basic.get(); }
}
class TimeStamped extends Decorator {
private final long timeStamp;
TimeStamped(Basic basic) {
super(basic);
timeStamp = new Date().getTime();
}
public long getStamp() { return timeStamp; }
}
class SerialNumbered extends Decorator {
private static long counter = 1;
private final long serialNumber = counter++;
```

```
SerialNumbered(Basic basic) { super(basic); }
public long getSerialNumber() { return serialNumber; }
}
public class Decoration {
public static void main(String[] args) {
TimeStamped t = new TimeStamped(new Basic());
TimeStamped t2 = new TimeStamped(
new SerialNumbered(new Basic()));
//- t2.getSerialNumber(); // Not available
SerialNumbered s = new SerialNumbered(new Basic());
SerialNumbered s2 = new SerialNumbered(
```

```
new TimeStamped(new Basic()));
//- s2.getStamp(); // Not available
}
}
```

The class resulting from a mixin contains all the methods of interest, but the type of the object that results from using decorators is the last

type it was decorated with. That is, although it's *possible* to add more than one layer, the final layer is the actual type, so only the final layer's methods are visible, whereas the type of the mixin is *all* the types that get mixed together. So a significant drawback to Decorator is it only effectively works with one layer of decoration (the final one), and the mixin approach is arguably more natural. Thus, Decorator is only a limited solution to the problem addressed by mixins.

Mixins with Dynamic Proxies

It's possible to use a dynamic proxy to create a mechanism that more closely models mixins than does the Decorator (see the Type Information chapter for an explanation of how Java's dynamic proxies work). With a dynamic proxy, the *dynamic* type of the resulting class is the combined types that were mixed.

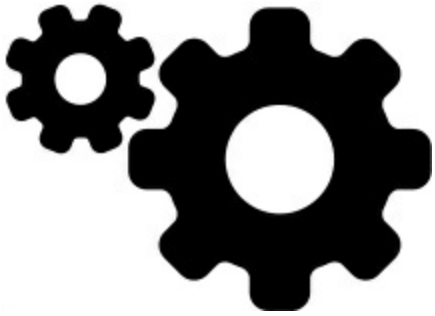
Because of the constraints of dynamic proxies, each class that is mixed in must be the implementation of an interface:

```
// generics/DynamicProxyMixin.java
import java.lang.reflect.*;
import java.util.*;
import onjava.*;
import static onjava.Tuple.*;
class MixinProxy implements InvocationHandler {
```

```
Map<String, Object> delegatesByMethod;
@SuppressWarnings("unchecked")
MixinProxy(Tuple2<Object, Class<?>> ... pairs) {
delegatesByMethod = new HashMap<>();
for(Tuple2<Object, Class<?>> pair : pairs) {
for(Method method : pair.a2.getMethods()) {
String methodName = method.getName();
// The first interface in the map
// implements the method.
if(!delegatesByMethod.containsKey(methodName))
delegatesByMethod.put(methodName, pair.a1);
}
}
}
@Override
public Object invoke(Object proxy, Method method,
Object[] args) throws Throwable {
String methodName = method.getName();
Object delegate = delegatesByMethod.get(methodName);
return method.invoke(delegate, args);
```

```
}
@SuppressWarnings("unchecked")
public static Object newInstance(Tuple2... pairs) {
Class[] interfaces = new Class[pairs.length];
for(int i = 0; i < pairs.length; i++) {
interfaces[i] = (Class)pairs[i].a2;
}
ClassLoader cl =
pairs[0].a1.getClass().getClassLoader();
return Proxy.newProxyInstance(
cl, interfaces, new MixinProxy(pairs));
}
}
public class DynamicProxyMixin {
public static void main(String[] args) {
Object mixin = MixinProxy.newInstance(
tuple(new BasicImp(), Basic.class),
tuple(new TimeStampedImp(), TimeStamped.class),
tuple(new SerialNumberedImp(),
SerialNumbered.class));
```

```
Basic b = (Basic)mixin;
TimeStamped t = (TimeStamped)mixin;
SerialNumbered s = (SerialNumbered)mixin;
b.set("Hello");
System.out.println(b.get());
System.out.println(t.getStamp());
System.out.println(s.getSerialNumber());
```



```
}
}
/* Output:
Hello
1494331653339
1
*/
```

Because only the dynamic type, and not the static type, includes all the mixed-in types, this is still not as nice as the C++ approach, because

you’re forced to downcast to the appropriate type before you can call methods for it. However, it is significantly closer to a true mixin.

There is a fair amount of work done towards the support of mixins for Java, including the creation of at least one language add-on, the Jam language, specifically for supporting mixins.

Latent Typing

The beginning of this chapter introduced the idea of writing code to apply as generally as possible. To do this, we need ways to loosen the constraints on the types our code works with, without losing the benefits of static type checking. We can then write code for use in more situations—that is, more “generic” code.

Java generics appear to take a further step in this direction. When you are writing or using generics that simply hold objects, the code works with any type (except for primitives, although autoboxing can fix this). Or, put another way, “holder” generics are able to say, “I don’t care what type you are.” Code that doesn’t care what type it works with can indeed be applied everywhere, and is thus quite “generic.”

You’ve seen the problem that arises when you perform manipulations on generic types (other than calling **Object** methods). Erasure forces you to specify the bounds of your generic types in order to safely call

specific methods for the generic objects in your code. This is a significant limitation to the concept of “generic” because you must constrain your generic types so they inherit from particular classes or implement particular interfaces. In some cases you might end up using an ordinary class or interface instead, because a bounded generic might be no different from specifying a class or interface.

One solution that some programming languages provide is called *latent typing* or *structural typing*. A more whimsical term is *duck typing*, as in, “If it walks like a duck and talks like a duck, you might as well treat it like a duck.” Duck typing has become a fairly popular term, possibly because it doesn’t carry the historical baggage that

other terms do.

Generic code typically only calls a few methods on a generic type, and a language with latent typing loosens the constraint (and produces more generic code) by only requiring that a subset of methods be implemented, *not* a particular class or interface. Because of this, latent typing cuts across class hierarchies, calling methods that are not part of a common interface. So a piece of code might say, in effect, "I don't care what type you are as long as you can **speak()** and **sit()**." By not requiring a specific type, your code is more generic.

Latent typing is a code organization and reuse mechanism. With it you can write a piece of code that is easier to reuse than without it. Code organization and reuse are the foundational levers of all computer programming: Write it once, use it more than once, and keep the code in one place. Because I am not required to name an exact interface that my code operates upon, with latent typing I can write less code and apply it more easily in more places.

Languages that support latent typing include Python (from *www.Python.org*), C++, Ruby, SmallTalk, and Go. Python is a dynamically typed language (virtually all the type checking happens at run time), while C++ and Go are statically typed languages (the type

checking happens at compile time), so latent typing does not require either static or dynamic type checking.

Latent Typing in Python

If we take the description of latent typing and express it in Python, it looks like this:

```
# generics/DogsAndRobots.py
class Dog:
def speak(self):
print("Arf!")
def sit(self):
print("Sitting")
def reproduce(self):
pass
class Robot:
def speak(self):
print("Click!")
def sit(self):
```

```
print("Clank!")

def oilChange(self):

pass

def perform(anything):

anything.speak()

anything.sit()

a = Dog()

b = Robot()

perform(a)

perform(b)

output = """

Arf!

Sitting

Click!

Clank!

"""
```

Python uses indentation to determine scope (so no curly braces are

needed), and a colon to begin a new scope. A # indicates a comment to the end of the line, like // in Java. The methods of a class explicitly specify the equivalent of the **this** reference as the first argument, called **self** by convention. Constructor calls do not require any sort of "new" keyword. And Python allows regular (non-member) functions, as evidenced by **perform()**.

In **perform(anything)**, notice there is no type information for **anything**, and **anything** is just an identifier. It must execute the operations that **perform()** asks of it, so an interface is implied. But you never explicitly write out that interface—it's *latent*. **perform()** doesn't care about the type of its argument, so I can pass any object to it as long as it supports the **speak()** and **sit()** methods. If you pass an object to **perform()** that does not support these operations, you'll get a runtime exception.

The **output** assignment uses triple quotes to create a string with embedded newlines.

Latent Typing in C++

We can produce the same effect in C++:

```
// generics/DogsAndRobots.cpp
#include <iostream>
```

```
using namespace std;
class Dog {
public:
void speak() { cout << "Arf!" << endl; }
void sit() { cout << "Sitting" << endl; }
void reproduce() {}
};
class Robot {
public:
void speak() { cout << "Click!" << endl; }
void sit() { cout << "Clank!" << endl; }
void oilChange() {}
};
template< class T> void perform(T anything) {
anything.speak();
anything.sit();
}
int main() {
Dog d;
Robot r;
```

```
perform(d);
perform(r);
}
/* Output:
Arf!
Sitting
Click!
Clank!
*/
```

In both Python and C++, **Dog** and **Robot** have nothing in common—they just happen to have two methods with identical signatures. From a type standpoint, they are completely distinct types. However, **perform()** doesn't care about the specific type of its argument, and latent typing allows it to accept both types of object.

The C++ compiler ensures it can actually send those messages. It gives you an error message if you try to pass the wrong type (these error messages have historically been terrible and verbose, and are the primary reason that C++ templates have a poor reputation). Although they do it at different times—C++ at compile time, and Python at run time—both languages ensure that types cannot be misused and are

thus considered *strongly typed*. 5 Latent typing does not compromise strong typing.

Latent Typing in Go

Here's the same program written in Go:

```
// generics/dogsandrobots.go

package main

import "fmt"

type Dog struct {}

func (this Dog) speak() { fmt.Printf("Arf!\n")}

func (this Dog) sit() { fmt.Printf("Sitting\n")}

func (this Dog) reproduce() {}

type Robot struct {}

func (this Robot) speak() { fmt.Printf("Click!\n") }

func (this Robot) sit() { fmt.Printf("Clank!\n") }

func (this Robot) oilChange() {}

func perform(speaker interface { speak(); sit() }) {

speaker.speak();
```

```
speaker.sit();
}
func main() {
perform(Dog{})
perform(Robot{})
}
/* Output:
Arf!
Sitting
Click!
Clank!
*/
```

Go has no **class** keyword, but you can create the equivalent of basic classes using the above form: what you would ordinarily define as a class, you instead define as a **struct**, within which dwell your data fields (there are none here). For each method, you start with the **func** keyword, then—in order to attach the method to your class—you put

parentheses containing the object reference, which can be any identifier but I use **this** here to remind you that it's like the **this** in C++ or Java. Then you define the rest of the function as you do for any other function in Go.

There's also no inheritance in Go, so this form of "object-orientedness" is relatively primitive, and probably the main thing that keeps me from spending more time with the language. Composition, however, is straightforward.

The **perform()** function uses latent typing: the exact type of the argument is unimportant as long as it contains a **speak()** and **sit()** method. The **interface** is define here anonymously, inline, as seen in the argument list to **perform()**.

main() demonstrates that **perform()** is indeed indifferent to the exact type of its argument, as long as **speak()** and **sit()** can be called on that argument. However, just like C++ template functions, the types are checked at compile time.

The syntax **Dog{}** and **Robot{}** creates anonymous **Dog** and **Robot struct**s.

Direct Latent Typing in Java

Because generics were added to Java late in the game, there was no

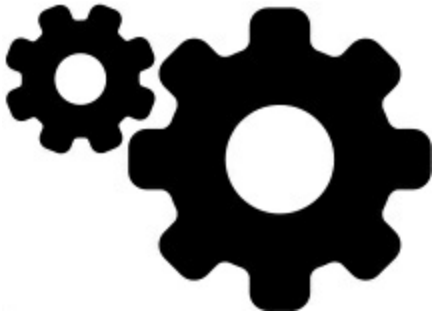
chance that any kind of latent typing could be implemented, so Java has no support for this feature. As a result, it initially seems that Java's generic mechanism is "less generic" than a language that supports latent typing (The implementation of Java's generics using erasure is sometimes called *second-class* generic types). For example, if we try to implement the dogs-and-robots example before Java 8, we must use a class or an interface and specify it in a bounds expression:

```
// generics/Performs.java
public interface Performs {
void speak();
void sit();
}
// generics/DogsAndRobots.java
// No (direct) latent typing in Java
import typeinfo.pets.*;
class PerformingDog extends Dog implements Performs {
@Override
public void speak() { System.out.println("Woof!"); }
@Override
public void sit() { System.out.println("Sitting"); }
```

```
public void reproduce() {}
}
class Robot implements Performs {
public void speak() { System.out.println("Click!"); }
public void sit() { System.out.println("Clank!"); }
public void oilChange() {}
}
class Communicate {
public static <T extends Performs>
void perform(T performer) {
performer.speak();
performer.sit();
}
}
public class DogsAndRobots {
public static void main(String[] args) {
Communicate.perform(new PerformingDog());
Communicate.perform(new Robot());
}
}
```

/ *Output:*

Woof!



Sitting

Click!

Clank!

**/*

However, note that **perform()** does not need generics to work. It can be specified to accept a **Performs** object:

```
// generics/SimpleDogsAndRobots.java
// Removing the generic; code still works
class CommunicateSimply {
static void perform(Performs performer) {
performer.speak();
performer.sit();
}
}
```

```
public class SimpleDogsAndRobots {
public static void main(String[] args) {
CommunicateSimply.perform(new PerformingDog());
CommunicateSimply.perform(new Robot());
}
}
/* Output:
Woof!
Sitting
Click!
Clank!
*/
```

Here, generics were not necessary because the classes were already forced to implement the **Performs** interface.

Compensating for the

Lack of (Direct) Latent

Typing

Although Java does not directly support latent typing, this does not mean your generic code cannot be applied across different type hierarchies. You can create truly generic code, but it takes some extra effort.

Reflection

One approach you can use is reflection. Here's a reflective **perform()** that implements latent typing:

```
// generics/LatentReflection.java
// Using reflection for latent typing
import java.lang.reflect.*;
// Does not implement Performs:
class Mime {
public void walkAgainstTheWind() {}
public void sit() {
System.out.println("Pretending to sit");
}
public void pushInvisibleWalls() {}
@Override
public String toString() { return "Mime"; }
}
```

```
// Does not implement Performs:
class SmartDog {
public void speak() { System.out.println("Woof!"); }
public void sit() { System.out.println("Sitting"); }
public void reproduce() {}
}
class CommunicateReflectively {
public static void perform(Object speaker) {
Class<?> spkr = speaker.getClass();
try {
try {
Method speak = spkr.getMethod("speak");
speak.invoke(speaker);
} catch(NoSuchMethodException e) {
System.out.println(speaker + " cannot speak");
}
try {
Method sit = spkr.getMethod("sit");
sit.invoke(speaker);
} catch(NoSuchMethodException e) {
```

```
System.out.println(speaker + " cannot sit");
}
} catch(SecurityException |
IllegalAccessException |
IllegalArgumentException |
InvocationTargetException e) {
throw new RuntimeException(speaker.toString(), e);
}
}
}
public class LatentReflection {
public static void main(String[] args) {
CommunicateReflectively.perform(new SmartDog());
CommunicateReflectively.perform(new Robot());
CommunicateReflectively.perform(new Mime());
}
}
/* Output:
Woof!
Sitting
```

Click!

Clank!

Mime cannot speak

Pretending to sit

*/

Here, the classes are completely disjoint and have no base classes (other than **Object**) or interfaces in common. Through reflection, **CommunicateReflectively.perform()** is able to

dynamically establish whether the desired methods are available and call them. It is even able to deal with the fact that **Mime** only has one of the necessary methods, and partially fulfills its goal.

Applying a Method to a

Sequence

Reflection has useful possibilities, but it relegates all the type checking to run time, and is thus undesirable in many situations. If you can achieve compile-time type checking, that's usually more desirable. But can you have both compile-time type checking *and* latent typing?

Let’s look at an example that explores the problem. Suppose you create an **apply()** method that applies any method to every object in a sequence. This is a situation where interfaces don’t seem to fit. You want to apply any method to a collection of objects, and interfaces constrain you too much to describe “any method.” How do you do this in Java?

Initially, we can solve the problem with reflection, which turns out to be fairly elegant using varargs:

```
// generics/Apply.java
import java.lang.reflect.*;
import java.util.*;
public class Apply {
public static <T, S extends Iterable<T>>
void apply(S seq, Method f, Object... args) {
try {
for(T t: seq)
f.invoke(t, args);
} catch(IllegalAccessException |
IllegalArgumentException |
InvocationTargetException e) {
```

// Failures are programmer errors

throw new RuntimeException(e);

}

}

}

Exceptions are converted to **RuntimeException**s because there's not much of a way to recover from exceptions—they really do represent programmer errors here.

Why don't we just use a Java 8 method reference (this is shown later) instead of the reflective **Method f**? Notice that **invoke()**, and thus **apply()**, have the advantage that they can take any number of arguments. There are situations when that flexibility might be essential.

To test **Apply**, we'll first create a **Shape** class:

// generics/Shape.java

public class Shape {

private static long counter = 0;

private final long id = counter++;

@Override

public String toString() {

```
return getClass().getSimpleName() + " " + id;
}
public void rotate() {
System.out.println(this + " rotate");
}
public void resize(int newSize) {
System.out.println(this + " resize " + newSize);
}
}
```

Followed by a subclass:

```
// generics/Square.java
public class Square extends Shape {}
```

Using these, we can test **Apply**:

```
// generics/ApplyTest.java
import java.util.*;
import java.util.function.*;
import onjava.*;
public class ApplyTest {
public static
void main(String[] args) throws Exception {
```

```
List<Shape> shapes =
Suppliers.create(ArrayList::new, Shape::new, 3);
Apply.apply(shapes,
Shape.class.getMethod("rotate"));
Apply.apply(shapes,
Shape.class.getMethod("resize", int.class), 7);
List<Square> squares =
Suppliers.create(ArrayList::new, Square::new, 3);
Apply.apply(squares,
Shape.class.getMethod("rotate"));
Apply.apply(squares,
Shape.class.getMethod("resize", int.class), 7);
Apply.apply(new FilledList<>(Shape::new, 3),
Shape.class.getMethod("rotate"));
Apply.apply(new FilledList<>(Square::new, 3),
Shape.class.getMethod("rotate"));
SimpleQueue<Shape> shapeQ = Suppliers.fill(
new SimpleQueue<>(), SimpleQueue::add,
Shape::new, 3);
Suppliers.fill(shapeQ, SimpleQueue::add,
```

```
Square::new, 3);
Apply.apply(shapeQ,
Shape.class.getMethod("rotate"));
}
}
/* Output:
Shape 0 rotate
Shape 1 rotate
Shape 2 rotate
Shape 0 resize 7
Shape 1 resize 7
Shape 2 resize 7
Square 3 rotate
Square 4 rotate
Square 5 rotate
Square 3 resize 7
Square 4 resize 7
Square 5 resize 7
Shape 6 rotate
Shape 7 rotate
```

Shape 8 rotate

Square 9 rotate

Square 10 rotate

Square 11 rotate

Shape 12 rotate

Shape 13 rotate

Shape 14 rotate

Square 15 rotate

Square 16 rotate

Square 17 rotate

**/*

In **Apply**, we get lucky because there happens to be an **Iterable** interface built into Java, used by the Java collections library. Because of this, the **apply()** method can accept anything that implements the **Iterable** interface, which includes all the **Collection** classes such as **List**. But it can also accept anything else, as long as you make it **Iterable**—for example, the **SimpleQueue** class defined here and used above in **main()**:

// generics/SimpleQueue.java

// A different kind of Iterable collection

```
import java.util.*;
public class SimpleQueue<T> implements Iterable<T> {
private LinkedList<T> storage = new LinkedList<>();
public void add(T t) { storage.offer(t); }
public T get() { return storage.poll(); }
@Override
public Iterator<T> iterator() {
return storage.iterator();
}
}
```

As elegant as the reflection solution seems, we must observe that reflection (although improved significantly in recent versions of Java) is usually slower than a non-reflection implementation, since so much is happening at run time. This should not stop you from trying the solution, but it's certainly a point for consideration.

You'd almost certainly use the Java 8 functional approach first, and only resort to reflection if it solved a special need. Here's **ApplyTest.java** rewritten to take advantage of Java 8 streams and functional tools:

```
// generics/ApplyFunctional.java
```

```
import java.util.*;
import java.util.stream.*;
import java.util.function.*;
import onjava.*;
public class ApplyFunctional {
public static void main(String[] args) {
Stream.of(
Stream.generate(Shape::new).limit(2),
Stream.generate(Square::new).limit(2))
.flatMap(c -> c) // flatten into one stream
.peek(Shape::rotate)
.forEach(s -> s.resize(7));
new FilledList<>(Shape::new, 2)
.forEach(Shape::rotate);
new FilledList<>(Square::new, 2)
.forEach(Shape::rotate);
SimpleQueue<Shape> shapeQ = Suppliers.fill(
new SimpleQueue<>(), SimpleQueue::add,
Shape::new, 2);
Suppliers.fill(shapeQ, SimpleQueue::add,
```

```
Square::new, 2);
shapeQ.forEach(Shape::rotate);
}
}
/* Output:
Shape 0 rotate
Shape 0 resize 7
Shape 1 rotate
Shape 1 resize 7
Square 2 rotate
Square 2 resize 7
Square 3 rotate
Square 3 resize 7
Shape 4 rotate
Shape 5 rotate
Square 6 rotate
Square 7 rotate
Shape 8 rotate
Shape 9 rotate
Square 10 rotate
```

Square 11 rotate

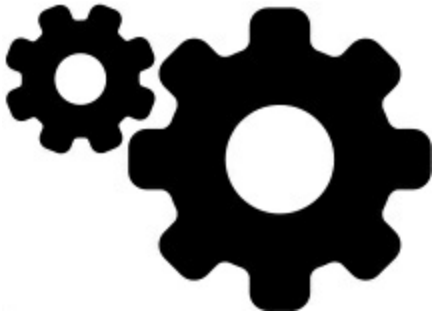
*/

Because of Java 8, there's no need for **Apply.apply()**.

We start by generating two **Stream**s: one of **Shape** and one of **Square**, and flattening them into a single stream. Although Java is missing the **flatten()** often found in functional languages, we can produce the same result with **flatMap(c -> c)**, which uses a identity mapping to reduce the operation to only "flatten."

We use **peek()** for the call to **rotate()** because **peek()** performs an operation (here, for its side effect) and passes the object on unchanged.

Notice how much cleaner the call to **forEach()** is with the **FilledList**s and **shapeQ** than **Apply.apply()**.



The result is far preferable to the previous approach, just in code simplicity and readability alone. Also there is now no possibility of an exception being thrown from **main()**.

Assisted Latent Typing

in Java 8

The prior statements about Java's lack of support for latent typing are strictly true before Java 8. However, unbound method references in Java 8 allow us to produce a form of latent typing that satisfies the requirement of creating a single piece of code that works across unrelated types. Since Java wasn't originally designed to do this the result is—as you might expect by now—slightly more awkward than in other languages. But it is now *possible*, which I consider just short of amazing.

I have not encountered this technique elsewhere, so I shall call it *assisted latent typing*.

We'll rewrite **DogsAndRobots.java** to demonstrate this technique. To make things look as similar as possible to the original example, I've simply added an **A** to each of the original class names:

```
// generics/DogsAndRobotMethodReferences.java
// "Assisted Latent Typing"
import typeinfo.pets.*;
import java.util.function.*;
class PerformingDogA extends Dog {
```

```
public void speak() { System.out.println("Woof!"); }
public void sit() { System.out.println("Sitting"); }
public void reproduce() {}
}
class RobotA {
public void speak() { System.out.println("Click!"); }
public void sit() { System.out.println("Clank!"); }
public void oilChange() {}
}
class CommunicateA {
public static <P> void perform(P performer,
Consumer<P> action1, Consumer<P> action2) {
action1.accept(performer);
action2.accept(performer);
}
}
public class DogsAndRobotMethodReferences {
public static void main(String[] args) {
CommunicateA.perform(new PerformingDogA(),
PerformingDogA::speak, PerformingDogA::sit);
```

```
CommunicateA.perform(new RobotA(),
RobotA::speak, RobotA::sit);
CommunicateA.perform(new Mime(),
Mime::walkAgainstTheWind,
Mime::pushInvisibleWalls);
}
}
/* Output:
Woof!
Sitting
Click!
Clank!
*/
```

PerformingDogA and **RobotA** are the same as they are in **DogsAndRobots.java**, except they do not inherit the common interface **Performs**, so they have no commonality.

CommunicateA.perform() is generified on **P** which has *no constraints*. It can be anything as long as there are **Consumer<P>** s available for it—here, those **Consumer<P>** s represent unbound method references for **P** methods that take no arguments. When you

call **Consumer**'s **accept()** method, it binds the method reference to the performer object and calls that method. Because of the "magic" described in the Functional Programming chapter, we can pass any signature-conforming unbound method references to **CommunicateA.perform()**.

The reason for calling it "assisted" is because you must explicitly give **perform()** the method references to use; it can't just call the methods by name.

Although passing the unbound method references might seem like a lot of extra hand-holding, the ultimate goal of latent typing is achieved. We have created a single piece of code, **CommunicateA.perform()**, which works on any types that have signature-conformant method references. Notice this is somewhat different than latent typing in other languages we've seen, because those languages require not just the signature to conform, but also the method names. Thus, this technique arguably produces even *more* generic code.

Just to prove the point, I've also thrown in a **Mime** from **LatentReflection.java**.

Generic Methods to Use with Suppliers

With assisted latent typing, we can define the **Suppliers** class used in other parts of this chapter. This class contains utility methods that use generators to fill **Collection**s. It makes sense to "generify" these operations:

```
// onjava/Suppliers.java
// A utility to use with Suppliers
package onjava;
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
public class Suppliers {
// Create a collection and fill it:
public static <T, C extends Collection<T>> C
create(Supplier<C> factory, Supplier<T> gen, int n) {
return Stream.generate(gen)
.limit(n)
```

```
.collect(factory, C::add, C::addAll);
}
// Fill an existing collection:
public static <T, C extends Collection<T>>
C fill(C coll, Supplier<T> gen, int n) {
Stream.generate(gen)
.limit(n)
.forEach(coll::add);
return coll;
}
// Use an unbound method reference to
// produce a more general method:
public static <H, A> H fill(H holder,
BiConsumer<H, A> adder, Supplier<A> gen, int n) {
Stream.generate(gen)
.limit(n)
.forEach(a -> adder.accept(holder, a));
return holder;
}
}
```

create() makes a new **Collection** subtype for you, while the first version of **fill()** puts elements into an existing subtype of **Collection**. Notice the exact type of container passed in is also returned, so the type information is not lost.6

The first two methods are generically constrained to work with **Collection** subtypes. The second version of **fill()** works with a **holder** of any type. It takes an additional argument: the unbound method reference **adder**. **fill()** uses assisted latent typing to make it work with any **holder** type that has a method to add elements. Because this unbound method **adder** must take an argument (the element to add to the **holder**), **adder** must be a **BiConsumer<H, A>** where **H** is the type of the **holder** object to bind to, and **A** is the type of element being added. The call to **accept()** invokes the unbound method **adder** on the object **holder** with the argument **a**.

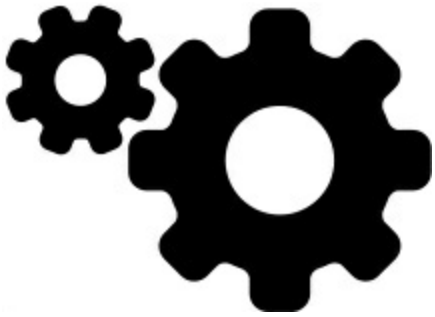
The **Suppliers** utility is tested within a little simulation that also uses **RandomList**, defined earlier in the chapter:

```
// generics/BankTeller.java
// A very simple bank teller simulation
import java.util.*;
import onjava.*;
class Customer {
```

```
private static long counter = 1;
private final long id = counter++;
@Override
public String toString() {
return "Customer " + id;
}
}
class Teller {
private static long counter = 1;
private final long id = counter++;
@Override
public String toString() {
return "Teller " + id;
}
}
class Bank {
private List<BankTeller> tellers =
new ArrayList<>();
public void put(BankTeller bt) {
tellers.add(bt);
```

```
}
}
public class BankTeller {
public static void serve(Teller t, Customer c) {
System.out.println(t + " serves " + c);
}
public static void main(String[] args) {
// Demonstrate create():
RandomList<Teller> tellers =
Suppliers.create(
RandomList::new, Teller::new, 4);
// Demonstrate fill():
List<Customer> customers = Suppliers.fill(
new ArrayList<>(), Customer::new, 12);
customers.forEach(c ->
serve(tellers.select(), c));
// Demonstrate assisted latent typing:
Bank bank = Suppliers.fill(
new Bank(), Bank::put, BankTeller::new, 3);
// Can also use second version of fill():
```

```
List<Customer> customers2 = Suppliers.fill(
new ArrayList<>(),
List::add, Customer::new, 12);
}
}
/* Output:
Teller 3 serves Customer 1
Teller 2 serves Customer 2
Teller 3 serves Customer 3
Teller 1 serves Customer 4
Teller 1 serves Customer 5
Teller 3 serves Customer 6
Teller 1 serves Customer 7
Teller 2 serves Customer 8
Teller 3 serves Customer 9
Teller 3 serves Customer 10
Teller 2 serves Customer 11
Teller 4 serves Customer 12
*/
```



You can see that **create()** generates a new **Collection** object, while **fill()** adds to an existing **Collection**. The second version of **fill()** is shown not only working with the new and unrelated type **Bank**, but also with a **List**—thus the first version of **fill()** is not technically necessary but provides shorter syntax when working with **Collection**s.

Summary: Is Casting Really So Bad?

Having worked to explain C++ templates since their inception, I have probably been putting forward the following argument longer than most people. Only recently have I stopped to wonder how often this argument is valid—how many times does the problem I'm about to describe really slip through the cracks?

The argument goes like this. One of the most compelling places to use a generic type mechanism is with collection classes such as the **List**s, **Set**s, **Map**s, etc. you saw in Collections and you shall see more of in the

Appendix: Collection Topics. Before Java 5, when you put an object into a collection, it was upcast to **Object**, so you'd lose the

type information. When you wanted to pull it back out to do

something with it, you had to cast it back down to the proper type. My

example was a **List** of **Cat** (a variation of this using apples and

oranges is shown at the beginning of the Collections chapter). Without the Java 5 generic version of the collection, you put **Object**s in and

you get **Object**s out, so it's easily possible to put a **Dog** in a **List** of **Cat**.

However, pre-generic Java wouldn't let you *misuse* the objects you put

into a collection. If you threw a **Dog** into a collection of **Cat**s, then tried to treat everything in the collection as a **Cat**, you'd get a

RuntimeException when you pulled the **Dog** reference out of the

Cat collection and tried to cast it to a **Cat**. You'd still discover the

problem, but at run time rather than compile time.

In earlier times, I went on to argue:

This is more than just an annoyance. It's

something that can create difficult-to-find

bugs. If one part (or several parts) of a

program inserts objects into a collection,

and you discover only in a separate part

of the program through an exception that

a bad object was placed in the collection,
then you must find out where the bad
insert occurred.

However, upon further examination of the argument, I began to wonder about it. First, how often does it happen? I don't remember this kind of thing ever happening to me, and when I asked people at conferences, I didn't hear anyone say it had happened to them. Another book used an example of a list called **files** that contained **String** objects—in this example it seemed perfectly natural to add a **File** object to **files**, so a better name for the object might be **fileNames**. No matter how much type checking Java provides, it's still possible to write obscure programs, and a badly written program that compiles is still a badly written program. Perhaps most people use well-named collections such as **cats** that provide a visual warning to the programmer who would try to add a non-**Cat**. And even if it did happen, how long would the issue really stay buried? It would seem that as soon as you started running tests with real data, you'd see an exception pretty quickly.

One author even asserted that such a bug could "remain buried for years." But I do not recall any deluge of reports of people having great

difficulty finding “dog in cat list” bugs, or even producing them very often. With Concurrent Programming, it is easy and common for bugs to appear extremely rarely, and only give you a vague idea of what’s wrong. So is the “dog in cat list” argument really the reason this very significant and fairly complex feature was added to Java?

I believe the *intent* of the general-purpose language feature called “generics” is *expressiveness*, not just creating type-safe collections. Type-safe collections come as a side effect of the ability to create more general-purpose code.

So even though the “dog in cat list” argument is often used to justify generics, it is questionable. And as I’ve asserted throughout this chapter, I do not believe this is what the *concept* of generics is really about. Instead, generics are as their name implies—a way to write more “generic” code that is less constrained by the types it can work with, so a single piece of code can be applied to more types. As you have seen in this chapter, it is fairly easy to write truly generic “holder” classes (which the Java collections are). To write generic code that manipulates its generic types requires extra effort, on the part of both the class creator *and* the class consumer, who must understand the concept and implementation of such code. That extra effort reduces the ease of use of the feature, and can thus make it less applicable in

places where it might otherwise have added value.

Also note that because generics were back-engineered into Java instead of designed into the language from the start, some of the collections cannot be made as robust as they should be. For example, look at **Map**, in particular the methods **containsKey(Object key)** and **get(Object key)**. If these classes had been designed with pre-existing generics, these methods would have used parameterized types instead of **Object**, thus affording the compile-

time checking that generics are meant to provide. In C++ **map**s, for example, the key type is always checked at compile time.

It is clear that introducing any kind of generic mechanism in a later version of a language, after that language has come into general use, is a very, very messy proposition, and one that cannot be accomplished without pain. In C++, templates were introduced in the initial ISO version of the language (although even that caused some distress because there was an earlier non-template version in use before the first Standard C++ appeared), so in effect templates were *always* a

part of the language. In Java, generics were not introduced until almost 10 years after the language was first released, so the issues of migrating to generics are considerable, and have made a significant impact on the design of generics. The result is that you, the programmer, will suffer because of the lack of vision exhibited by the Java designers when they created version 1.0. When Java was first created, the designers knew about C++ templates, and they even considered including them in the language, but for one reason or another decided to leave them out (indications are they were in a hurry). As a result, both the language and the programmers that use it will suffer. Only time will show the ultimate impact that Java's approach to generics have on the language.

Some languages have incorporated cleaner and less impactful approaches to parameterized types. It's not impossible to imagine such a language becoming a successor to Java, because it takes exactly the approach that C++ did with C: Use what's there and improve upon it.

Further Reading

The introductory document for generics is *Generics in the Java Programming Language*, by Gilad Bracha, located at *http://java.oracle.com* (search from there).

Angelika Langer's *Java Generics FAQs* is a very helpful resource, located at *www.angelikalanger.com/GenericsFAQ/JavaGenericsFAQ.html*.

You can find out more about wildcards in *Adding Wildcards to the Java Programming Language*, by Torgerson, Ernst, Hansen, von der Ahe, Bracha and Gafter, located at *www.jot.fm/issues/issue_2004_12/article5*.

Neal Gafter's opinions on Java problems (erasure in particular) can be found at *http://www.infoq.com/articles/neal-gafter-on-java*.

1. Angelika Langer's Java Generics FAQ as well as her other writings (together with Klaus Kreft) were invaluable during the preparation of this chapter. ↩

2. *http://gafter.blogspot.com/2004/09/puzzling-through-erasure-answer.html*↩

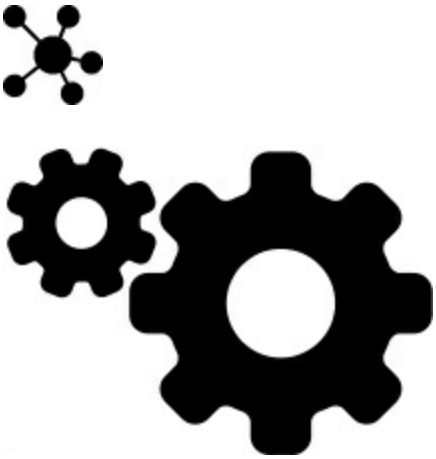
3. See citation at the end of this chapter. ↩

4. Note that some programming environments, such as Eclipse and IntelliJ Idea, will automatically generate delegation code. ↩

5. Because you can use casts, which effectively disable the type system, some people argue that C++ is weakly typed, but that's

extreme. It’s probably safer to say that C++ is “strongly typed with a trap door.” ↩

6. Once again, I got help from Brian Goetz.↩



Arrays

At the end of the Housekeeping chapter, you learned to define and initialize an array.

The simple view of arrays is that you create and populate them, you select elements from them using **int** indexes, and they don’t change their size. Most of the time that’s all you must know, but sometimes you must perform more sophisticated operations on arrays, and you might also evaluate an array vs. a more flexible **Collection**. This chapter looks at arrays in more depth.

Note: As Java **Collection**s and **Stream**s have added more high-

level capabilities, the need to use arrays in day-to-day programming has diminished, so you can safely skim or even skip this chapter for the time being. Ultimately, however, there will come a time when—even if you avoid using arrays yourself—you will need to read and understand someone else's array code. At that time, this chapter will still be here, waiting for you.

Why Arrays are Special

There are a number of other ways to hold objects, so what makes an array special?

There are three issues that distinguish arrays from other types of **Collection**s: efficiency, type, and the ability to hold primitives. The array is Java's most efficient way to store and randomly access a sequence of object references. The array is a simple linear sequence, which makes element access fast. The cost of this speed is that the size of an array object is fixed and cannot be changed for the lifetime of that array.

Speed is not usually an issue, and if it is, the way you hold and retrieve objects is rarely the culprit. You should always start with an **ArrayList** (from Collections), which uses and manages an array internally. When necessary, it automatically allocates more array

space, creating a new array and moving all the references from the old array to the new array. This flexibility has overhead, so an **ArrayList** is less efficient than an array. In the rare cases where this is an issue, you can use arrays directly.

Both arrays and **Collection**s guarantee you can't abuse them. Whether you're using an array or a **Collection**, you'll get a **RuntimeException** if you exceed the bounds, indicating a programmer error.

Before generics, the other **Collection** classes dealt with objects as if they had no specific type. That is, they treated them as type **Object**, the root class of all classes in Java. Arrays are superior to *pre-generic* **Collection**s because you create an array to hold a specific type. This means you get compile-time type checking to prevent you from inserting the wrong type or mistaking the type that you're extracting. Of course, Java prevents you from sending inappropriate messages to objects at either compile time or run time. So it's not riskier one way or the other; it's just nicer if the compiler points it out to you, and there's less likelihood that the end user will get surprised by an exception.

An array can hold primitives, whereas a pre-generic **Collection**

could not. With generics, however, **Collection**s can specify and check the type of objects they hold, and with autoboxing **Collection**s can act as if they are able to hold primitives, since the conversion is automatic. Here's a comparison between arrays and generic **Collection**s:

```
// arrays/CollectionComparison.java
import java.util.*;
import onjava.*;
import static onjava.ArrayShow.*;
class BerylliumSphere {
private static long counter;
private final long id = counter++;
@Override
public String toString() {
return "Sphere " + id;
}
}
public class CollectionComparison {
public static void main(String[] args) {
BerylliumSphere[] spheres =
```

```
new BerylliumSphere[10];
for(int i = 0; i < 5; i++)
spheres[i] = new BerylliumSphere();
show(spheres);
System.out.println(spheres[4]);
List<BerylliumSphere> sphereList = Suppliers.create(
ArrayList::new, BerylliumSphere::new, 5);
System.out.println(sphereList);
System.out.println(sphereList.get(4));
int[] integers = { 0, 1, 2, 3, 4, 5 };
show(integers);
System.out.println(integers[4]);
List<Integer> intList = new ArrayList<>(
Arrays.asList(0, 1, 2, 3, 4, 5));
intList.add(97);
System.out.println(intList);
System.out.println(intList.get(4));
}
}
/* Output:
```

[Sphere 0, Sphere 1, Sphere 2, Sphere 3, Sphere 4,

null, null, null, null, null]

Sphere 4

[Sphere 5, Sphere 6, Sphere 7, Sphere 8, Sphere 9]

Sphere 9

[0, 1, 2, 3, 4, 5]

4

[0, 1, 2, 3, 4, 5, 97]

4

**/*

Suppliers.create() was defined in the Generics chapter.

Both ways of holding objects are type-checked, and the only apparent difference is that arrays use **[ ]** for accessing elements, and a **List** uses methods such as **add()** and **get()**. The similarity between arrays and the **ArrayList** is intentional, so it's conceptually easy to switch between the two. But as you saw in the Collections chapter, **Collection**s have significantly more functionality than arrays.

With the advent of autoboxing, **Collection**s are nearly as easy to use for primitives as arrays. The only remaining advantage to arrays is efficiency. However, when you're solving a more general problem, arrays can be too restrictive, and in those cases you use a

Collection class.

A Utility for Displaying Arrays

Throughout this chapter we must display arrays. Java provides **Arrays.toString()** to convert an array into a readable string, which we can then display on the console. However, this is visually noisy so we'll create a little library to do the work:

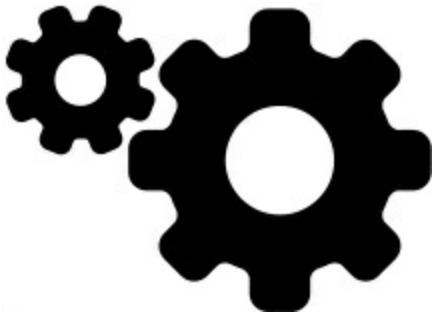
```
// onjava/ArrayShow.java
package onjava;
import java.util.*;
public interface ArrayShow {
static void show(Object[] a) {
System.out.println(Arrays.toString(a));
}
static void show(boolean[] a) {
System.out.println(Arrays.toString(a));
}
static void show(byte[] a) {
```

```
System.out.println(Arrays.toString(a));
}
static void show(char[] a) {
System.out.println(Arrays.toString(a));
}
static void show(short[] a) {
System.out.println(Arrays.toString(a));
}
static void show(int[] a) {
System.out.println(Arrays.toString(a));
}
static void show(long[] a) {
System.out.println(Arrays.toString(a));
}
static void show(float[] a) {
System.out.println(Arrays.toString(a));
}
static void show(double[] a) {
System.out.println(Arrays.toString(a));
}
```

```
// Start with a description:
static void show(String info, Object[] a) {
System.out.print(info + ": ");
show(a);
}
static void show(String info, boolean[] a) {
System.out.print(info + ": ");
show(a);
}
static void show(String info, byte[] a) {
System.out.print(info + ": ");
show(a);
}
static void show(String info, char[] a) {
System.out.print(info + ": ");
show(a);
}
static void show(String info, short[] a) {
System.out.print(info + ": ");
show(a);
```

```
}
static void show(String info, int[] a) {
System.out.print(info + ": ");
show(a);
}
static void show(String info, long[] a) {
System.out.print(info + ": ");
show(a);
}
static void show(String info, float[] a) {
System.out.print(info + ": ");
show(a);
}
static void show(String info, double[] a) {
System.out.print(info + ": ");
show(a);
}
}
```

The first version works for **Object** arrays, including arrays of



wrapped primitives. All the overloaded versions are necessary for the various different primitive types.

The second overloaded group is so you can prefix the array display with an information **String**.

For simplicity, you'll normally import this statically.

Arrays are First-Class Objects

Regardless of what type of array you're working with, the array identifier is actually a reference to a true object that's created on the heap. This is the object that holds the references to the other objects, and it can be created either implicitly, as part of the array initialization syntax, or explicitly with a **new** expression. Part of the array object (in fact, the only field or method you can access) is the read-only **length** member that tells how many elements can be stored in that array object. The **[]** syntax is the only other access you have to the array object.

The following example summarizes the various ways to initialize an array, and how to assign array references to different array objects. It also shows that arrays of objects and arrays of primitives are almost identical in use. The only difference is that arrays of objects hold references, but arrays of primitives hold the primitive values directly.

```
// arrays/ArrayOptions.java
// Initialization & re-assignment of arrays
import java.util.*;
import static onjava.ArrayShow.*;
public class ArrayOptions {
public static void main(String[] args) {
// Arrays of objects:
BerylliumSphere[] a; // Uninitialized local
BerylliumSphere[] b = new BerylliumSphere[5];
// The references inside the array are
// automatically initialized to null:
show("b", b);
BerylliumSphere[] c = new BerylliumSphere[4];
for(int i = 0; i < c.length; i++)
if(c[i] == null) // Can test for null reference
```

```
c[i] = new BerylliumSphere();
// Aggregate initialization:
BerylliumSphere[] d = {
new BerylliumSphere(),
new BerylliumSphere(),
new BerylliumSphere()
};
// Dynamic aggregate initialization:
a = new BerylliumSphere[]{
new BerylliumSphere(), new BerylliumSphere(),
};
// (Trailing comma is optional)
System.out.println("a.length = " + a.length);
System.out.println("b.length = " + b.length);
System.out.println("c.length = " + c.length);
System.out.println("d.length = " + d.length);
a = d;
System.out.println("a.length = " + a.length);
// Arrays of primitives:
int[] e; // Null reference
```

```
int[] f = new int[5];
// The primitives inside the array are
// automatically initialized to zero:
show("f", f);
int[] g = new int[4];
for(int i = 0; i < g.length; i++)
g[i] = i*i;
int[] h = { 11, 47, 93 };
// Compile error: variable e not initialized:
//- System.out.println("e.length = " + e.length);
System.out.println("f.length = " + f.length);
System.out.println("g.length = " + g.length);
System.out.println("h.length = " + h.length);
e = h;
System.out.println("e.length = " + e.length);
e = new int[]{ 1, 2 };
System.out.println("e.length = " + e.length);
}
}
/* Output:
```

b: [null, null, null, null, null]

a.length = 2

b.length = 5

c.length = 4

d.length = 3

a.length = 3

f: [0, 0, 0, 0, 0]

f.length = 5

g.length = 4

h.length = 3

e.length = 3

e.length = 2

**/*

The array **a** is an uninitialized local variable, and the compiler prevents you from doing anything with this reference until you've properly initialized it. The array **b** is initialized to point to an array of **BerylliumSphere** references, but no actual **BerylliumSphere** objects are ever placed in that array. However, you can still ask what the size of the array is, since **b** is pointing to a legitimate object. This brings up a slight drawback: You can't find out how many elements are

actually *in* the array, since **length** tells you only how many elements *can* be placed in the array; that is, the size of the array object, not the number of elements it actually holds. However, when you create an array object, its references are automatically initialized to **null**, so you test whether a particular array slot has an object in it by checking to see whether it's **null**. Similarly, an array of primitives is automatically initialized to zero for numeric types, **(char)0** for **char**, and **false** for **boolean**.

Array **c** shows the creation of the array object followed by the assignment of **BerylliumSphere** objects to all the slots in the array. Array **d** shows the "aggregate initialization" syntax that causes the array object to be created (implicitly with **new** on the heap, just like for array **c**) *and* initialized with **BerylliumSphere** objects, all in one statement.

The next array initialization can be thought of as a "dynamic aggregate initialization." The aggregate initialization used by **d** must be used at the point of **d**s definition, but with the second syntax you can create and initialize an array object anywhere. For example, suppose **hide()** is a method that takes an array of **BerylliumSphere** objects. You call it by saying:

hide(d);

You can also dynamically create the array you pass as the argument:

hide(**new** BerylliumSphere[]{

new BerylliumSphere(),

new BerylliumSphere()

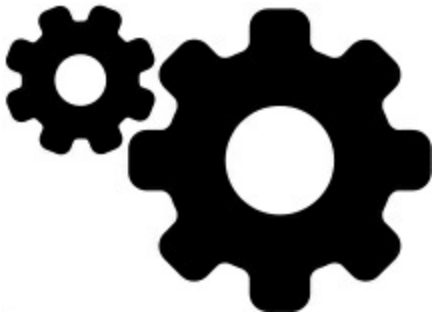
});

In many situations this syntax is a more convenient way to write code.

The expression:

a = d;

shows how you can take a reference that’s attached to one array object and assign it to another array object, just as you can do with any other



type of object reference. Now both **a** and **d** are pointing to the same array object on the heap.

The second part of **ArrayOptions.java** shows that primitive arrays work just like object arrays *except* that primitive arrays hold the primitive values directly.

Returning an Array

Suppose you write a method that returns not one element, but many elements. Languages like C and C++ make this difficult because you can't just return an array, only a pointer to an array. This introduces problems because it becomes messy to control the lifetime of the array, which leads to memory leaks.

In Java, you just return the array. You never worry about responsibility for that array—it is around as long as you need it, and the garbage collector will clean it up when you're done.

Here, we return an array of **String**:

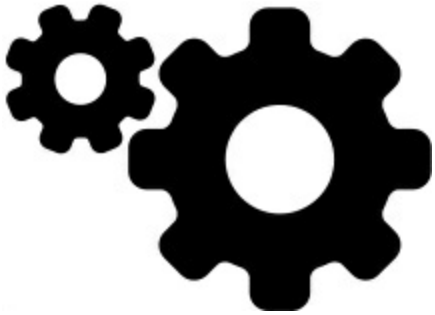
```
// arrays/IceCreamFlavors.java
// Returning arrays from methods
import java.util.*;
import static onjava.ArrayShow.*;
public class IceCreamFlavors {
private static SplittableRandom rand =
new SplittableRandom(47);
static final String[] FLAVORS = {
"Chocolate", "Strawberry", "Vanilla Fudge Swirl",
"Mint Chip", "Mocha Almond Fudge", "Rum Raisin",
```

```
"Praline Cream", "Mud Pie"
};
public static String[] flavorSet(int n) {
if(n > FLAVORS.length)
throw new IllegalArgumentException("Set too big");
String[] results = new String[n];
boolean[] picked = new boolean[FLAVORS.length];
for(int i = 0; i < n; i++) {
int t;
do
t = rand.nextInt(FLAVORS.length);
while(picked[t]);
results[i] = FLAVORS[t];
picked[t] = true;
}
return results;
}
public static void main(String[] args) {
for(int i = 0; i < 7; i++)
show(flavorSet(3));
```

```
}
}
/* Output:
[Praline Cream, Mint Chip, Vanilla Fudge Swirl]
[Strawberry, Vanilla Fudge Swirl, Mud Pie]
[Chocolate, Strawberry, Vanilla Fudge Swirl]
[Rum Raisin, Praline Cream, Chocolate]
[Mint Chip, Rum Raisin, Mocha Almond Fudge]
[Mocha Almond Fudge, Mud Pie, Vanilla Fudge Swirl]
[Mocha Almond Fudge, Mud Pie, Mint Chip]
*/
```

flavorSet() creates an array of **String** called **results**. The size of this array is **n**, determined by the argument you pass into the method. Then it chooses flavors randomly from the array **FLAVORS** and places them into **results**, which it returns. Returning an array is just like returning any other object—it's a reference. It's not important that the array was created within **flavorSet()**, or that the array was created anyplace else, for that matter. The garbage collector takes care of cleaning up the array when you're done with it, and the array will persist for as long as you need it.

If you must return a number of elements of different types, you can instead use the **tuple** utilities introduced in Generics.



As an aside, when **flavorSet()** chooses flavors randomly, it ensures that a particular choice hasn't already been selected. This is performed in a **do** loop that keeps making random choices until it finds one not already in the **picked** array. (A **String** comparison would also show whether the random choice is already in the **results** array.) If it's successful, it adds the entry and finds the next one (**i** gets incremented). The output shows that **flavorSet()** chooses flavors in a random order each time.

Up to this point in the book, random numbers have been generated by the **java.util.Random** class that has been with the language since version 1.0, and has even been updated to provide Java 8 streams. Now we introduce the Java 8 **SplittableRandom**, which not only works with parallel operations (which you'll learn about eventually), but provides higher-quality random numbers. We'll use

SplittableRandom throughout the rest of the book.

Multidimensional Arrays

To create a multidimensional array of primitives, you delimit each vector in the array using curly braces:

```
// arrays/MultidimensionalPrimitiveArray.java
import java.util.*;
public class MultidimensionalPrimitiveArray {
public static void main(String[] args) {
int[][] a = {
{ 1, 2, 3, },
{ 4, 5, 6, },
};
System.out.println(Arrays.deepToString(a));
}
}
/* Output:
[[1, 2, 3], [4, 5, 6]]
*/
```

Each nested set of curly braces moves you into the next level of the

array.

This example uses the **Arrays.deepToString()** method, which turns multidimensional arrays into **String**s, as shown in the output.

You can also allocate an array using **new**. Here's a three-dimensional array allocated in a **new** expression:

```
// arrays/ThreeDWithNew.java
import java.util.*;
public class ThreeDWithNew {
public static void main(String[] args) {
// 3-D array with fixed length:
int[][][] a = new int[2][2][4];
System.out.println(Arrays.deepToString(a));
}
}
/* Output:
[[[0, 0, 0, 0], [0, 0, 0, 0]], [[0, 0, 0, 0], [0, 0, 0,
0]]]
*/
```

Primitive array values are automatically initialized if you don't give them an explicit initialization value. Arrays of objects are initialized to

null.

Each vector in the arrays that make up the matrix can be of any length (this is called a *ragged array*):

```
// arrays/RaggedArray.java
import java.util.*;
public class RaggedArray {
static int val = 1;
public static void main(String[] args) {
SplittableRandom rand = new SplittableRandom(47);
// 3-D array with varied-length vectors:
int[][][] a = new int[rand.nextInt(7)][][];
for(int i = 0; i < a.length; i++) {
a[i] = new int[rand.nextInt(5)][];
for(int j = 0; j < a[i].length; j++) {
a[i][j] = new int[rand.nextInt(5)];
Arrays.setAll(a[i][j], n -> val++); // [1]
}
}
System.out.println(Arrays.deepToString(a));
}
```

}

/ *Output:*

[[[1], []], [[2, 3, 4, 5], [6]], [[7, 8, 9], [10, 11,

12], []]]

**/*

The first **new** creates an array with a random-length first element and the rest undetermined. The second **new** inside the **for** loop fills out the elements but leaves the third index undetermined until you hit the third **new**.

[1] Java 8 added **Arrays.setAll()** which uses a generator to produce values inserted into the array. This generator conforms to the functional interface **IntUnaryOperator** with a single non-**default** method **applyAsInt(int operand)**.

Arrays.setAll() passes the current array index as the **operand**, so one option is to provide a lambda of **n -> n** to show the index in the array (it's easy to try in the above code). Here, we ignore the index and simply insert the value of an incremented counter.

Arrays of non-primitive objects can also be defined as ragged arrays. Here, we collect many **new** expressions using curly braces:

```
// arrays/MultidimensionalObjectArrays.java
import java.util.*;
public class MultidimensionalObjectArrays {
public static void main(String[] args) {
BerylliumSphere[][] spheres = {
{ new BerylliumSphere(), new BerylliumSphere() },
{ new BerylliumSphere(), new BerylliumSphere(),
new BerylliumSphere(), new BerylliumSphere() },
{ new BerylliumSphere(), new BerylliumSphere(),
new BerylliumSphere(), new BerylliumSphere(),
new BerylliumSphere(), new BerylliumSphere(),
new BerylliumSphere(), new BerylliumSphere() },
};
System.out.println(Arrays.deepToString(spheres));
}
}
/* Output:
[[Sphere 0, Sphere 1], [Sphere 2, Sphere 3, Sphere 4,
Sphere 5], [Sphere 6, Sphere 7, Sphere 8, Sphere 9,
Sphere 10, Sphere 11, Sphere 12, Sphere 13]]
```

*/

Autoboxing works with array initializers:

```
// arrays/AutoboxingArrays.java
import java.util.*;
public class AutoboxingArrays {
public static void main(String[] args) {
Integer[][] a = { // Autoboxing:
{ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 },
{ 21, 22, 23, 24, 25, 26, 27, 28, 29, 30 },
{ 51, 52, 53, 54, 55, 56, 57, 58, 59, 60 },
{ 71, 72, 73, 74, 75, 76, 77, 78, 79, 80 },
};
System.out.println(Arrays.deepToString(a));
}
}
/* Output:
[[1, 2, 3, 4, 5, 6, 7, 8, 9, 10], [21, 22, 23, 24, 25,
26, 27, 28, 29, 30], [51, 52, 53, 54, 55, 56, 57, 58,
59, 60], [71, 72, 73, 74, 75, 76, 77, 78, 79, 80]]
*/
```

Here’s how an array of non-primitive objects can be built up piece-by-piece:

```
// arrays/AssemblingMultidimensionalArrays.java
// Creating multidimensional arrays
import java.util.*;
public class AssemblingMultidimensionalArrays {
public static void main(String[] args) {
Integer[][] a;
a = new Integer[3][];
for(int i = 0; i < a.length; i++) {
a[i] = new Integer[3];
for(int j = 0; j < a[i].length; j++)
a[i][j] = i * j; // Autoboxing
}
System.out.println(Arrays.deepToString(a));
}
}
/* Output:
[[0, 0, 0], [0, 1, 2], [0, 2, 4]]
*/
```

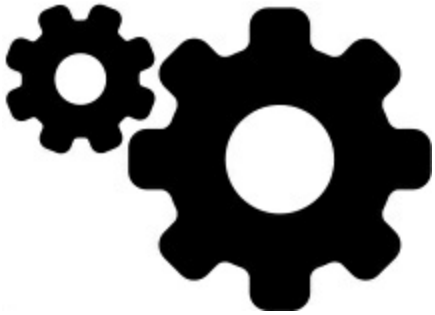
The **i * j** is only there to put an interesting value into the

Integer.

The **Arrays.deepToString()** method works with both primitive

arrays and object arrays:

```
// arrays/MultiDimWrapperArray.java
// Multidimensional arrays of "wrapper" objects
import java.util.*;
public class MultiDimWrapperArray {
public static void main(String[] args) {
```



```
Integer[][] a1 = { // Autoboxing
{ 1, 2, 3, },
{ 4, 5, 6, },
};
Double[][][] a2 = { // Autoboxing
{ { 1.1, 2.2 }, { 3.3, 4.4 } },
{ { 5.5, 6.6 }, { 7.7, 8.8 } },
```

```
{ { 9.9, 1.2 }, { 2.3, 3.4 } },
};
String[][] a3 = {
{ "The", "Quick", "Sly", "Fox" },
{ "Jumped", "Over" },
{ "The", "Lazy", "Brown", "Dog", "&", "friend" },
};
System.out.println(
"a1: " + Arrays.deepToString(a1));
System.out.println(
"a2: " + Arrays.deepToString(a2));
System.out.println(
"a3: " + Arrays.deepToString(a3));
}
}
/* Output:
a1: [[1, 2, 3], [4, 5, 6]]
a2: [[[1.1, 2.2], [3.3, 4.4]], [[5.5, 6.6], [7.7,
8.8]], [[9.9, 1.2], [2.3, 3.4]]]
a3: [[The, Quick, Sly, Fox], [Jumped, Over], [The,
```

Lazy, Brown, Dog, &, friend]]

/

Again, in the **Integer** and **Double** arrays, autoboxing creates the wrapper objects for you.

Arrays and Generics

In general, arrays and generics do not mix well. You cannot instantiate arrays of parameterized types:

```
Peel<Banana>[] peels = new Peel<Banana>[10]; // Illegal
```

Erasure removes the parameter type information, and arrays must know the exact type they hold, to enforce type safety.

However, you can parameterize the type of the array itself:

```
// arrays/ParameterizedArrayType.java
class ClassParameter<T> {
public T[] f(T[] arg) { return arg; }
}
class MethodParameter {
public static <T> T[] f(T[] arg) { return arg; }
}
public class ParameterizedArrayType {
public static void main(String[] args) {
```

```
Integer[] ints = { 1, 2, 3, 4, 5 };
Double[] doubles = { 1.1, 2.2, 3.3, 4.4, 5.5 };
Integer[] ints2 =
new ClassParameter<Integer>().f(ints);
Double[] doubles2 =
new ClassParameter<Double>().f(doubles);
ints2 = MethodParameter.f(ints);
doubles2 = MethodParameter.f(doubles);
}
}
```

It’s convenient to use a parameterized method instead of a parameterized class. You don’t instantiate a class with a parameter for each different type you apply it to, and you can make it **static**. You can’t always choose to use a parameterized method instead of a parameterized class, but it’s usually preferable.

It’s not precisely correct to say you cannot create arrays of generic types. True, the compiler won’t let you *instantiate* an array of a generic type. However, it will let you create a reference to such an array. For example:

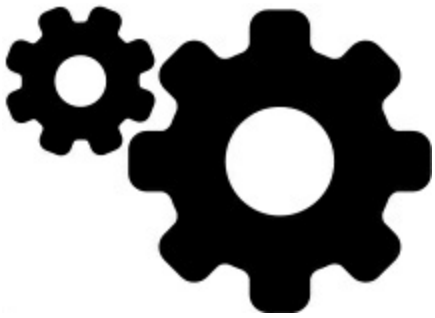
```
List<String>[] ls;
```

This passes through the compiler without complaint. And although you cannot create an actual array object that holds generics, you can create an array of the non-generified type and cast it:

```
// arrays/ArrayOfGenerics.java
import java.util.*;
public class ArrayOfGenerics {
@SuppressWarnings("unchecked")
public static void main(String[] args) {
List<String>[] ls;
List[] la = new List[10];
ls = (List<String>[])la; // Unchecked cast
ls[0] = new ArrayList<>();
//- ls[1] = new ArrayList<Integer>();
// error: incompatible types: ArrayList<Integer>
// cannot be converted to List<String>
// ls[1] = new ArrayList<Integer>();
// ^
// The problem: List<String> is a subtype of Object
Object[] objects = ls; // So assignment is OK
// Compiles and runs without complaint:
```

```
objects[1] = new ArrayList<>();
// However, if your needs are straightforward it is
// possible to create an array of generics, albeit
// with an "unchecked cast" warning:
List<BerylliumSphere>[] spheres =
(List<BerylliumSphere>[])new List[10];
Arrays.setAll(spheres, n -> new ArrayList<>());
}
}
```

Once you have a reference to a **List<String>[]**, you see you get some compile-time checking. The problem is that arrays are covariant, so a **List<String>[]** is also an **Object[]**, and you can use this to assign an **ArrayList<Integer>** into your array, with no error at either compile time or run time.



If you know you’re not going to upcast and your needs are relatively simple, however, it is possible to create an array of generics, which will

provide basic compile-time type checking. However, a generic **Collection** will virtually always be a better choice than an array of generics.

In general you'll find that generics are effective at the *boundaries* of a class or method. In the interiors, erasure usually makes generics unusable. So you cannot, for example, create an array of a generic type:

```
// arrays/ArrayOfGenericType.java
public class ArrayOfGenericType<T> {
T[] array; // OK
@SuppressWarnings("unchecked")
public ArrayOfGenericType(int size) {
// error: generic array creation:
//- array = new T[size];
array = (T[])new Object[size]; // unchecked cast
}
// error: generic array creation:
//- public <U> U[] makeArray() { return new U[10]; }
}
```

Erasure gets in the way again—this example attempts to create arrays

of types that have been erased, and are thus unknown types. You can create an array of **Object**, and cast it, but without the **@SuppressWarnings** annotation you get an “unchecked” warning at compile time because the array doesn’t really hold or dynamically check for type **T**. That is, if I create a **String[]**, Java will enforce, at both compile time and run time, that I can only place **String** objects in that array. However, if I create an **Object[]**, I can put anything into that array except primitive types.

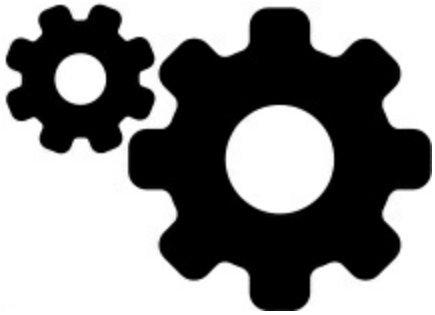
Arrays.fill()

When experimenting with arrays, and with programs in general, it’s helpful to easily generate arrays filled with test data. The Java standard library **Arrays** class includes a trivial **fill()** method that duplicates a single value into each location, or in the case of objects, copies the same reference into each location:

```
// arrays/FillingArrays.java
// Using Arrays.fill()
import java.util.*;
import static onjava.ArrayShow.*;
public class FillingArrays {
public static void main(String[] args) {
```

```
int size = 6;
boolean[] a1 = new boolean[size];
byte[] a2 = new byte[size];
char[] a3 = new char[size];
short[] a4 = new short[size];
int[] a5 = new int[size];
long[] a6 = new long[size];
float[] a7 = new float[size];
double[] a8 = new double[size];
String[] a9 = new String[size];
Arrays.fill(a1, true);
show("a1", a1);
Arrays.fill(a2, (byte)11);
show("a2", a2);
Arrays.fill(a3, 'x');
show("a3", a3);
Arrays.fill(a4, (short)17);
show("a4", a4);
Arrays.fill(a5, 19);
show("a5", a5);
```

```
Arrays.fill(a6, 23);
show("a6", a6);
Arrays.fill(a7, 29);
show("a7", a7);
Arrays.fill(a8, 47);
show("a8", a8);
Arrays.fill(a9, "Hello");
show("a9", a9);
// Manipulating ranges:
```



```
Arrays.fill(a9, 3, 5, "World");
show("a9", a9);
}
}
/* Output:
a1: [true, true, true, true, true, true]
a2: [11, 11, 11, 11, 11, 11]
```

a3: [x, x, x, x, x, x]

a4: [17, 17, 17, 17, 17, 17]

a5: [19, 19, 19, 19, 19, 19]

a6: [23, 23, 23, 23, 23, 23]

a7: [29.0, 29.0, 29.0, 29.0, 29.0, 29.0]

a8: [47.0, 47.0, 47.0, 47.0, 47.0, 47.0]

a9: [Hello, Hello, Hello, Hello, Hello, Hello]

a9: [Hello, Hello, Hello, World, World, Hello]

**/*

You can either fill the entire array or, as the last two statements show, fill a range of elements. But since you can only call **Arrays.fill()** with a single data value, the results are not especially useful.

Arrays.setAll()

Introduced in **RaggedArray.java** and used again in **ArrayOfGenerics.java**, **Arrays.setAll()** was added in Java 8. It takes a generator and produces different values, optionally based on the index element of the array (with access to the current index, your generator can read the array value and modify it). The overloaded signatures of the **static Arrays.setAll()** are:

void setAll(int[] a, IntUnaryOperator gen)

void setAll(long[] a, IntToLongFunction gen)

void setAll(double[] a, IntToDoubleFunction

gen)

<T> void setAll(T[] a, IntFunction<? extends

T> gen)

There are special versions for **int**, **long**, and **double**, and everything else is handled by the generic version. The generators are not **Supplier**s because those take no arguments, and these must take the **int** array index as an argument.

This very simple **setAll()** example uses trivial lambda expressions and method references:

```
// arrays/SimpleSetAll.java
import java.util.*;
import static onjava.ArrayShow.*;
class Bob {
final int id;
Bob(int n) { id = n; }
@Override
public String toString() { return "Bob" + id; }
}
```

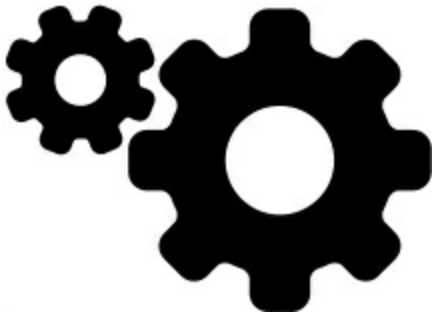
```
public class SimpleSetAll {
public static final int SZ = 8;
static int val = 1;
static char[] chars = "abcdefghijklmnopqrstuvwxyz"
.toCharArray();
static char getChar(int n) { return chars[n]; }
public static void main(String[] args) {
int[] ia = new int[SZ];
long[] la = new long[SZ];
double[] da = new double[SZ];
Arrays.setAll(ia, n -> n); // [1]
Arrays.setAll(la, n -> n);
Arrays.setAll(da, n -> n);
show(ia);
show(la);
show(da);
Arrays.setAll(ia, n -> val++); // [2]
Arrays.setAll(la, n -> val++);
Arrays.setAll(da, n -> val++);
show(ia);
```

```
show(la);
show(da);
Bob[] ba = new Bob[SZ];
Arrays.setAll(ba, Bob::new); // [3]
show(ba);
Character[] ca = new Character[SZ];
Arrays.setAll(ca, SimpleSetAll::getChar); // [4]
show(ca);
}
}
/* Output:
[0, 1, 2, 3, 4, 5, 6, 7]
[0, 1, 2, 3, 4, 5, 6, 7]
[0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0]
[1, 2, 3, 4, 5, 6, 7, 8]
[9, 10, 11, 12, 13, 14, 15, 16]
[17.0, 18.0, 19.0, 20.0, 21.0, 22.0, 23.0, 24.0]
[Bob0, Bob1, Bob2, Bob3, Bob4, Bob5, Bob6, Bob7]
[a, b, c, d, e, f, g, h]
*/
```

[1] Here, we just insert the array index as the value. This is automatically converted for the **long** and **double** versions.

[2] The function only needs to accept the index and produce an appropriate result. Here we ignore the index value and produce the result using **val**.

[3] The method reference works because **Bob**'s constructor takes an **int** argument. As long as the function we pass takes an **int** argument and produces the expected result, it does the job.



[4] To deal with a primitive type other than **int**, **long**, or **double**, make the array of the wrapper type for your primitive. Then the generic version of **setAll()** is used. Notice that **getChar()** produces the primitive type, so this is autoboxed to **Character**.

Incremental

Generators

Here is a package of methods to produce incremental values for

different types.

These are written as inner classes to produce easy-to-remember names; for example, to use the **Integer** tool you say **new Count.Integer()**, and if you want the primitive **int** tool you say **new Count.Pint()** (the primitive names could not be used directly, so they are all preceded by a **P** for "primitive"—my first choice was to use the primitive name followed by a trailing underscore, such as **int_** and **double_**, but that violates Java naming conventions).

Each generator for a wrapper class also implements its associated **Supplier** with a **get()** method. To work with **Arrays.setAll()**, an overloaded **get(int n)** method takes (and ignores) its argument so it accepts the index value passed by **setAll()**.

Note that, by using the name of a wrapper class as an inner class name, we must qualify the name of the actual wrapper with **java.lang**:

```
// onjava/Count.java
// Generate incremental values of different types
package onjava;
import java.util.*;
```

```
import java.util.function.*;
import static onjava.ConvertTo.*;
public interface Count {
class Boolean
implements Supplier<java.lang.Boolean> {
private boolean b = true;
@Override
public java.lang.Boolean get() {
b = !b;
return java.lang.Boolean.valueOf(b);
}
public java.lang.Boolean get(int n) {
return get();
}
public java.lang.Boolean[] array(int sz) {
java.lang.Boolean[] result =
new java.lang.Boolean[sz];
Arrays.setAll(result, n -> get());
return result;
}
```

```
}
class Pboolean {
private boolean b = true;
public boolean get() {
b = !b;
return b;
}
public boolean get(int n) { return get(); }
public boolean[] array(int sz) {
return primitive(new Boolean().array(sz));
}
}
class Byte
implements Supplier<java.lang.Byte> {
private byte b;
@Override
public java.lang.Byte get() { return b++; }
public java.lang.Byte get(int n) {
return get();
}
```

```
public java.lang.Byte[] array(int sz) {
java.lang.Byte[] result =
new java.lang.Byte[sz];
Arrays.setAll(result, n -> get());
return result;
}
}
class Pbyte {
private byte b;
public byte get() { return b++; }
public byte get(int n) { return get(); }
public byte[] array(int sz) {
return primitive(new Byte().array(sz));
}
}
char[] CHARS =
"abcdefghijklmnopqrstuvwxyz".toCharArray();
class Character
implements Supplier<java.lang.Character> {
private int i;
```

```
@Override
public java.lang.Character get() {
i = (i + 1) % CHARS.length;
return CHARS[i];
}
public java.lang.Character get(int n) {
return get();
}
public java.lang.Character[] array(int sz) {
java.lang.Character[] result =
new java.lang.Character[sz];
Arrays.setAll(result, n -> get());
return result;
}
}
class Pchar {
private int i;
public char get() {
i = (i + 1) % CHARS.length;
return CHARS[i];
```

```
}
public char get(int n) { return get(); }
public char[] array(int sz) {
return primitive(new Character().array(sz));
}
}
class Short
implements Supplier<java.lang.Short> {
short s;
@Override
public java.lang.Short get() { return s++; }
public java.lang.Short get(int n) {
return get();
}
public java.lang.Short[] array(int sz) {
java.lang.Short[] result =
new java.lang.Short[sz];
Arrays.setAll(result, n -> get());
return result;
}
```

```
}
class Pshort {
short s;
public short get() { return s++; }
public short get(int n) { return get(); }
public short[] array(int sz) {
return primitive(new Short().array(sz));
}
}
class Integer
implements Supplier<java.lang.Integer> {
int i;
@Override
public java.lang.Integer get() { return i++; }
public java.lang.Integer get(int n) {
return get();
}
public java.lang.Integer[] array(int sz) {
java.lang.Integer[] result =
new java.lang.Integer[sz];
```

```
Arrays.setAll(result, n -> get());
return result;
}
}
class Pint implements IntSupplier {
int i;
public int get() { return i++; }
public int get(int n) { return get(); }
@Override
public int getAsInt() { return get(); }
public int[] array(int sz) {
return primitive(new Integer().array(sz));
}
}
class Long
implements Supplier<java.lang.Long> {
private long l;
@Override
public java.lang.Long get() { return l++; }
public java.lang.Long get(int n) {
```

```
return get();
}
public java.lang.Long[] array(int sz) {
java.lang.Long[] result =
new java.lang.Long[sz];
Arrays.setAll(result, n -> get());
return result;
}
}
class Plong implements LongSupplier {
private long l;
public long get() { return l++; }
public long get(int n) { return get(); }
@Override
public long getAsLong() { return get(); }
public long[] array(int sz) {
return primitive(new Long().array(sz));
}
}
class Float
```

```
implements Supplier<java.lang.Float> {
private int i;
@Override
public java.lang.Float get() {
return java.lang.Float.valueOf(i++);
}
public java.lang.Float get(int n) {
return get();
}
public java.lang.Float[] array(int sz) {
java.lang.Float[] result =
new java.lang.Float[sz];
Arrays.setAll(result, n -> get());
return result;
}
}
class Pfloat {
private int i;
public float get() { return i++; }
public float get(int n) { return get(); }
```

```
public float[] array(int sz) {
return primitive(new Float().array(sz));
}
}
class Double
implements Supplier<java.lang.Double> {
private int i;
@Override
public java.lang.Double get() {
return java.lang.Double.valueOf(i++);
}
public java.lang.Double get(int n) {
return get();
}
public java.lang.Double[] array(int sz) {
java.lang.Double[] result =
new java.lang.Double[sz];
Arrays.setAll(result, n -> get());
return result;
}
```

```
}
class Pdouble implements DoubleSupplier {
private int i;
public double get() { return i++; }
public double get(int n) { return get(); }
@Override
public double getAsDouble() { return get(0); }
public double[] array(int sz) {
return primitive(new Double().array(sz));
}
}
}
```

For the three primitive types **int**, **long** and **double** where special **Supplier** interfaces are available, **Pint**, **Plong** and **Pdouble** implement those interfaces.

Here is a test for **Count**, which also gives examples of how to use it:

```
// arrays/TestCount.java
// Test counting generators
import java.util.*;
import java.util.stream.*;
```

```
import onjava.*;
import static onjava.ArrayShow.*;
public class TestCount {
static final int SZ = 5;
public static void main(String[] args) {
System.out.println("Boolean");
Boolean[] a1 = new Boolean[SZ];
Arrays.setAll(a1, new Count.Boolean()::get);
show(a1);
a1 = Stream.generate(new Count.Boolean())
.limit(SZ + 1).toArray(Boolean[]::new);
show(a1);
a1 = new Count.Boolean().array(SZ + 2);
show(a1);
boolean[] a1b =
new Count.Pboolean().array(SZ + 3);
show(a1b);
System.out.println("Byte");
Byte[] a2 = new Byte[SZ];
Arrays.setAll(a2, new Count.Byte()::get);
```

```
show(a2);
a2 = Stream.generate(new Count.Byte())
.limit(SZ + 1).toArray(Byte[]::new);
show(a2);
a2 = new Count.Byte().array(SZ + 2);
show(a2);
byte[] a2b = new Count.Pbyte().array(SZ + 3);
show(a2b);
System.out.println("Character");
Character[] a3 = new Character[SZ];
Arrays.setAll(a3, new Count.Character()::get);
show(a3);
a3 = Stream.generate(new Count.Character())
.limit(SZ + 1).toArray(Character[]::new);
show(a3);
a3 = new Count.Character().array(SZ + 2);
show(a3);
char[] a3b = new Count.Pchar().array(SZ + 3);
show(a3b);
System.out.println("Short");
```

```
Short[] a4 = new Short[SZ];
Arrays.setAll(a4, new Count.Short()::get);
show(a4);
a4 = Stream.generate(new Count.Short())
.limit(SZ + 1).toArray(Short[]::new);
show(a4);
a4 = new Count.Short().array(SZ + 2);
show(a4);
short[] a4b = new Count.Pshort().array(SZ + 3);
show(a4b);
System.out.println("Integer");
int[] a5 = new int[SZ];
Arrays.setAll(a5, new Count.Integer()::get);
show(a5);
Integer[] a5b =
Stream.generate(new Count.Integer())
.limit(SZ + 1).toArray(Integer[]::new);
show(a5b);
a5b = new Count.Integer().array(SZ + 2);
show(a5b);
```

```
a5 = IntStream.generate(new Count.Pint())
.limit(SZ + 1).toArray();
show(a5);
a5 = new Count.Pint().array(SZ + 3);
show(a5);
System.out.println("Long");
long[] a6 = new long[SZ];
Arrays.setAll(a6, new Count.Long()::get);
show(a6);
Long[] a6b = Stream.generate(new Count.Long())
.limit(SZ + 1).toArray(Long[]::new);
show(a6b);
a6b = new Count.Long().array(SZ + 2);
show(a6b);
a6 = LongStream.generate(new Count.Plong())
.limit(SZ + 1).toArray();
show(a6);
a6 = new Count.Plong().array(SZ + 3);
show(a6);
System.out.println("Float");
```

```
Float[] a7 = new Float[SZ];
Arrays.setAll(a7, new Count.Float()::get);
show(a7);
a7 = Stream.generate(new Count.Float())
.limit(SZ + 1).toArray(Float[]::new);
show(a7);
a7 = new Count.Float().array(SZ + 2);
show(a7);
float[] a7b = new Count.Pfloat().array(SZ + 3);
show(a7b);
System.out.println("Double");
double[] a8 = new double[SZ];
Arrays.setAll(a8, new Count.Double()::get);
show(a8);
Double[] a8b =
Stream.generate(new Count.Double())
.limit(SZ + 1).toArray(Double[]::new);
show(a8b);
a8b = new Count.Double().array(SZ + 2);
show(a8b);
```

```
a8 = DoubleStream.generate(new Count.Pdouble())
.limit(SZ + 1).toArray();
show(a8);
a8 = new Count.Pdouble().array(SZ + 3);
show(a8);
}
}
/* Output:
```

Boolean

[false, true, false, true, false]

[false, true, false, true, false, true]

[false, true, false, true, false, true, false]

[false, true, false, true, false, true, false, true]

Byte

[0, 1, 2, 3, 4]

[0, 1, 2, 3, 4, 5]

[0, 1, 2, 3, 4, 5, 6]

[0, 1, 2, 3, 4, 5, 6, 7]

Character

[b, c, d, e, f]

[b, c, d, e, f, g]

[b, c, d, e, f, g, h]

[b, c, d, e, f, g, h, i]

Short

[0, 1, 2, 3, 4]

[0, 1, 2, 3, 4, 5]

[0, 1, 2, 3, 4, 5, 6]

[0, 1, 2, 3, 4, 5, 6, 7]

Integer

[0, 1, 2, 3, 4]

[0, 1, 2, 3, 4, 5]

[0, 1, 2, 3, 4, 5, 6]

[0, 1, 2, 3, 4, 5]

[0, 1, 2, 3, 4, 5, 6, 7]

Long

[0, 1, 2, 3, 4]

[0, 1, 2, 3, 4, 5]

[0, 1, 2, 3, 4, 5, 6]

[0, 1, 2, 3, 4, 5]

[0, 1, 2, 3, 4, 5, 6, 7]

Float

[0.0, 1.0, 2.0, 3.0, 4.0]

[0.0, 1.0, 2.0, 3.0, 4.0, 5.0]

[0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0]

[0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0]

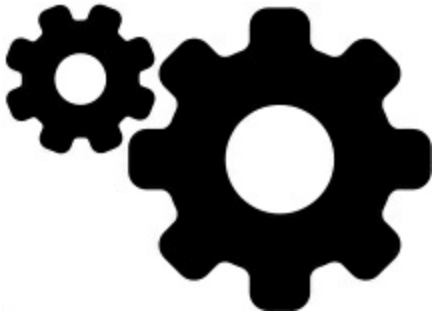
Double

[0.0, 1.0, 2.0, 3.0, 4.0]

[0.0, 1.0, 2.0, 3.0, 4.0, 5.0]

[0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0]

[0.0, 1.0, 2.0, 3.0, 4.0, 5.0]



[0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0]

*/

Notice the primitive array types **int[]**, **long[]** and **double[]** can be filled directly using **Arrays.setAll()**, but all other primitives require arrays of their wrapper types.

The wrapped arrays created via **Stream.generate()** show the overloaded use of **toArray()**, where you provide it with the constructor for the type of array to create.

Random Generators

We can follow the structure of **Count.java** to create a tool that produces random values:

// onjava/Rand.java

// Generate random values of different types

package onjava;

```
import java.util.*;
import java.util.function.*;
import static onjava.ConvertTo.*;
public interface Rand {
int MOD = 10_000;
class Boolean
implements Supplier<java.lang.Boolean> {
SplittableRandom r = new SplittableRandom(47);
@Override
public java.lang.Boolean get() {
return r.nextBoolean();
}
public java.lang.Boolean get(int n) {
return get();
}
public java.lang.Boolean[] array(int sz) {
java.lang.Boolean[] result =
new java.lang.Boolean[sz];
Arrays.setAll(result, n -> get());
return result;
```

```
}
}
class Pboolean {
public boolean[] array(int sz) {
return primitive(new Boolean().array(sz));
}
}
class Byte
implements Supplier<java.lang.Byte> {
SplittableRandom r = new SplittableRandom(47);
@Override
public java.lang.Byte get() {
return (byte)r.nextInt(MOD);
}
public java.lang.Byte get(int n) {
return get();
}
public java.lang.Byte[] array(int sz) {
java.lang.Byte[] result =
new java.lang.Byte[sz];
```

```
Arrays.setAll(result, n -> get());
return result;
}
}
class Pbyte {
public byte[] array(int sz) {
return primitive(new Byte().array(sz));
}
}
class Character
implements Supplier<java.lang.Character> {
SplittableRandom r = new SplittableRandom(47);
@Override
public java.lang.Character get() {
return (char)r.nextInt('a', 'z' + 1);
}
public java.lang.Character get(int n) {
return get();
}
public java.lang.Character[] array(int sz) {
```

```
java.lang.Character[] result =
new java.lang.Character[sz];
Arrays.setAll(result, n -> get());
return result;
}
}
class Pchar {
public char[] array(int sz) {
return primitive(new Character().array(sz));
}
}
class Short
implements Supplier<java.lang.Short> {
SplittableRandom r = new SplittableRandom(47);
@Override
public java.lang.Short get() {
return (short)r.nextInt(MOD);
}
public java.lang.Short get(int n) {
return get();
```

```
}
public java.lang.Short[] array(int sz) {
java.lang.Short[] result =
new java.lang.Short[sz];
Arrays.setAll(result, n -> get());
return result;
}
}
class Pshort {
public short[] array(int sz) {
return primitive(new Short().array(sz));
}
}
class Integer
implements Supplier<java.lang.Integer> {
SplittableRandom r = new SplittableRandom(47);
@Override
public java.lang.Integer get() {
return r.nextInt(MOD);
}
```

```
public java.lang.Integer get(int n) {
return get();
}
public java.lang.Integer[] array(int sz) {
int[] primitive = new Pint().array(sz);
java.lang.Integer[] result =
new java.lang.Integer[sz];
for(int i = 0; i < sz; i++)
result[i] = primitive[i];
return result;
}
}
class Pint implements IntSupplier {
SplittableRandom r = new SplittableRandom(47);
@Override
public int getAsInt() {
return r.nextInt(MOD);
}
public int get(int n) { return getAsInt(); }
public int[] array(int sz) {
```

```
return r.ints(sz, 0, MOD).toArray();
}
}
class Long
implements Supplier<java.lang.Long> {
SplittableRandom r = new SplittableRandom(47);
@Override
public java.lang.Long get() {
return r.nextLong(MOD);
}
public java.lang.Long get(int n) {
return get();
}
public java.lang.Long[] array(int sz) {
long[] primitive = new Plong().array(sz);
java.lang.Long[] result =
new java.lang.Long[sz];
for(int i = 0; i < sz; i++)
result[i] = primitive[i];
return result;
```

```
}
}
class Plong implements LongSupplier {
SplittableRandom r = new SplittableRandom(47);
@Override
public long getAsLong() {
return r.nextLong(MOD);
}
public long get(int n) { return getAsLong(); }
public long[] array(int sz) {
return r.longs(sz, 0, MOD).toArray();
}
}
class Float
implements Supplier<java.lang.Float> {
SplittableRandom r = new SplittableRandom(47);
@Override
public java.lang.Float get() {
return (float)trim(r.nextDouble());
}
```

```
public java.lang.Float get(int n) {
return get();
}
public java.lang.Float[] array(int sz) {
java.lang.Float[] result =
new java.lang.Float[sz];
Arrays.setAll(result, n -> get());
return result;
}
}
class Pfloat {
public float[] array(int sz) {
return primitive(new Float().array(sz));
}
}
static double trim(double d) {
return
((double)Math.round(d * 1000.0)) / 100.0;
}
class Double
```

```
implements Supplier<java.lang.Double> {
SplittableRandom r = new SplittableRandom(47);
@Override
public java.lang.Double get() {
return trim(r.nextDouble());
}
public java.lang.Double get(int n) {
return get();
}
public java.lang.Double[] array(int sz) {
double[] primitive =
new Rand.Pdouble().array(sz);
java.lang.Double[] result =
new java.lang.Double[sz];
for(int i = 0; i < sz; i++)
result[i] = primitive[i];
return result;
}
}
class Pdouble implements DoubleSupplier {
```

```
SplittableRandom r = new SplittableRandom(47);
@Override
public double getAsDouble() {
return trim(r.nextDouble());
}
public double get(int n) {
return getAsDouble();
}
public double[] array(int sz) {
double[] result = r.doubles(sz).toArray();
Arrays.setAll(result,
n -> result[n] = trim(result[n]));
return result;
}
}
class String
implements Supplier<java.lang.String> {
SplittableRandom r = new SplittableRandom(47);
private int strlen = 7; // Default length
public String() {}
```

```
public String(int strLength) {
strlen = strLength;
}
@Override
public java.lang.String get() {
return r.ints(strlen, 'a', 'z' + 1)
.collect(StringBuilder::new,
StringBuilder::appendCodePoint,
StringBuilder::append).toString();
}
public java.lang.String get(int n) {
return get();
}
public java.lang.String[] array(int sz) {
java.lang.String[] result =
new java.lang.String[sz];
Arrays.setAll(result, n -> get());
return result;
}
}
```

}

For all primitive generators except for **int**, **long** and **double**, only arrays are generated rather than the full set of operations seen in **Count**. This is just a design choice, because the book doesn't need the extra features.

Here's a test for all the **Rand** tools:

```
// arrays/TestRand.java
// Test random generators
import java.util.*;
import java.util.stream.*;
import onjava.*;
import static onjava.ArrayShow.*;
public class TestRand {
static final int SZ = 5;
public static void main(String[] args) {
System.out.println("Boolean");
Boolean[] a1 = new Boolean[SZ];
Arrays.setAll(a1, new Rand.Boolean()::get);
show(a1);
a1 = Stream.generate(new Rand.Boolean())
```

```
.limit(SZ + 1).toArray(Boolean[]::new);
show(a1);
a1 = new Rand.Boolean().array(SZ + 2);
show(a1);
boolean[] a1b =
new Rand.Pboolean().array(SZ + 3);
show(a1b);
System.out.println("Byte");
Byte[] a2 = new Byte[SZ];
Arrays.setAll(a2, new Rand.Byte()::get);
show(a2);
a2 = Stream.generate(new Rand.Byte())
.limit(SZ + 1).toArray(Byte[]::new);
show(a2);
a2 = new Rand.Byte().array(SZ + 2);
show(a2);
byte[] a2b = new Rand.Pbyte().array(SZ + 3);
show(a2b);
System.out.println("Character");
Character[] a3 = new Character[SZ];
```

```
Arrays.setAll(a3, new Rand.Character()::get);
show(a3);
a3 = Stream.generate(new Rand.Character())
.limit(SZ + 1).toArray(Character[]::new);
show(a3);
a3 = new Rand.Character().array(SZ + 2);
show(a3);
char[] a3b = new Rand.Pchar().array(SZ + 3);
show(a3b);
System.out.println("Short");
Short[] a4 = new Short[SZ];
Arrays.setAll(a4, new Rand.Short()::get);
show(a4);
a4 = Stream.generate(new Rand.Short())
.limit(SZ + 1).toArray(Short[]::new);
show(a4);
a4 = new Rand.Short().array(SZ + 2);
show(a4);
short[] a4b = new Rand.Pshort().array(SZ + 3);
show(a4b);
```

```
System.out.println("Integer");
int[] a5 = new int[SZ];
Arrays.setAll(a5, new Rand.Integer()::get);
show(a5);
Integer[] a5b =
Stream.generate(new Rand.Integer())
.limit(SZ + 1).toArray(Integer[]::new);
show(a5b);
a5b = new Rand.Integer().array(SZ + 2);
show(a5b);
a5 = IntStream.generate(new Rand.Pint())
.limit(SZ + 1).toArray();
show(a5);
a5 = new Rand.Pint().array(SZ + 3);
show(a5);
System.out.println("Long");
long[] a6 = new long[SZ];
Arrays.setAll(a6, new Rand.Long()::get);
show(a6);
Long[] a6b = Stream.generate(new Rand.Long())
```

```
.limit(SZ + 1).toArray(Long[]::new);
show(a6b);
a6b = new Rand.Long().array(SZ + 2);
show(a6b);
a6 = LongStream.generate(new Rand.Plong())
.limit(SZ + 1).toArray();
show(a6);
a6 = new Rand.Plong().array(SZ + 3);
show(a6);
System.out.println("Float");
Float[] a7 = new Float[SZ];
Arrays.setAll(a7, new Rand.Float()::get);
show(a7);
a7 = Stream.generate(new Rand.Float())
.limit(SZ + 1).toArray(Float[]::new);
show(a7);
a7 = new Rand.Float().array(SZ + 2);
show(a7);
float[] a7b = new Rand.Pfloat().array(SZ + 3);
show(a7b);
```

```
System.out.println("Double");
double[] a8 = new double[SZ];
Arrays.setAll(a8, new Rand.Double()::get);
show(a8);
Double[] a8b =
Stream.generate(new Rand.Double())
.limit(SZ + 1).toArray(Double[]::new);
show(a8b);
a8b = new Rand.Double().array(SZ + 2);
show(a8b);
a8 = DoubleStream.generate(new Rand.Pdouble())
.limit(SZ + 1).toArray();
show(a8);
a8 = new Rand.Pdouble().array(SZ + 3);
show(a8);
System.out.println("String");
String[] s = new String[SZ - 1];
Arrays.setAll(s, new Rand.String()::get);
show(s);
s = Stream.generate(new Rand.String())
```

```
.limit(SZ).toArray(String[]::new);
show(s);
s = new Rand.String().array(SZ + 1);
show(s);
Arrays.setAll(s, new Rand.String(4)::get);
show(s);
s = Stream.generate(new Rand.String(4))
.limit(SZ).toArray(String[]::new);
show(s);
s = new Rand.String(4).array(SZ + 1);
show(s);
}
}
/* Output:
Boolean
[true, false, true, true, true]
[true, false, true, true, true, false]
[true, false, true, true, true, false, false]
[true, false, true, true, true, false, false, true]
Byte
```

[123, 33, 101, 112, 33]

[123, 33, 101, 112, 33, 31]

[123, 33, 101, 112, 33, 31, 0]

[123, 33, 101, 112, 33, 31, 0, -72]

Character

[b, t, p, e, n]

[b, t, p, e, n, p]

[b, t, p, e, n, p, c]

[b, t, p, e, n, p, c, c]

Short

[635, 8737, 3941, 4720, 6177]

[635, 8737, 3941, 4720, 6177, 8479]

[635, 8737, 3941, 4720, 6177, 8479, 6656]

[635, 8737, 3941, 4720, 6177, 8479, 6656, 3768]

Integer

[635, 8737, 3941, 4720, 6177]

[635, 8737, 3941, 4720, 6177, 8479]

[635, 8737, 3941, 4720, 6177, 8479, 6656]

[635, 8737, 3941, 4720, 6177, 8479]

[635, 8737, 3941, 4720, 6177, 8479, 6656, 3768]

Long

[6882, 3765, 692, 9575, 4439]

[6882, 3765, 692, 9575, 4439, 2638]

[6882, 3765, 692, 9575, 4439, 2638, 4011]

[6882, 3765, 692, 9575, 4439, 2638]

[6882, 3765, 692, 9575, 4439, 2638, 4011, 9610]

Float

[4.83, 2.89, 2.9, 1.97, 3.01]

[4.83, 2.89, 2.9, 1.97, 3.01, 0.18]

[4.83, 2.89, 2.9, 1.97, 3.01, 0.18, 0.99]

[4.83, 2.89, 2.9, 1.97, 3.01, 0.18, 0.99, 8.28]

Double

[4.83, 2.89, 2.9, 1.97, 3.01]

[4.83, 2.89, 2.9, 1.97, 3.01, 0.18]

[4.83, 2.89, 2.9, 1.97, 3.01, 0.18, 0.99]

[4.83, 2.89, 2.9, 1.97, 3.01, 0.18]

[4.83, 2.89, 2.9, 1.97, 3.01, 0.18, 0.99, 8.28]

String

[btpenpc, cuxszgv, gmeinne, eloztdv]

[btpenpc, cuxszgv, gmeinne, eloztdv, ewcippc]

[btpenpc, cuxszgv, gmeinne, eloztdv, ewcippc, ygpoalk]

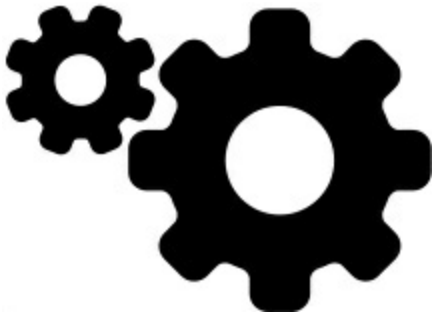
[btpe, npcc, uxsz, gvgm, einn, eelo]

[btpe, npcc, uxsz, gvgm, einn]

[btpe, npcc, uxsz, gvgm, einn, eelo]

*/

Notice that (with the exception of the **String** section), this code is identical to that in **TestCount.java**, with **Count** replaced by **Rand**.



Generics and Primitive Arrays

Earlier in this chapter we were reminded that generics don't work with primitives. It's not uncommon to encounter situations where we must convert from arrays of primitives to arrays of wrapped types, and also to convert in the other direction. Here's a converter that performs both operations for all types:

// onjava/ConvertTo.java

```
package onjava;
public interface ConvertTo {
static boolean[] primitive(Boolean[] in) {
boolean[] result = new boolean[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i]; // Autounboxing
return result;
}
static char[] primitive(Character[] in) {
char[] result = new char[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
static byte[] primitive(Byte[] in) {
byte[] result = new byte[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
```

```
static short[] primitive(Short[] in) {
short[] result = new short[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
static int[] primitive(Integer[] in) {
int[] result = new int[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
static long[] primitive(Long[] in) {
long[] result = new long[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
static float[] primitive(Float[] in) {
float[] result = new float[in.length];
```

```
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
static double[] primitive(Double[] in) {
double[] result = new double[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
// Convert from primitive array to wrapped array:
static Boolean[] boxed(boolean[] in) {
Boolean[] result = new Boolean[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i]; // Autoboxing
return result;
}
static Character[] boxed(char[] in) {
Character[] result = new Character[in.length];
for(int i = 0; i < in.length; i++)
```

```
result[i] = in[i];
return result;
}
static Byte[] boxed(byte[] in) {
Byte[] result = new Byte[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
static Short[] boxed(short[] in) {
Short[] result = new Short[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
static Integer[] boxed(int[] in) {
Integer[] result = new Integer[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
```

```
}
static Long[] boxed(long[] in) {
Long[] result = new Long[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
static Float[] boxed(float[] in) {
Float[] result = new Float[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
static Double[] boxed(double[] in) {
Double[] result = new Double[in.length];
for(int i = 0; i < in.length; i++)
result[i] = in[i];
return result;
}
}
```

Each version of **primitive()** creates an appropriate primitive array of the correct length, then copies the elements from the **in** array of wrapper types. If any of the wrapped-array elements is **null**, you'll get an exception (this is reasonable—what value would you substitute that has meaning?). Notice how autounboxing takes place during assignment.

Here's a test for each method in **ConvertTo**:

```
// arrays/TestConvertTo.java
import java.util.*;
import onjava.*;
import static onjava.ArrayShow.*;
import static onjava.ConvertTo.*;
public class TestConvertTo {
static final int SIZE = 6;
public static void main(String[] args) {
Boolean[] a1 = new Boolean[SIZE];
Arrays.setAll(a1, new Rand.Boolean()::get);
boolean[] a1p = primitive(a1);
show("a1p", a1p);
Boolean[] a1b = boxed(a1p);
```

```
show("a1b", a1b);
Byte[] a2 = new Byte[SIZE];
Arrays.setAll(a2, new Rand.Byte()::get);
byte[] a2p = primitive(a2);
show("a2p", a2p);
Byte[] a2b = boxed(a2p);
show("a2b", a2b);
Character[] a3 = new Character[SIZE];
Arrays.setAll(a3, new Rand.Character()::get);
char[] a3p = primitive(a3);
show("a3p", a3p);
Character[] a3b = boxed(a3p);
show("a3b", a3b);
Short[] a4 = new Short[SIZE];
Arrays.setAll(a4, new Rand.Short()::get);
short[] a4p = primitive(a4);
show("a4p", a4p);
Short[] a4b = boxed(a4p);
show("a4b", a4b);
Integer[] a5 = new Integer[SIZE];
```

```
Arrays.setAll(a5, new Rand.Integer()::get);
int[] a5p = primitive(a5);
show("a5p", a5p);
Integer[] a5b = boxed(a5p);
show("a5b", a5b);
Long[] a6 = new Long[SIZE];
Arrays.setAll(a6, new Rand.Long()::get);
long[] a6p = primitive(a6);
show("a6p", a6p);
Long[] a6b = boxed(a6p);
show("a6b", a6b);
Float[] a7 = new Float[SIZE];
Arrays.setAll(a7, new Rand.Float()::get);
float[] a7p = primitive(a7);
show("a7p", a7p);
Float[] a7b = boxed(a7p);
show("a7b", a7b);
Double[] a8 = new Double[SIZE];
Arrays.setAll(a8, new Rand.Double()::get);
double[] a8p = primitive(a8);
```

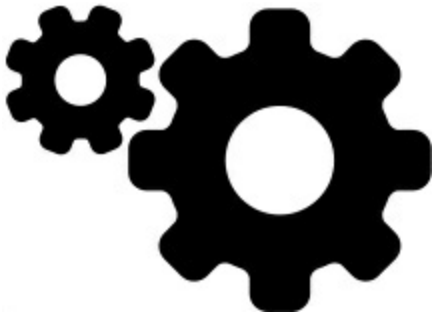
```
show("a8p", a8p);
Double[] a8b = boxed(a8p);
show("a8b", a8b);
}
}
/* Output:
a1p: [true, false, true, true, true, false]
a1b: [true, false, true, true, true, false]
a2p: [123, 33, 101, 112, 33, 31]
a2b: [123, 33, 101, 112, 33, 31]
a3p: [b, t, p, e, n, p]
a3b: [b, t, p, e, n, p]
a4p: [635, 8737, 3941, 4720, 6177, 8479]
a4b: [635, 8737, 3941, 4720, 6177, 8479]
a5p: [635, 8737, 3941, 4720, 6177, 8479]
a5b: [635, 8737, 3941, 4720, 6177, 8479]
a6p: [6882, 3765, 692, 9575, 4439, 2638]
a6b: [6882, 3765, 692, 9575, 4439, 2638]
a7p: [4.83, 2.89, 2.9, 1.97, 3.01, 0.18]
a7b: [4.83, 2.89, 2.9, 1.97, 3.01, 0.18]
```

a8p: [4.83, 2.89, 2.9, 1.97, 3.01, 0.18]

a8b: [4.83, 2.89, 2.9, 1.97, 3.01, 0.18]

**/*

In each case, the original array is created for the wrapper type and



filled using **Arrays.setAll()** as we did in **TestCounter.java** (this also verifies that **Arrays.setAll()** works with the wrapper arrays for **Integer**, **Long**, and **Double**). Then **ConvertTo.primitive()** converts the wrapper array to its corresponding primitive array, and **ConvertTo.boxed()** converts it back.

Modifying Existing Array Elements

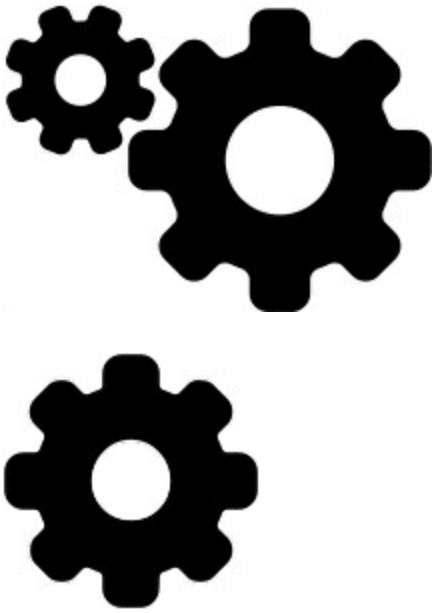
The generator function passed to **Arrays.setAll()** can modify existing array elements by using the array index it receives:

// arrays/ModifyExisting.java

import java.util.*;

```
import onjava.*;
import static onjava.ArrayShow.*;
public class ModifyExisting {
public static void main(String[] args) {
double[] da = new double[7];
Arrays.setAll(da, new Rand.Double()::get);
show(da);
Arrays.setAll(da, n -> da[n] / 100); // [1]
show(da);
}
}
/* Output:
[4.83, 2.89, 2.9, 1.97, 3.01, 0.18, 0.99]
[0.0483, 0.028900000000000002, 0.028999999999999998,
0.0197, 0.0301, 0.0018, 0.009899999999999999]
*/
```

[1] Lambdas are particularly useful here because the array will always be within the scope of the lambda expression.



An Aside On

Parallelism

We are soon forced to encounter the topic of parallelism. For example, the word “parallel” is used in a number of Java library methods. You might have heard something like “parallel programs run faster,” and it makes sense—why have only a single processor working on your program when you can have many? You can easily be forgiven for thinking you should just take advantage of anything with “parallel” in it.

It would be lovely if it were that simple. Unfortunately, by taking this approach you can quite easily write code that *runs slower* than the non-parallel version. And until you understand all the issues quite deeply, it could very well seem like parallel programming is more art

than science.

Here’s the short version: Write code the easy and simple way. Don’t start wrestling with parallelism unless it becomes a problem.

You’ll still encounter parallelism. In this chapter we’ll introduce some of the Java library methods written for parallel execution. So you must understand it enough for basic discussions, and to avoid the pitfalls.

After you read the Concurrent Programming chapter, you’ll understand it more deeply (but, alas, never enough. It turns out to be impossible to understand this topic enough).

There are also some situations where the parallel implementation is either the only one, or the best or logical choice regardless of whether you’re explicitly trying to be parallel or not, or even if you only have a single processor. It’s the one to use all the time, so you must understand the issues around it.

Strategies

It’s probably best to think about parallelism in terms of data. For a *lot* of data (and with extra processors available), parallel *might* help. But

it might not, and you could also make things worse.

Throughout the rest of the book, we will encounter different situations:

1. The only option provided is the parallel one. That's easy because we have no choice but to use it. This is rare.
2. There are multiple options but the parallel version (often the most recent version) is designed to be used everywhere (even in code that otherwise doesn't care about parallelism), as in case #1. We'll use the parallel version as intended.
3. Cases #1 and #2 don't happen that often. Instead, you'll encounter two versions of the algorithm, one for parallel usage and one for normal usage. I'll describe the parallel one but won't use it in normal code because of all the possible problems it could produce.

I recommend you adopt this approach for your own code.

For further insights into why this is a hard problem, see Doug Lea's Article.

parallelSetAll()

The **Stream** approach produces elegant code. For example, suppose we'd like to create an array of **long** filled with values counted up from

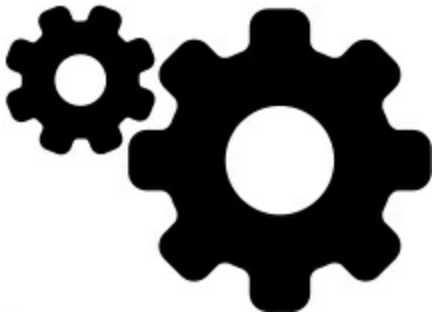
```
zero:
// arrays/CountUpward.java
import java.util.*;
import java.util.stream.*;
import static onjava.ArrayShow.*;
public class CountUpward {
static long[] fillCounted(int size) {
return LongStream.iterate(0, i -> i + 1)
.limit(size).toArray();
}
public static void main(String[] args) {
long[] l1 = fillCounted(20); // No problem
show(l1);
// On my machine, this runs out of heap space:
//- long[] l2 = fillCounted(10_000_000);
}
}
/* Output:
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15,
16, 17, 18, 19]
```

*/

Streams actually work up to nearly ten million, but then starts running out of heap space. Regular **setAll()** works but it's nice if we can do it faster with such large numbers.

We can initialize bigger arrays using **setAll()**. If speed becomes an issue, **Arrays.parallelSetAll()** will (probably) perform the initialization faster (keeping in mind the problems described in An Aside On Parallelism):

```
// arrays/ParallelSetAll.java
import java.util.*;
import onjava.*;
public class ParallelSetAll {
static final int SIZE = 10_000_000;
static void intArray() {
int[] ia = new int[SIZE];
Arrays.setAll(ia, new Rand.Pint()::get);
Arrays.parallelSetAll(ia, new Rand.Pint()::get);
}
static void longArray() {
long[] la = new long[SIZE];
```



```
Arrays.setAll(la, new Rand.Plong()::get);
Arrays.parallelSetAll(la, new Rand.Plong()::get);
}
public static void main(String[] args) {
intArray();
longArray();
}
}
```

The array allocations and initializations are performed in separate methods, because if both arrays are allocated in **main()**, it runs out of memory (on my machine, anyway. Also, there are ways of telling Java to allocate more memory on startup).

Arrays Utilities

You've already seen **fill()** and **setAll()**/**parallelSetAll()** from **java.util.Arrays**. That class contains a number of other useful **static** utility methods that we shall explore. Here's an

overview:

asList(): Takes any sequence or array and turns it into a **List Collection**—this method was covered in the Collections chapter.

copyOf(): Makes a new copy of an existing array, with a new length.

copyOfRange(): Makes a new copy of a section of an existing array.

equals(): Compare two arrays for equality.

deepEquals(): Equality comparison for multidimensional arrays.

stream(): Produce a **Stream** of the array elements.

hashCode(): Produce the hash value of an array (you'll learn what this means in the Appendix: Understanding **equals()** and **hashCode()**).

deepHashCode(): Hash value for a multidimensional array.

sort(): Sort an array.

parallelSort(): Sort an array in parallel, to increase speed.

binarySearch(): Find an element in a sorted array.

parallelPrefix(): Accumulate using the supplied function,

in parallel (for speed). Basically, a **reduce()** for arrays.

spliterator(): Produces a **Spliterator** from the array;

this is an advanced part of **Stream**s not covered in this book.

toString(): Produce a **String** representation for an array.

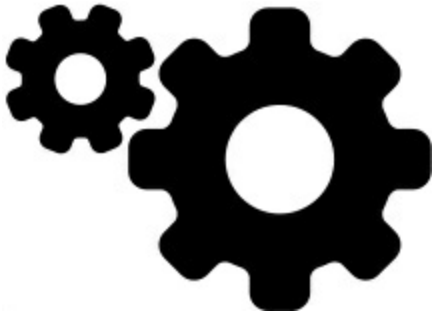
You've seen this used regularly throughout the chapter.

deepToString(): Produce a **String** for a multidimensional

array. You've seen this used regularly throughout the chapter.

All these methods are overloaded for all the primitive types and for

Objects.



Copying an Array

copyOf() and **copyOfRange()** copy arrays far more quickly than

if you use a **for** loop to perform the copy by hand. These methods are

overloaded to handle all types. We start by copying arrays of **int** and

Integer:

// arrays/ArrayCopying.java

// Demonstrate Arrays.copy() and Arrays.copyOf()

```
import java.util.*;
import onjava.*;
import static onjava.ArrayShow.*;
class Sup { // Superclass
private int id;
Sup(int n) { id = n; }
@Override
public String toString() {
return getClass().getSimpleName() + id;
}
}
class Sub extends Sup { // Subclass
Sub(int n) { super(n); }
}
public class ArrayCopying {
public static final int SZ = 15;
public static void main(String[] args) {
int[] a1 = new int[SZ];
Arrays.setAll(a1, new Count.Integer()::get);
show("a1", a1);
```

```
int[] a2 = Arrays.copyOf(a1, a1.length); // [1]
// Prove they are distinct arrays:
Arrays.fill(a1, 1);
show("a1", a1);
show("a2", a2);
// Create a shorter result:
a2 = Arrays.copyOf(a2, a2.length/2); // [2]
show("a2", a2);
// Allocate more space:
a2 = Arrays.copyOf(a2, a2.length + 5);
show("a2", a2);
// Also copies wrapped arrays:
Integer[] a3 = new Integer[SZ]; // [3]
Arrays.setAll(a3, new Count.Integer()::get);
Integer[] a4 = Arrays.copyOfRange(a3, 4, 12);
show("a4", a4);
Sub[] d = new Sub[SZ/2];
Arrays.setAll(d, Sub::new);
// Produce Sup[] from Sub[]:
Sup[] b =
```

```
Arrays.copyOf(d, d.length, Sup[].class); // [4]
show(b);
// This "downcast" works fine:
Sub[] d2 =
Arrays.copyOf(b, b.length, Sub[].class); // [5]
show(d2);
// Bad "downcast" compiles but throws exception:
Sup[] b2 = new Sup[SZ/2];
Arrays.setAll(b2, Sup::new);
try {
Sub[] d3 = Arrays.copyOf(
b2, b2.length, Sub[].class); // [6]
} catch(Exception e) {
System.out.println(e);
}
}
}
/* Output:
a1: [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]
a1: [1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]
```

a2: [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]

a2: [0, 1, 2, 3, 4, 5, 6]

a2: [0, 1, 2, 3, 4, 5, 6, 0, 0, 0, 0, 0]

a4: [4, 5, 6, 7, 8, 9, 10, 11]

[Sub0, Sub1, Sub2, Sub3, Sub4, Sub5, Sub6]

[Sub0, Sub1, Sub2, Sub3, Sub4, Sub5, Sub6]

java.lang.ArrayStoreException

**/*

[1] Here's the basic way to make a copy; just give it the size of the result. This is helpful if you're writing an algorithm that needs to resize storage. After the copy, we set all the elements of **a1** to 1, to demonstrate that this doesn't change anything in **a2**.

[2] By changing the result size (the last argument), we can shorten or lengthen the resulting array.

[3] Both **copyOf()** and **copyOfRange()** also work with wrapped types. **copyOfRange()** requires a start and end index.

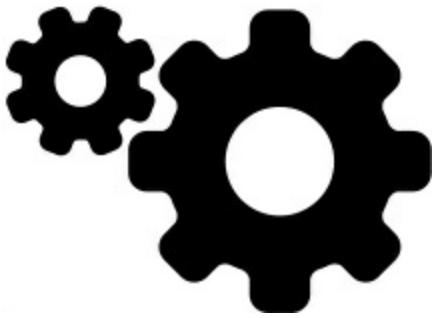
[4] Both **copyOf()** and **copyOfRange()** have a version that creates an array of a different type, by adding the destination type at the end of the method call. I first though this might be a way to produce a wrapped array from a primitive array, and vice-versa.

But that doesn't work. What it's actually for is "upcasting" and "downcasting" arrays. That is, if you have an array of a subtype (derived type) and you'd like an array of the base type instead, these methods will produce the desired array.

[5] You can even successfully "downcast" and produce an array of the subtype from an array of the supertype. This version works fine because we just "upcast."

[6] This "array cast" will compile, but if the types are incompatible, you'll get a runtime exception. Here, forcing the base type to pretend it's a derived type is illegal because there are probably data and methods in the derived objects that are not in the base objects.

The example shows that both primitive arrays and object arrays can be copied. However, if you copy arrays of objects, then only the references



get copied—there's no duplication of the objects themselves. This is called a *shallow copy* (see the Appendix: Passing and Returning

Objects for more details).

There's also a method **System.arraycopy()** that copies one array into another, already allocated, array. This will not perform autoboxing or autounboxing—the two arrays must be of exactly the same type.

Comparing Arrays

Arrays provides **equals()** to compare one-dimensional arrays for equality, and **deepEquals()** to compare multi-dimensional arrays. These methods are overloaded for all the primitives and for **Object**. To be equal, the arrays must have the same number of elements, and each element must be equivalent to each corresponding element in the other array, using the **equals()** for each element (For primitives, that primitive's wrapper class **equals()** is used; for example, **Integer.equals()** for **int**).

```
// arrays/ComparingArrays.java
// Using Arrays.equals()
import java.util.*;
import onjava.*;
public class ComparingArrays {
public static final int SZ = 15;
```

```
static String[][] twoDArray() {
String[][] md = new String[5][];
Arrays.setAll(md, n -> new String[n]);
for(int i = 0; i < md.length; i++)
Arrays.setAll(md[i], new Rand.String()::get);
return md;
}
public static void main(String[] args) {
int[] a1 = new int[SZ], a2 = new int[SZ];
Arrays.setAll(a1, new Count.Integer()::get);
Arrays.setAll(a2, new Count.Integer()::get);
System.out.println(
"a1 == a2: " + Arrays.equals(a1, a2));
a2[3] = 11;
System.out.println(
"a1 == a2: " + Arrays.equals(a1, a2));
Integer[] a1w = new Integer[SZ],
a2w = new Integer[SZ];
Arrays.setAll(a1w, new Count.Integer()::get);
Arrays.setAll(a2w, new Count.Integer()::get);
```

```
System.out.println(
"a1w == a2w: " + Arrays.equals(a1w, a2w));
a2w[3] = 11;
System.out.println(
"a1w == a2w: " + Arrays.equals(a1w, a2w));
String[][] md1 = twoDArray(), md2 = twoDArray();
System.out.println(Arrays.deepToString(md1));
System.out.println("deepEquals(md1, md2): " +
Arrays.deepEquals(md1, md2));
System.out.println(
"md1 == md2: " + Arrays.equals(md1, md2));
md1[4][1] = "#$#$#$#";
System.out.println(Arrays.deepToString(md1));
System.out.println("deepEquals(md1, md2): " +
Arrays.deepEquals(md1, md2));
}
}
/* Output:
a1 == a2: true
a1 == a2: false
```

a1w == a2w: true

a1w == a2w: false

[[], [btpenpc], [btpenpc, cuxszgv], [btpenpc, cuxszgv,

gmeinne], [btpenpc, cuxszgv, gmeinne, eloztdv]]

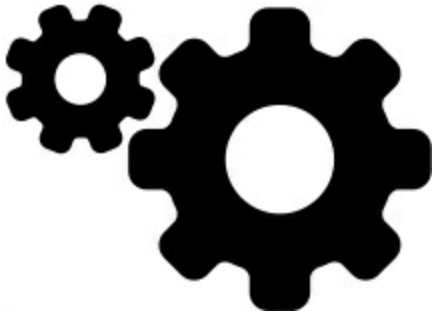
deepEquals(md1, md2): true

md1 == md2: false

[[], [btpenpc], [btpenpc, cuxszgv], [btpenpc, cuxszgv,

gmeinne], [btpenpc, #$#$#$#, gmeinne, eloztdv]]

deepEquals(md1, md2): false



**/*

Originally, **a1** and **a2** are exactly equal, so the output is **true**, but then one of the elements is changed, which makes the result **false**.

a1w and **a2w** repeat the exercise for a wrapped array.

md1 and **md2** are multidimensional **String** arrays initialized identically via **twoDArray()**. Notice that **deepEquals()** produces **true** because it performs a proper comparison, while the

normal **equals()** incorrectly produces **false**. If we change one of the elements in the array, **deepEquals()** detects it.

Streams and Arrays

The **stream()** method easily produces a **Stream** of elements from some types of arrays:

```
// arrays/StreamFromArray.java
import java.util.*;
import onjava.*;
public class StreamFromArray {
public static void main(String[] args) {
String[] s = new Rand.String().array(10);
Arrays.stream(s)
.skip(3)
.limit(5)
.map(ss -> ss + "!")
.forEach(System.out::println);
int[] ia = new Rand.Pint().array(10);
Arrays.stream(ia)
.skip(3)
.limit(5)
```

```
.map(i -> i * 10)
.forEach(System.out::println);
Arrays.stream(new long[10]);
Arrays.stream(new double[10]);
// Only int, long and double work:
//- Arrays.stream(new boolean[10]);
//- Arrays.stream(new byte[10]);
//- Arrays.stream(new char[10]);
//- Arrays.stream(new short[10]);
//- Arrays.stream(new float[10]);
// For the other types you must use wrapped arrays:
float[] fa = new Rand.Pfloat().array(10);
Arrays.stream(ConvertTo.boxed(fa));
Arrays.stream(new Rand.Float().array(10));
}
}
/* Output:
eloztdv!
ewcippc!
ygpoalk!
```

ljlbynx!

taprwxz!

47200

61770

84790

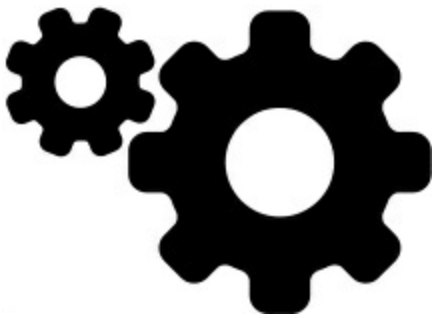
66560

37680

**/*

Only the “primary” supported types **int**, **long** and **double** work with **Arrays.stream()**; for the others you must somehow get a wrapped array.

Often it is easier to turn an array into a **Stream** to produce your desired results, instead of manipulating the array directly. Note that even though the **Stream** is “used up” (you can’t repeat it), you still have the array so you can use that in other ways—including generating another **Stream**.



Sorting Arrays

Sorting performs comparisons based on the actual type of the object. One approach is to write a different sorting method for every different type, but such code is not reusable for new types.

A primary goal of programming design is to "separate things that change from things that stay the same," and here, the code that stays the same is the general sort algorithm, but the thing that changes from one use to the next is the way objects are compared. So instead of placing the comparison code into many different sort routines, the *Strategy* design pattern is used. 1 With a Strategy, the part of the code that varies is encapsulated inside a separate class (the Strategy object).

You hand a Strategy object to the code that's always the same, which uses the Strategy to fulfill its algorithm. That way, you can make different objects expressing different ways of comparison and feed them to the same sorting code.

Java has two ways to provide comparison functionality. The first is with the "natural" comparison method that is imparted to a class by implementing the **java.lang.Comparable** interface. This is a very simple interface with a single method, **compareTo()**. This method takes another object of the same type as an argument and produces a negative value if the current object is less than the

argument, zero if the argument is equal, and a positive value if the current object is greater than the argument.

Here's a class that implements **Comparable** and demonstrates comparability using the Java standard library method **Arrays.sort()**:

```
// arrays/CompType.java
// Implementing Comparable in a class
import java.util.*;
import java.util.function.*;
import onjava.*;
import static onjava.ArrayShow.*;
public class CompType implements Comparable<CompType> {
int i;
int j;
private static int count = 1;
public CompType(int n1, int n2) {
i = n1;
j = n2;
}
@Override
```

```
public String toString() {
String result = "[i = " + i + ", j = " + j + "]";
if(count++ % 3 == 0)
result += "\n";
return result;
}
@Override
public int compareTo(CompType rv) {
return (i < rv.i ? -1 : (i == rv.i ? 0 : 1));
}
private static SplittableRandom r =
new SplittableRandom(47);
public static CompType get() {
return new CompType(r.nextInt(100), r.nextInt(100));
}
public static void main(String[] args) {
CompType[] a = new CompType[12];
Arrays.setAll(a, n -> get());
show("Before sorting", a);
Arrays.sort(a);
```

```
show("After sorting", a);
}
}
/* Output:
Before sorting: [[i = 35, j = 37], [i = 41, j = 20], [i
= 77, j = 79]
, [i = 56, j = 68], [i = 48, j = 93], [i = 70, j = 7]
, [i = 0, j = 25], [i = 62, j = 34], [i = 50, j = 82]
, [i = 31, j = 67], [i = 66, j = 54], [i = 21, j = 6]
]
After sorting: [[i = 0, j = 25], [i = 21, j = 6], [i =
31, j = 67]
, [i = 35, j = 37], [i = 41, j = 20], [i = 48, j = 93]
, [i = 50, j = 82], [i = 56, j = 68], [i = 62, j = 34]
, [i = 66, j = 54], [i = 70, j = 7], [i = 77, j = 79]
]
*/
```

When you define the comparison method, you are responsible for deciding what it means to compare one of your objects to another. Here, only the **i** values are used in the comparison, and the **j** values

are ignored.

The **get()** method builds **CompType** objects by initializing them with random values. In **main()**, **get()** is used with **Arrays.setAll()** to fill an array of **CompType**, which is then sorted. If **Comparable** hadn't been implemented, you'd get a **ClassCastException** at run time when you tried to call **sort()**. This is because **sort()** casts its argument to **Comparable**.

Now suppose someone hands you a class that doesn't implement **Comparable**, or hands you this class that *does* implement **Comparable**, but you decide you don't like the way it works and would rather have a different comparison method for the type. To solve the problem, create a separate class that implements the **Comparator** interface (briefly introduced in the Collections chapter). It has two methods, **compare()** and **equals()**. However, you don't implement **equals()** except for special performance needs, because anytime you create a class, it is implicitly inherited from **Object**, which has an **equals()**. You can just use the default **Object equals()** and satisfy the contract imposed by the interface.

The **Collections** class (note the plural; we'll look at it more in the next chapter) contains a method **reverseOrder()** that produces a

Comparator to reverse the natural sorting order. This can be applied to **CompType**:

```
// arrays/Reverse.java
// The Collections.reverseOrder() Comparator
import java.util.*;
import onjava.*;
import static onjava.ArrayShow.*;
public class Reverse {
public static void main(String[] args) {
CompType[] a = new CompType[12];
Arrays.setAll(a, n -> CompType.get());
show("Before sorting", a);
Arrays.sort(a, Collections.reverseOrder());
show("After sorting", a);
}
}
/* Output:
Before sorting: [[i = 35, j = 37], [i = 41, j = 20], [i
= 77, j = 79]
, [i = 56, j = 68], [i = 48, j = 93], [i = 70, j = 7]
```

, [i = 0, j = 25], [i = 62, j = 34], [i = 50, j = 82]

, [i = 31, j = 67], [i = 66, j = 54], [i = 21, j = 6]

]

After sorting: [[i = 77, j = 79], [i = 70, j = 7], [i =

66, j = 54]

, [i = 62, j = 34], [i = 56, j = 68], [i = 50, j = 82]

, [i = 48, j = 93], [i = 41, j = 20], [i = 35, j = 37]

, [i = 31, j = 67], [i = 21, j = 6], [i = 0, j = 25]

]

**/*

You can also write your own **Comparator**. This one compares

CompType objects based on their **j** values rather than their **i** values:

// arrays/ComparatorTest.java

// Implementing a Comparator for a class

import java.util.*;

import onjava.*;

import static onjava.ArrayShow.*;

```
class CompTypeComparator
implements Comparator<CompType> {
public int compare(CompType o1, CompType o2) {
return (o1.j < o2.j ? -1 : (o1.j == o2.j ? 0 : 1));
}
}
public class ComparatorTest {
public static void main(String[] args) {
CompType[] a = new CompType[12];
Arrays.setAll(a, n -> CompType.get());
show("Before sorting", a);
Arrays.sort(a, new CompTypeComparator());
show("After sorting", a);
}
}
/* Output:
Before sorting: [[i = 35, j = 37], [i = 41, j = 20], [i
= 77, j = 79]
, [i = 56, j = 68], [i = 48, j = 93], [i = 70, j = 7]
, [i = 0, j = 25], [i = 62, j = 34], [i = 50, j = 82]
```

, [i = 31, j = 67], [i = 66, j = 54], [i = 21, j = 6]

]

After sorting: [[i = 21, j = 6], [i = 70, j = 7], [i =

41, j = 20]

, [i = 0, j = 25], [i = 62, j = 34], [i = 35, j = 37]

, [i = 66, j = 54], [i = 31, j = 67], [i = 56, j = 68]

, [i = 77, j = 79], [i = 50, j = 82], [i = 48, j = 93]

]

**/*

Using Arrays.sort()

With the built-in sorting methods, you can sort any array of

primitives, or any array of objects that either implements

Comparable or has an associated **Comparator**. Here we generate an array of random **String** objects and sort it:2

// arrays/StringSorting.java

// Sorting an array of Strings

import java.util.*;

import onjava.*;

import static onjava.ArrayShow.*;

public class StringSorting {

public static void main(String[] args) {

```
String[] sa = new Rand.String().array(20);
show("Before sort", sa);
Arrays.sort(sa);
show("After sort", sa);
Arrays.sort(sa, Collections.reverseOrder());
show("Reverse sort", sa);
Arrays.sort(sa, String.CASE_INSENSITIVE_ORDER);
show("Case-insensitive sort", sa);
}
}
/* Output:
Before sort: [btpenpc, cuxszgv, gmeinne, eloztdv,
ewcippc, ygpoalk, ljlbynx, taprwxz, bhmupju, cjwzmmr,
anmkkyh, fcjpthl, skddcat, jbvlgwc, mvducuj, ydpulcq,
zehpfmm, zrxmclh, qgekgly, hyoubzl]
After sort: [anmkkyh, bhmupju, btpenpc, cjwzmmr,
cuxszgv, eloztdv, ewcippc, fcjpthl, gmeinne, hyoubzl,
jbvlgwc, ljlbynx, mvducuj, qgekgly, skddcat, taprwxz,
ydpulcq, ygpoalk, zehpfmm, zrxmclh]
Reverse sort: [zrxmclh, zehpfmm, ygpoalk, ydpulcq,
```

taprwxz, skddcat, qgekgly, mvducuj, ljlbynx, jbvlgwc,

hyoubzl, gmeinne, fcjpthl, ewcippc, eloztdv, cuxszgv,

cjwzmmr, btpenpc, bhmupju, anmkkyh]

Case-insensitive sort: [anmkkyh, bhmupju, btpenpc,

cjwzmmr, cuxszgv, eloztdv, ewcippc, fcjpthl, gmeinne,

hyoubzl, jbvlgwc, ljlbynx, mvducuj, qgekgly, skddcat,

taprwxz, ydpulcq, ygpoalk, zehpfmm, zrxmclh]

**/*

Notice the output in the **String** sorting algorithm. It's *lexicographic*,

so it puts all the words starting with uppercase letters first, followed by all the words starting with lowercase letters. (Telephone books are typically sorted this way.) To group the words together regardless of case, use **String.CASE_INSENSITIVE_ORDER** as shown in the last call to **sort()**.

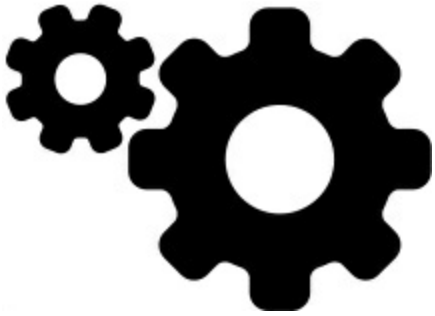
The sorting algorithm that's used in the Java standard library is designed to be optimal for the particular type you're sorting—a Quicksort for primitives, and a stable merge sort for objects.

Sorting in Parallel

If sorting performance is an issue, you can use the Java 8 **parallelSort()**, which has overloaded versions for all contingencies, including sorting regions of an array or using a **Comparator**. To see the benefits of **parallelSort()** vs. the ordinary **sort()**, we use JMH which was introduced in Validating Your Code:

```
// arrays/jmh/ParallelSort.java
package arrays.jmh;
import java.util.*;
import onjava.*;
import org.openjdk.jmh.annotations.*;
@State(Scope.Thread)
public class ParallelSort {
private long[] la;
@Setup
public void setup() {
la = new Rand.Plong().array(100_000);
}
@Benchmark
```

```
public void sort() {
Arrays.sort(la);
}
```



```
@Benchmark
public void parallelSort() {
Arrays.parallelSort(la);
}
}
```

The **parallelSort()** algorithm breaks the large array into smaller arrays until the array size reaches a limit, at which point it uses the ordinary **Arrays.sort()** method. Then the results are merged. The algorithm requires additional working space, but this is no larger than the space of the original array.

You might see different results, but on my machine the parallel sort sped things up about 3 times. Since the parallel version is trivial to use, it’s tempting to consider using it everywhere, in preference to

Arrays.sort(). Of course, it might not be that simple—see Microbenchmarking.

Searching with

Arrays.binarySearch()

Once an array is sorted, you can perform a fast search for a particular item by using **Arrays.binarySearch()**. However, if you try to use **binarySearch()** on an unsorted array the results are unpredictable. The following example uses the **Rand.Pint** class to create an array filled with random **int** values, then calls **getAsInt()** (because **Rand.Pint** is an **IntSupplier**) to produce search values:

```
// arrays/ArraySearching.java
// Using Arrays.binarySearch()
import java.util.*;
import onjava.*;
import static onjava.ArrayShow.*;
public class ArraySearching {
public static void main(String[] args) {
Rand.Pint rand = new Rand.Pint();
int[] a = new Rand.Pint().array(25);
```

```
Arrays.sort(a);
show("Sorted array", a);
while(true) {
int r = rand.getAsInt();
int location = Arrays.binarySearch(a, r);
if(location >= 0) {
System.out.println(
"Location of " + r + " is " + location +
", a[" + location + "] is " + a[location]);
break; // Out of while loop
}
}
}
}
/* Output:
Sorted array: [125, 267, 635, 650, 1131, 1506, 1634,
2400, 2766, 3063, 3768, 3941, 4720, 4762, 4948, 5070,
5682, 5807, 6177, 6193, 6656, 7021, 8479, 8737, 9954]
Location of 635 is 2, a[2] is 635
*/
```

In the **while** loop, random values are generated as search items until one of them is found in the array.

Arrays.binarySearch() produces a value greater than or equal to zero if the search item is found. Otherwise, it produces a negative value representing the place that the element should be inserted if you are maintaining the sorted array by hand. The value produced is

-(insertion point) - 1

The insertion point is the index of the first element greater than the key, or **a.size()**, if all elements in the array are less than the specified key.

If an array contains duplicate elements, there is no guarantee which of those duplicates are found. The search algorithm is not designed to support duplicate elements, but rather to tolerate them. If you need a sorted list of non-duplicated elements, use a **TreeSet** (to maintain sorted order) or **LinkedHashSet** (to maintain insertion order).

Those classes take care of all the details for you automatically. Only in cases of performance bottlenecks should you replace one of these classes with a hand-maintained array.

If you sort an object array using a **Comparator** (primitive arrays do not allow sorting with a **Comparator**), you must include that same

Comparator when you perform a **binarySearch()** (using the overloaded version of **binarySearch()**). For example, the **StringSorting.java** program can be modified to perform a search:

```
// arrays/AlphabeticSearch.java
// Searching with a Comparator import
import java.util.*;
import onjava.*;
import static onjava.ArrayShow.*;
public class AlphabeticSearch {
public static void main(String[] args) {
String[] sa = new Rand.String().array(30);
Arrays.sort(sa, String.CASE_INSENSITIVE_ORDER);
show(sa);
int index = Arrays.binarySearch(sa,
sa[10], String.CASE_INSENSITIVE_ORDER);
System.out.println(
"Index: "+ index + "\n"+ sa[index]);
}
}
```

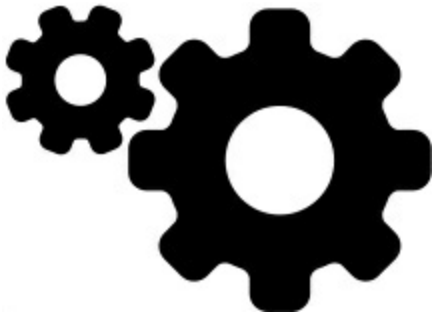
/ *Output:*

[anmkkyh, bhmupju, btpenpc, cjwzmmr, cuxszgv, eloztdv,

ewcippc, ezdeklu, fcjpthl, fqmlgsh, gmeinne, hyoubzl,

jbvlgwc, jlxpqds, ljlbynx, mvducuj, qgekgly, skddcat,

taprwxz, uybypgp, vjsszkn, vniyapk, vqqakbm, vwodhcf,



ydpulcq, ygpoalk, yskvett, zehpfmm, zofmmvm, zrxmclh]

Index: 10

gmeinne

**/*

The **Comparator** must be passed to the overloaded **binarySearch()** as the third argument. In this example, success is guaranteed because the search item is selected from the array itself.

Accumulating with parallelPrefix()

There's no "prefix()" method, only a **parallelPrefix()**. This is like the **reduce()** method from the **Stream** class: it performs an

operation on the previous and current elements, and puts the result into the current element location:

```
// arrays/ParallelPrefix1.java
import java.util.*;
import onjava.*;
import static onjava.ArrayShow.*;
public class ParallelPrefix1 {
public static void main(String[] args) {
int[] nums = new Count.Pint().array(10);
show(nums);
System.out.println(Arrays.stream(nums)
.reduce(Integer::sum).getAsInt());
Arrays.parallelPrefix(nums, Integer::sum);
show(nums);
System.out.println(Arrays.stream(
new Count.Pint().array(6))
.reduce(Integer::sum).getAsInt());
}
}
/* Output:
```

[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]

45

[0, 1, 3, 6, 10, 15, 21, 28, 36, 45]

15

*/

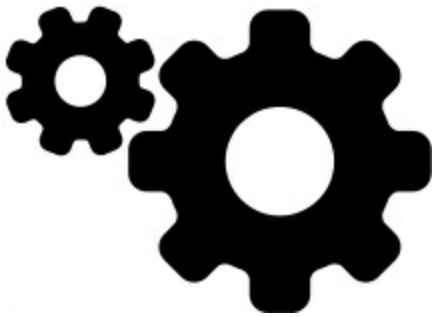
Here we apply **Integer::sum** to the array. In location zero, it puts the previously-calculated value (zero, as there is no previous) combined with the value in location zero of the original array. In location one, it takes the previously-calculated value (which it just stored in location zero) and combines it with the value previously in location one. And so on.

With the **Stream.reduce()**, you only get the final result, whereas with **Arrays.parallelPrefix()** you also get all the intermediate calculations in case those are useful. Notice how the result of the second **Stream.reduce()** calculation is already in the array calculated by **parallelPrefix()**.

It might be clearer using **String**s:

```
// arrays/ParallelPrefix2.java
import java.util.*;
import onjava.*;
```

```
import static onjava.ArrayShow.*;
public class ParallelPrefix2 {
public static void main(String[] args) {
String[] strings = new Rand.String(1).array(8);
show(strings);
Arrays.parallelPrefix(strings, (a, b) -> a + b);
show(strings);
}
}
/* Output:
[b, t, p, e, n, p, c, c]
[b, bt, btp, btpe, btpen, btpenp, btpenpc, btpenpcc]
*/
```



As noted previously, initialization using **Stream**s is elegant, but for large arrays that approach can run out of heap space. Performing initialization using **setAll()** is more memory-efficient:

```
// arrays/ParallelPrefix3.java
// {ExcludeFromTravisCI}
import java.util.*;
public class ParallelPrefix3 {
static final int SIZE = 10_000_000;
public static void main(String[] args) {
long[] nums = new long[SIZE];
Arrays.setAll(nums, n -> n);
Arrays.parallelPrefix(nums, Long::sum);
System.out.println("First 20: " + nums[19]);
System.out.println("First 200: " + nums[199]);
System.out.println("All: " + nums[nums.length-1]);
}
}
/* Output:
First 20: 190
First 200: 19900
All: 49999995000000
*/
```

Because it can be rather complicated to get right,

parallelPrefix() should generally only be used when you have memory or speed issues (or both). Otherwise, **Stream.reduce()** should be your first choice.

Summary

Java provides reasonable support for fixed-sized, low-level arrays. This kind of array emphasizes performance over flexibility, just like the C and C++ array model. In the initial version of Java, fixed-sized, low-level arrays were absolutely necessary, not only because the Java designers chose to include primitive types (also for performance), but because the support for **Collection**s in that version was very minimal. Thus, in early versions of Java, it was always reasonable to choose arrays.

In subsequent versions of Java, **Collection** support improved significantly, and now **Collection**s tend to outshine arrays in all ways except for performance, and even then, the performance of **Collection**s is significantly improved. As stated in other places in this book, performance problems are usually never where you imagine them to be, anyway.

With autoboxing and generics, holding primitives in **Collection**s is effortless, which further encourages you to replace low-level arrays

with **Collection**s. Because generics produce type-safe **Collection**s, arrays no long have an advantage on that front, either.

As noted in this chapter and as you'll see when you try to use them, generics are fairly hostile towards arrays. Often, even when you can get generics and arrays to work together in some form (as you'll see in the next chapter), you'll still end up with "unchecked" warnings during compilation.

On several occasions I heard directly from Java language designers that I should be using **Collection**s instead of arrays, when we were discussing particular examples (I was using arrays to demonstrate specific techniques so I did not have that option).

All these issues indicate you should "prefer **Collection**s to arrays" when programming in recent versions of Java. Only when you prove that performance is an issue (and that switching to an array will actually make a significant difference) should you refactor to arrays.

This is a rather bold statement, but some languages have no fixed-sized, low-level arrays at all. They only have resizable collections with significantly more functionality than C/C++/Java-style arrays. Python, for example, has a **list** type that uses basic array syntax, but with

much greater functionality—you can even inherit from it:

```
# arrays/PythonLists.py
aList = [1, 2, 3, 4, 5]
print(type(aList)) # <type 'list'>
print(aList) # [1, 2, 3, 4, 5]
print(aList[4]) # 5 Basic list indexing
aList.append(6) # lists can be resized
aList += [7, 8] # Add a list to a list
print(aList) # [1, 2, 3, 4, 5, 6, 7, 8]
aSlice = aList[2:4]
print(aSlice) # [3, 4]
class MyList(list): # Inherit from list
# Define a method; 'this' pointer is explicit:
def getReversed(self):
reversed = self[:] # Copy list using slices
reversed.reverse() # Built-in list method
return reversed
# No 'new' necessary for object creation:
list2 = MyList(aList)
print(type(list2)) # <class '__main__.MyList'>
```

```
print(list2.getReversed()) # [8, 7, 6, 5, 4, 3, 2, 1]

output = """
<class 'list'>
[1, 2, 3, 4, 5]
5
[1, 2, 3, 4, 5, 6, 7, 8]
[3, 4]
<class '__main__.MyList'>
[8, 7, 6, 5, 4, 3, 2, 1]
"""
```

Basic Python syntax was introduced in the previous chapter. Here, a list is created by surrounding a comma-separated sequence of objects with square brackets. The result is an object with a runtime type of **list** (the output of the **print** statements is shown as comments on the same line). The result of printing a **list** is the same as that of using **Arrays.toString()** in Java.

Creating a sub-sequence of a **list** is accomplished with *slicing*, by placing the **:** operator inside the index operation. The **list** type has many more built-in operations, to the point where it's usually all you need for a sequence type.

MyList is a **class** definition; the base classes are placed within the

parentheses. Inside the class, **def** statements produce methods, and the first argument to the method is automatically the equivalent of **this** in Java, except that in Python it's explicit and the identifier **self** is used by convention (it's not a keyword). Notice how the constructor is automatically inherited.

Although everything in Python really *is* an object (including integral and floating point types), you still have an escape hatch because you can optimize performance-critical portions of your code by writing extensions in C, C++ or using special tools designed to easily speed up your Python code (of which there are many). This way you can have object purity without being prevented from performance improvements.

The PHP language[3] goes even further by having only a single array type, which acts as both an **int**-indexed array and an associative array (a **Map**).

It's interesting to speculate, after this many years of Java evolution, whether the designers would put primitives and low-level arrays in the language if they were to start over again (the Scala language, which also runs on the JVM, does not include these). If these were left out, it would be possible to make a truly pure object-oriented language (despite claims, Java is not a pure OO language, precisely because of

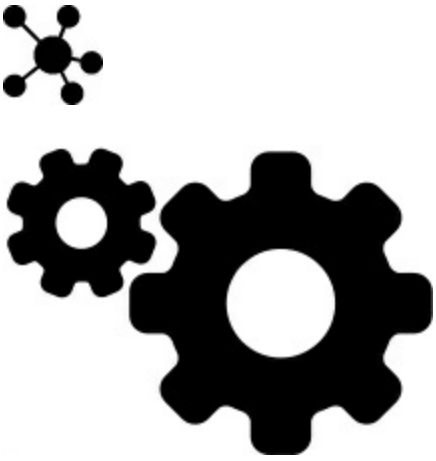
the low-level detritus). The initial argument for efficiency is always compelling, but over time we have seen an evolution away from this idea and towards higher-level components like **Collection**s. Add to this the fact that if **Collection**s can be built into the core language as they are in some languages, the compiler has a much better opportunity to optimize.

"Green-fields" speculation aside, we are certainly stuck with arrays, and you see them when reading code. **Collection**s, however, are almost always a better choice.

1. See the Patterns chapter at the end of this book.↩

2. Surprisingly, there was no support in Java 1.0 or 1.1 for sorting **String**s. ↩

3. See *www.php.net*. ↩



Enumerations

The **enum** keyword creates a new type with a restricted set of named values, and treats those values as regular program components. This turns out to be very useful. [1]

Enumerations were introduced briefly at the end of Housekeeping. However, now that you understand some of the deeper issues in Java, we can take a more detailed look at Java's enumerations. You'll see that **enum**s can be very useful, but this chapter should also give you more insight into other language features, such as generics and reflection. You'll also learn a few more design patterns.

Basic enum Features

As shown in Housekeeping, you can step through the list of **enum** constants by calling **values()** on the **enum**. The **values()** method produces an array of the **enum** constants in the order in which they were declared, so you can use the resulting array in (for example) a *for-in* loop.

When you create an **enum**, an associated class is produced for you by the compiler. This class is automatically inherited from **java.lang.Enum**, which provides certain capabilities shown in this example:

```
// enums/EnumClass.java
// Capabilities of the Enum class
enum Shrubbery { GROUND, CRAWLING, HANGING }
public class EnumClass {
public static void main(String[] args) {
for(Shrubbery s : Shrubbery.values()) {
System.out.println(
s + " ordinal: " + s.ordinal());
System.out.print(
s.compareTo(Shrubbery.CRAWLING) + " ");
System.out.print(
s.equals(Shrubbery.CRAWLING) + " ");
System.out.println(s == Shrubbery.CRAWLING);
System.out.println(s.getDeclaringClass());
System.out.println(s.name());
System.out.println("**********");
}
// Produce an enum value from a String name:
for(String s :
"HANGING CRAWLING GROUND".split(" ")) {
```

```
Shrubbery shrub =
Enum.valueOf(Shrubbery.class, s);
System.out.println(shrub);
}
}
}
```

/ Output:*

GROUND ordinal: 0

-1 false false

class Shrubbery

GROUND

****

CRAWLING ordinal: 1

0 true true

class Shrubbery

CRAWLING

****

HANGING ordinal: 2

1 false false

class Shrubbery

HANGING

****

HANGING

CRAWLING

GROUND

*/

The **ordinal()** method produces an **int** indicating the declaration order of each **enum** instance, starting from zero. You can always safely compare **enum** instances using ==, and **equals()** and **hashCode()** are automatically created for you. The **Enum** class is **Comparable**, so there's a **compareTo()** method, and it is also **Serializable**.

If you call **getDeclaringClass()** on an **enum** instance, you'll find out the enclosing **enum** class.

The **name()** method produces the name exactly as it is declared, and this is what you get with **toString()**, as well. **valueOf()** is a **static** member of **Enum**, and produces the **enum** instance that

corresponds to the **String** name you pass to it, or throws an exception if there's no match.

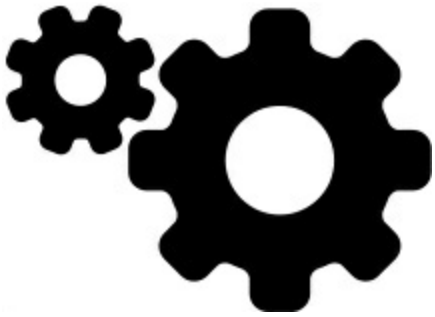
Using static Imports with enums

Consider a variation of **Burrito.java** from the Housekeeping chapter:

```
// enums/SpicinessEnum.java
package enums;
public enum SpicinessEnum {
NOT, MILD, MEDIUM, HOT, FLAMING
}
// enums/Burrito2.java
// {java enums.Burrito2}
package enums;
import static enums.SpicinessEnum.*;
public class Burrito2 {
SpicinessEnum degree;
public Burrito2(SpicinessEnum degree) {
this.degree = degree;
}
```

```
@Override
public String toString() {
return "Burrito is "+ degree;
}
public static void main(String[] args) {
System.out.println(new Burrito2(NOT));
System.out.println(new Burrito2(MEDIUM));
System.out.println(new Burrito2(HOT));
}
}
/* Output:
Burrito is NOT
Burrito is MEDIUM
Burrito is HOT
*/
```

The **static import** brings all the **enum** instance identifiers into the local namespace, so they don't need qualification. Is this a good idea, or is it better to be explicit and qualify all **enum** instances? It



probably depends on the complexity of your code. The compiler certainly won't let you use the wrong type, so your only concern is whether the code is confusing to the reader. In many situations it will probably be fine but evaluate it on an individual basis.

Note it is not possible to use this technique if the **enum** is defined in the same file or the default package (apparently there were some arguments within Sun about whether to allow this).

Adding Methods to an

enum

Except for the fact you can't inherit from it, an **enum** can be treated much like a regular class. This means you can add methods to an **enum**. It's even possible for an **enum** to have a **main()**.

You might produce different descriptions for an enumeration than the default **toString()**, which simply produces the name of that **enum** instance, as you've seen. To do this, you can provide a constructor to capture extra information, and additional methods to provide an

extended description, like this:

```
// enums/OzWitch.java
// The witches in the land of Oz
public enum OzWitch {
// Instances must be defined first, before methods:
WEST("Miss Gulch, aka the Wicked Witch of the West"),
NORTH("Glinda, the Good Witch of the North"),
EAST("Wicked Witch of the East, wearer of the Ruby " +
"Slippers, crushed by Dorothy's house"),
SOUTH("Good by inference, but missing");
private String description;
// Constructor must be package or private access:
private OzWitch(String description) {
```

```
this.description = description;
}
public String getDescription() { return description; }
public static void main(String[] args) {
```

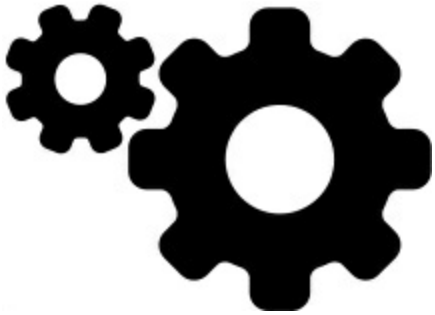
```
for(OzWitch witch : OzWitch.values())
System.out.println(
witch + ": " + witch.getDescription());
}
}
/* Output:
WEST: Miss Gulch, aka the Wicked Witch of the West
NORTH: Glinda, the Good Witch of the North
EAST: Wicked Witch of the East, wearer of the Ruby
Slippers, crushed by Dorothy's house
SOUTH: Good by inference, but missing
*/
```

If you are going to define methods you must end the sequence of **enum** instances with a semicolon. Also, Java forces you to define the instances first within the **enum**. You'll get a compile-time error if you try to define them after any of the methods or fields.

The constructor and methods have the same form as a regular class, because with a few restrictions this *is* a regular class. You can do pretty much anything you want with **enum**s (although you'll usually keep them pretty ordinary).

Although the constructor here is **private** as an example, it doesn't make much difference what access you use—the constructor can only be used to create the **enum** instances you declare inside the **enum** definition; the compiler won't let you use it to create any new instances once the **enum** definition is complete.

Overriding enum Methods



Here's another approach to producing different **String** values for enumerations. Here, the instance names are OK but we want to reformat them for display. Overriding the **toString()** method for an **enum** is the same as overriding it for a regular class:

```
// enums/SpaceShip.java
import java.util.stream.*;
public enum SpaceShip {
SCOUT, CARGO, TRANSPORT,
CRUISER, BATTLESHIP, MOTHERSHIP;
@Override
```

```
public String toString() {
String id = name();
String lower = id.substring(1).toLowerCase();
return id.charAt(0) + lower;
}
public static void main(String[] args) {
Stream.of(values())
.forEach(System.out::println);
}
}
/* Output:
Scout
Cargo
Transport
Cruiser
Battleship
Mothership
*/
```

The **toString()** method gets the **SpaceShip** name by calling **name()**, and modifies the result so only the first letter is capitalized.

enums in switch

Statements

One very convenient capability of **enum**s is the way they can be used in **switch** statements. Ordinarily, a **switch** only works with an

integral value, but since **enum**s have an established integral order and

the order of an instance can be produced with the **ordinal()**

method (apparently the compiler does something like this), **enum**s can

be used in **switch** statements.

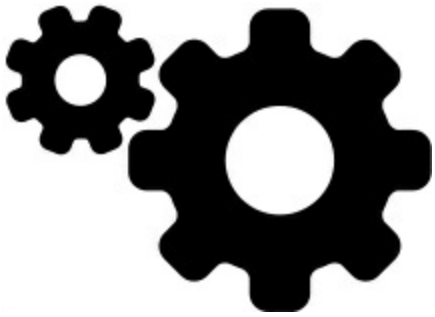
Although normally you must qualify an **enum** instance with its type,

you don’t do this in a **case** statement. Here’s an example that uses an

enum to create a little state machine:

```
// enums/TrafficLight.java
// Enums in switch statements
// Define an enum type:
enum Signal { GREEN, YELLOW, RED, }
public class TrafficLight {
Signal color = Signal.RED;
public void change() {
switch(color) {
// Note you don't have to say Signal.RED
// in the case statement:
```

```
case RED: color = Signal.GREEN;
break;
case GREEN: color = Signal.YELLOW;
break;
case YELLOW: color = Signal.RED;
break;
}
}
@Override
public String toString() {
return "The traffic light is " + color;
}
public static void main(String[] args) {
TrafficLight t = new TrafficLight();
for(int i = 0; i < 7; i++) {
```



```
System.out.println(t);
```

```
t.change();
}
}
}
/* Output:
The traffic light is RED
The traffic light is GREEN
The traffic light is YELLOW
The traffic light is RED
The traffic light is GREEN
The traffic light is YELLOW
The traffic light is RED
*/
```

The compiler does not complain because there is no **default** statement inside the **switch**, but that's not because it notices you have **case** statements for each **Signal** instance. If you comment out one of the **case** statements it still won't complain. This means you must pay attention and ensure you cover all the cases on your own. On the other hand, if you are calling **return** from **case** statements, the compiler *will* complain if you don't have a **default**—even if you've

covered all the possible values of the **enum**.

The Mystery of values()

As noted earlier, all **enum** classes are created for you by the compiler and extend the **Enum** class. However, if you look at **Enum**, you'll see there is no **values()** method, even though we've been using it. Are there any other "hidden" methods? We can write a small reflection program to find out:

```
// enums/Reflection.java
// Analyzing enums using reflection
import java.lang.reflect.*;
import java.util.*;
import onjava.*;
enum Explore { HERE, THERE }
public class Reflection {
public static
Set<String> analyze(Class<?> enumClass) {
System.out.println(
"_____ Analyzing " + enumClass + " _____");
System.out.println("Interfaces:");
for(Type t : enumClass.getGenericInterfaces())
```

```
System.out.println(t);
System.out.println(
"Base: " + enumClass.getSuperclass());
System.out.println("Methods: ");
Set<String> methods = new TreeSet<>();
for(Method m : enumClass.getMethods())
methods.add(m.getName());
System.out.println(methods);
return methods;
}
public static void main(String[] args) {
Set<String> exploreMethods =
analyze(Explore.class);
Set<String> enumMethods = analyze(Enum.class);
System.out.println(
"Explore.containsAll(Enum)? " +
exploreMethods.containsAll(enumMethods));
System.out.print("Explore.removeAll(Enum): ");
exploreMethods.removeAll(enumMethods);
System.out.println(exploreMethods);
```

// Decompile the code for the enum:

OSExecute.command(

"javap -cp build/classes/main Explore");

}

}

/ Output:*

_____ Analyzing class Explore _____

Interfaces:

Base: class java.lang.Enum

Methods:

[compareTo, equals, getClass, getDeclaringClass,

hashCode, name, notify, notifyAll, ordinal, toString,

valueOf, values, wait]

_____ Analyzing class java.lang.Enum _____

Interfaces:

java.lang.Comparable<E>

interface java.io.Serializable

Base: class java.lang.Object

Methods:

[compareTo, equals, getClass, getDeclaringClass,

hashCode, name, notify, notifyAll, ordinal, toString,

valueOf, wait]

Explore.containsAll(Enum)? true

Explore.removeAll(Enum): [values]

Compiled from "Reflection.java"

final class Explore extends java.lang.Enum<Explore> {

public static final Explore HERE;

public static final Explore THERE;

public static Explore[] values();

public static Explore valueOf(java.lang.String);

static {};

}

**/*

So the answer is that **values()** is a **static** method that is added by the compiler. Note that **valueOf()** is also added to **Explore** in the process of creating the **enum**. This is slightly confusing, because there's also a **valueOf()** that is part of the **Enum** class, but that method has two arguments and the added method only has one. However, the **Set** method here is only looking at method names, and not signatures, so after calling **Explore.removeAll(Enum)**, the

only thing that remains is **[values]**.

The output shows that **Explore** is made **final** by the compiler, so

you cannot inherit from an **enum**. There's also a **static** initialization

clause, which as you'll see later can be redefined.

Because of erasure (described in the Generics chapter), the decompiler does not have full information about **Enum**, so it shows the base class

of **Explore** as a raw **Enum** rather than the actual **Enum<Explore>** .

Because **values()** is a **static** method inserted into the **enum**

definition by the compiler, if you upcast an **enum** type to **Enum**, the

values() method is not available. Notice, however, there is a

getEnumConstants() method in **Class**, so even if **values()** is

not part of the interface of **Enum**, you can still get the **enum** instances

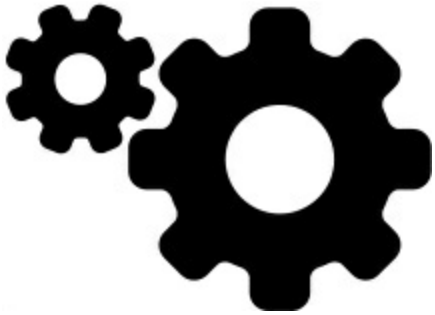
via the **Class** object:

```
// enums/UpcastEnum.java
// No values() method if you upcast an enum
enum Search { HITHER, YON }
public class UpcastEnum {
public static void main(String[] args) {
Search[] vals = Search.values();
Enum e = Search.HITHER; // Upcast
// e.values(); // No values() in Enum
```

```
for(Enum en : e.getClass().getEnumConstants())
System.out.println(en);
}
}
/* Output:
HITHER
YON
*/
```

Because **getEnumConstants()** is a method of **Class**, you can call it for a class that has no enumerations:

```
// enums/NonEnum.java
public class NonEnum {
public static void main(String[] args) {
```



```
Class<Integer> intClass = Integer.class;
try {
for(Object en : intClass.getEnumConstants())
```

```
System.out.println(en);
} catch(Exception e) {
System.out.println("Expected: " + e);
}
}
}
/* Output:
Expected: java.lang.NullPointerException
*/
```

The method returns **null**, so you get an exception if you try to use the result.

Implements, not

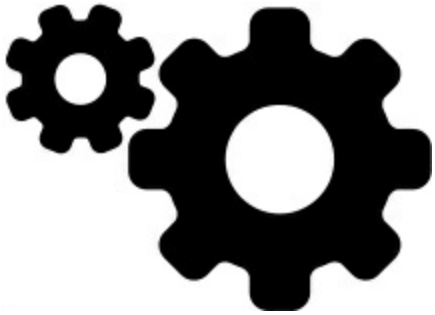
Inherits

We've established that all **enum**s extend **java.lang.Enum**. Since Java does not support multiple inheritance, this means you cannot create an **enum** via inheritance:

```
enum NotPossible extends Pet { ... // Won't work
```

However, it *is* possible to create an **enum** that implements one or more interfaces:

```
// enums/cartoons/EnumImplementation.java
// An enum can implement an interface
// {java enums.cartoons.EnumImplementation}
package enums.cartoons;
import java.util.*;
import java.util.function.*;
enum CartoonCharacter
```



```
implements Supplier<CartoonCharacter> {
SLAPPY, SPANKY, PUNCHY,
SILLY, BOUNCY, NUTTY, BOB;
private Random rand =
new Random(47);
@Override
public CartoonCharacter get() {
```

```
return values()[rand.nextInt(values().length)];
}
}
public class EnumImplementation {
public static <T> void printNext(Supplier<T> rg) {
System.out.print(rg.get() + ", ");
}
public static void main(String[] args) {
// Choose any instance:
CartoonCharacter cc = CartoonCharacter.BOB;
for(int i = 0; i < 10; i++)
printNext(cc);
}
}
/* Output:
BOB, PUNCHY, BOB, SPANKY, NUTTY, PUNCHY, SLAPPY, NUTTY,
NUTTY, SLAPPY,
*/
```

The result is slightly odd, because to call a method you must have an instance of the **enum** to call it on. However, a **CartoonCharacter**

can now be accepted by any method that takes a **Supplier**; for example, **printNext()**.

Random Selection

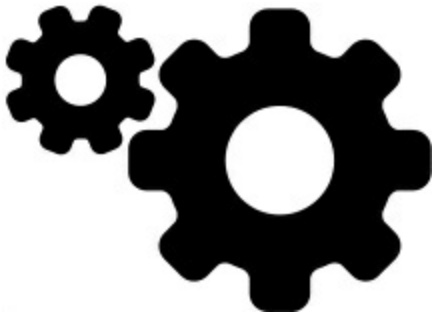
Many of the examples in this chapter require random selection from among **enum** instances, as you saw in **CartoonCharacter.get()**. It's possible to generalize this task using generics and put the result in the common library:

```
// onjava/Enums.java
package onjava;
import java.util.*;
public class Enums {
private static Random rand = new Random(47);
public static
<T extends Enum<T>> T random(Class<T> ec) {
return random(ec.getEnumConstants());
}
public static <T> T random(T[] values) {
return values[rand.nextInt(values.length)];
}
}
```

The rather odd syntax **<T extends Enum<T>>** describes **T** as an **enum** instance. By passing in **Class<T>** , we make the class object available, and the array of **enum** instances can thus be produced. The overloaded **random()** method must only know it gets a **T[]** because it doesn't perform **Enum** operations; it only selects an array element at random. The return type is the exact type of the **enum**.

Here's a simple test of the **random()** method:

```
// enums/RandomTest.java
import onjava.*;
enum Activity { SITTING, LYING, STANDING, HOPPING,
RUNNING, DODGING, JUMPING, FALLING, FLYING }
public class RandomTest {
public static void main(String[] args) {
for(int i = 0; i < 20; i++)
System.out.print(
Enums.random(Activity.class) + " ");
}
}
```



/ Output:*

STANDING FLYING RUNNING STANDING RUNNING STANDING LYING

DODGING SITTING RUNNING HOPPING HOPPING HOPPING RUNNING

STANDING LYING FALLING RUNNING FLYING LYING

**/*

Although **Enums** is a small class, you'll see it prevents a fair amount of duplication in this chapter. Duplication tends to produce mistakes, so eliminating duplication is a useful pursuit.

Using Interfaces for

Organization

The inability to inherit from an **enum** can be a bit frustrating at times. The motivation for inheriting from an **enum** comes partly from wanting to extend the number of elements in the original **enum**, and partly from wanting to create subcategories by using subtypes.

You can categorize elements by grouping then together inside an

interface and creating an enumeration based on that interface. For example, suppose you have different classes of food that you'd like to create as **enum**s, but you'd still like each one to be a type of **Food**. Here's what it looks like:

```
// enums/menu/Food.java
// Subcategorization of enums within interfaces
package enums.menu;
public interface Food {
enum Appetizer implements Food {
SALAD, SOUP, SPRING_ROLLS;
}
enum MainCourse implements Food {
LASAGNE, BURRITO, PAD_THAI,
LENTILS, HUMMOUS, VINDALOO;
}
enum Dessert implements Food {
TIRAMISU, GELATO, BLACK_FOREST_CAKE,
FRUIT, CREME_CARAMEL;
}
enum Coffee implements Food {
```

```
BLACK_COFFEE, DECAF_COFFEE, ESPRESSO,
LATTE, CAPPUCCINO, TEA, HERB_TEA;
}
}
```

Since the only subtyping available for an **enum** is that of interface implementation, each nested **enum** implements the surrounding interface **Food**. Now it's possible to say that "everything is a type of **Food**" as shown here:

```
// enums/menu/TypeOfFood.java
// {java enums.menu.TypeOfFood}
package enums.menu;
import static enums.menu.Food.*;
public class TypeOfFood {
public static void main(String[] args) {
Food food = Appetizer.SALAD;
food = MainCourse.LASAGNE;
food = Dessert.GELATO;
food = Coffee.CAPPUCCINO;
}
}
```

The upcast to **Food** works for each **enum** type that **implements Food**, so they are all types of **Food**.

An interface, however, is not as useful as an **enum** when you deal with a set of types. For an "**enum** of **enum**s" you can create a surrounding **enum** with one instance for each **enum** in **Food**:

```
// enums/menu/Course.java
package enums.menu;
import onjava.*;
public enum Course {
APPETIZER(Food.Appetizer.class),
MAINCOURSE(Food.MainCourse.class),
DESSERT(Food.Dessert.class),
COFFEE(Food.Coffee.class);
private Food[] values;
private Course(Class<? extends Food> kind) {
values = kind.getEnumConstants();
}
public Food randomSelection() {
return Enums.random(values);
}
```

}

Each of the above **enum**s takes the corresponding **Class** object as a constructor argument, from which it can extract and store all the **enum** instances using **getEnumConstants()**. These instances are later used in **randomSelection()**, so now we can create a randomly generated meal by selecting one **Food** item from each **Course**:

```
// enums/menu/Meal.java
// {java enums.menu.Meal}
package enums.menu;
public class Meal {
public static void main(String[] args) {
for(int i = 0; i < 5; i++) {
for(Course course : Course.values()) {
Food food = course.randomSelection();
System.out.println(food);
}
System.out.println("***");
}
}
```

}

/ Output:*

SPRING_ROLLS

VINDALOO

FRUIT

DECAF_COFFEE

***

SOUP

VINDALOO

FRUIT

TEA

***

SALAD

BURRITO

FRUIT

TEA

***

SALAD

BURRITO

CREME_CARAMEL

LATTE

***

SOUP

BURRITO

TIRAMISU

ESPRESSO

***

*/

Here, the value of creating an **enum** of **enum**s is to iterate through each **Course**. Later, in the **VendingMachine.java** example, you'll see another approach to categorization dictated by different constraints.

Another, more compact, approach to the problem of categorization is to nest **enum**s within **enum**s, like this:

```
// enums/SecurityCategory.java
// More succinct subcategorization of enums
import onjava.*;
enum SecurityCategory {
STOCK(Security.Stock.class),
BOND(Security.Bond.class);
```

```
Security[] values;
SecurityCategory(Class<? extends Security> kind) {
values = kind.getEnumConstants();
}
interface Security {
enum Stock implements Security {
SHORT, LONG, MARGIN
}
enum Bond implements Security {
MUNICIPAL, JUNK
}
}
public Security randomSelection() {
return Enums.random(values);
}
public static void main(String[] args) {
for(int i = 0; i < 10; i++) {
SecurityCategory category =
Enums.random(SecurityCategory.class);
System.out.println(category + ": " +
```

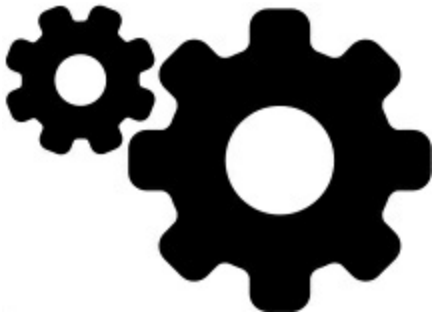
```
category.randomSelection());
}
}
}
/* Output:
BOND: MUNICIPAL
BOND: MUNICIPAL
STOCK: MARGIN
STOCK: MARGIN
BOND: JUNK
STOCK: SHORT
STOCK: LONG
STOCK: LONG
BOND: MUNICIPAL
BOND: JUNK
*/
```

The **Security** interface is necessary to collect the contained **enum**s together as a common type. These are then categorized into the **enum**s within **SecurityCategory**.

If we take this approach with the **Food** example, the result is:

```
// enums/menu/Meal2.java
// {java enums.menu.Meal2}
package enums.menu;
import onjava.*;
public enum Meal2 {
APPETIZER(Food.Appetizer.class),
MAINCOURSE(Food.MainCourse.class),
DESSERT(Food.Dessert.class),
COFFEE(Food.Coffee.class);
private Food[] values;
private Meal2(Class<? extends Food> kind) {
values = kind.getEnumConstants();
}
public interface Food {
enum Appetizer implements Food {
SALAD, SOUP, SPRING_ROLLS;
}
enum MainCourse implements Food {
LASAGNE, BURRITO, PAD_THAI,
LENTILS, HUMMOUS, VINDALOO;
```

```
}
enum Dessert implements Food {
TIRAMISU, GELATO, BLACK_FOREST_CAKE,
FRUIT, CREME_CARAMEL;
}
enum Coffee implements Food {
BLACK_COFFEE, DECAF_COFFEE, ESPRESSO,
LATTE, CAPPUCCINO, TEA, HERB_TEA;
}
}
public Food randomSelection() {
return Enums.random(values);
}
public static void main(String[] args) {
for(int i = 0; i < 5; i++) {
for(Meal2 meal : Meal2.values()) {
Food food = meal.randomSelection();
System.out.println(food);
}
```



```
System.out.println("***");
}
}
}
/* Output:
SPRING_ROLLS
VINDALOO
FRUIT
DECAF_COFFEE
***
SOUP
VINDALOO
FRUIT
TEA
***
SALAD
```

BURRITO

FRUIT

TEA

***

SALAD

BURRITO

CREME_CARAMEL

LATTE

***

SOUP

BURRITO

TIRAMISU

ESPRESSO

***

*/

In the end, it’s only a reorganization of the code but it can produce a

clearer structure in some cases.

Using EnumSet Instead

of Flags

A **Set** is a kind of collection that only allows one of each type of object to be added. An **enum** requires that all its members be unique, so

seems to have set behavior, but since you can't add or remove elements it's not very useful as a set. The **EnumSet** was added to work in concert with **enum**s to create a replacement for traditional **int**-based "bit flags." Such flags are used to indicate some kind of on-off information, but you end up manipulating bits rather than concepts, so it's easy to write confusing code.

The **EnumSet** is designed for speed, because it must compete effectively with bit flags (operations are typically much faster than a **HashSet**). Internally, it is represented by (if possible) a single **long** that is treated as a bit-vector, so it's extremely fast and efficient. The benefit is that you now have a much more expressive way to indicate the presence or absence of a binary feature, without worrying about performance.

The elements of an **EnumSet** must come from a single **enum**. A possible example uses an **enum** of positions in a building where alarm sensors are present:

```
// enums/AlarmPoints.java
package enums;
public enum AlarmPoints {
STAIR1, STAIR2, LOBBY, OFFICE1, OFFICE2, OFFICE3,
```

OFFICE4, BATHROOM, UTILITY, KITCHEN

}

The **EnumSet** keeps track of the alarm status:

```
// enums/EnumSets.java
// Operations on EnumSets
// {java enums.EnumSets}
package enums;
import java.util.*;
import static enums.AlarmPoints.*;
public class EnumSets {
public static void main(String[] args) {
EnumSet<AlarmPoints> points =
EnumSet.noneOf(AlarmPoints.class); // Empty
points.add(BATHROOM);
System.out.println(points);
points.addAll(
EnumSet.of(STAIR1, STAIR2, KITCHEN));
System.out.println(points);
points = EnumSet.allOf(AlarmPoints.class);
points.removeAll(
```

```
EnumSet.of(STAIR1, STAIR2, KITCHEN));
System.out.println(points);
points.removeAll(
EnumSet.range(OFFICE1, OFFICE4));
System.out.println(points);
points = EnumSet.complementOf(points);
System.out.println(points);
}
}
/* Output:
[BATHROOM]
[STAIR1, STAIR2, BATHROOM, KITCHEN]
[LOBBY, OFFICE1, OFFICE2, OFFICE3, OFFICE4, BATHROOM,
UTILITY]
[LOBBY, BATHROOM, UTILITY]
[STAIR1, STAIR2, OFFICE1, OFFICE2, OFFICE3, OFFICE4,
KITCHEN]
*/
```

A **static import** is used to simplify using **enum** constants. The method names are fairly self-explanatory, and you can find the full

details in the JDK documentation. When you look at this documentation, you'll see that the **of()** method is overloaded both with varargs and with individual methods taking two through five explicit arguments. This is an indication of the concern for performance with **EnumSet**, because a single **of()** method using varargs could have solved the problem, but it's slightly less efficient than having explicit arguments. Thus, if you call **of()** with two through five arguments you get the explicit (slightly faster) method calls, but if you call it with one argument or more than five, you get the varargs version of **of()**. Notice that if you call it with one argument, the compiler will not construct the varargs array and so there is no extra overhead for calling that version with a single argument.

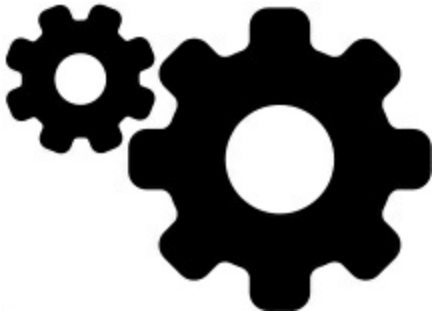
EnumSets are built on top of **long**s, a **long** is 64 bits, and each **enum** instance requires one bit to indicate presence or absence. This means you can have an **EnumSet** for an **enum** of up to 64 elements without going beyond a single **long**. What happens for more than 64 elements in your **enum**?

```
// enums/BigEnumSet.java
import java.util.*;
public class BigEnumSet {
```

```
enum Big { A0, A1, A2, A3, A4, A5, A6, A7, A8, A9,
A10, A11, A12, A13, A14, A15, A16, A17, A18, A19,
A20, A21, A22, A23, A24, A25, A26, A27, A28, A29,
A30, A31, A32, A33, A34, A35, A36, A37, A38, A39,
A40, A41, A42, A43, A44, A45, A46, A47, A48, A49,
A50, A51, A52, A53, A54, A55, A56, A57, A58, A59,
A60, A61, A62, A63, A64, A65, A66, A67, A68, A69,
A70, A71, A72, A73, A74, A75 }
public static void main(String[] args) {
EnumSet<Big> bigEnumSet = EnumSet.allOf(Big.class);
System.out.println(bigEnumSet);
}
}
/* Output:
[A0, A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12,
A13, A14, A15, A16, A17, A18, A19, A20, A21, A22, A23,
A24, A25, A26, A27, A28, A29, A30, A31, A32, A33, A34,
A35, A36, A37, A38, A39, A40, A41, A42, A43, A44, A45,
A46, A47, A48, A49, A50, A51, A52, A53, A54, A55, A56,
A57, A58, A59, A60, A61, A62, A63, A64, A65, A66, A67,
```

A68, A69, A70, A71, A72, A73, A74, A75]

*/



The **EnumSet** clearly has no problem with an **enum** that has more than 64 elements, so we can presume it adds another **long** when necessary.

Using EnumMap

An **EnumMap** is a specialized **Map** that requires its keys be from a single **enum**. Because of the constraints on an **enum**, an **EnumMap** can be implemented internally as an array. Thus they are extremely fast, so you can freely use **EnumMap**s for **enum**-based lookups.

You can only call **put()** for keys in your **enum**, but other than that it's like using an ordinary **Map**.

Here's an example that demonstrates the *Command* design pattern. This pattern starts with an interface containing (typically) a single method, and creates multiple implementations with different behavior for that method. You install Command objects, and your program calls

them when necessary:

```
// enums/EnumMaps.java
// Basics of EnumMaps
// {java enums.EnumMaps}
package enums;
import java.util.*;
import static enums.AlarmPoints.*;
interface Command { void action(); }
public class EnumMaps {
public static void main(String[] args) {
EnumMap<AlarmPoints,Command> em =
new EnumMap<>(AlarmPoints.class);
em.put(KITCHEN,
() -> System.out.println("Kitchen fire!"));
em.put(BATHROOM,
() -> System.out.println("Bathroom alert!"));
for(Map.Entry<AlarmPoints,Command> e:
em.entrySet()) {
System.out.print(e.getKey() + ": ");
e.getValue().action();
```

```
}
try { // If there's no value for a particular key:
em.get(UTILITY).action();
} catch(Exception e) {
System.out.println("Expected: " + e);
}
}
}
/* Output:
BATHROOM: Bathroom alert!
KITCHEN: Kitchen fire!
Expected: java.lang.NullPointerException
*/
```

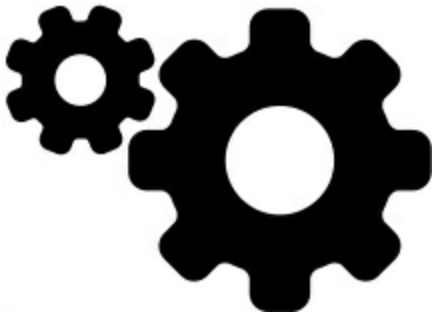
Just as with **EnumSet**, the order of elements in the **EnumMap** is determined by their order of definition in the **enum**.

The last part of **main()** shows there is always a key entry for each of the **enum**s, but the value is **null** unless you have called **put()** for that key.

One advantage of **EnumMap** over *constant-specific methods* (described next) is that with an **EnumMap** you can change the value

objects, whereas you'll see that constant-specific methods are fixed at compile time.

As you'll see later in the chapter, **EnumMap**s can perform *multiple dispatching* for situations where you have multiple types of **enum**s interacting with each other.



Constant-Specific Methods

Java **enum**s can give each **enum** instance different behavior by creating methods for each one. To do this, you define one or more **abstract** methods as part of the **enum**, then define the methods for each **enum** instance. For example:

```
// enums/ConstantSpecificMethod.java
import java.util.*;
import java.text.*;
public enum ConstantSpecificMethod {
DATE_TIME {
```

```
@Override
String getInfo() {
return
DateFormat.getDateInstance()
.format(new Date());
}
},
CLASSPATH {
@Override
String getInfo() {
return System.getenv("CLASSPATH");
}
},
VERSION {
@Override
String getInfo() {
return System.getProperty("java.version");
}
};
abstract String getInfo();
```

```
public static void main(String[] args) {
for(ConstantSpecificMethod csm : values())
System.out.println(csm.getInfo());
}
}
/* Output:
May 9, 2017
C:\Users\Bruce\Documents\GitHub\on-
java\ExtractedExamples\\gradle\wrapper\gradle-
wrapper.jar
1.8.0_112
*/
```

You can look up and call methods via their associated **enum** instance. This is often called *table-driven code* (and note the similarity to the aforementioned Command pattern).

In object-oriented programming, different behavior is associated with different classes. Because each instance of an **enum** can have its own behavior via constant-specific methods, this suggests that each instance is a distinct type. In the above example, each **enum** instance is treated as the "base type" **ConstantSpecificMethod** but you

get polymorphic behavior with the method call **getInfo()**.

However, you can only take the similarity so far. You cannot treat **enum** instances as class types:

```
// enums/NotClasses.java
// {javap -c LikeClasses}
enum LikeClasses {
WINKEN {
@Override
void behavior() {
System.out.println("Behavior1");
}
},
BLINKEN {
@Override
void behavior() {
System.out.println("Behavior2");
}
},
NOD {
@Override
```

```
void behavior() {
System.out.println("Behavior3");
}
};
abstract void behavior();
}
public class NotClasses {
// void f1(LikeClasses.WINKEN instance) {} // Nope
}
/* Output: (First 12 Lines)
Compiled from "NotClasses.java"
abstract class LikeClasses extends
java.lang.Enum<LikeClasses> {
public static final LikeClasses WINKEN;
public static final LikeClasses BLINKEN;
public static final LikeClasses NOD;
public static LikeClasses[] values();
Code:
0: getstatic #2 // Field
$VALUES:[LLikeClasses;
```

3: invokevirtual #3 // Method

"[LLikeClasses;".clone:()Ljava/lang/Object;

...

/

In **f1()**, the compiler doesn't allow you to use an **enum** instance as a class type, which makes sense if you consider the code generated by the compiler—each **enum** element is a **static final** instance of **LikeClasses**.

Also, because they are **static**, **enum** instances of inner **enum**s do not behave like ordinary inner classes; you cannot access non-**static** fields or methods in the outer class.

Now consider a car wash. Each customer is given a menu of choices for their wash, and each option performs a different action. A constant-specific method can be associated with each option, and an **EnumSet** holds the customer's selections:

// enums/CarWash.java

import java.util.*;

public class CarWash {

public enum Cycle {

UNDERBODY {

```
@Override
void action() {
System.out.println("Spraying the underbody");
}
},
WHEELWASH {
@Override
void action() {
System.out.println("Washing the wheels");
}
},
PREWASH {
@Override
void action() {
System.out.println("Loosening the dirt");
}
},
BASIC {
@Override
void action() {
```

```
System.out.println("The basic wash");
}
},
HOTWAX {
@Override
void action() {
System.out.println("Applying hot wax");
}
},
RINSE {
@Override
void action() {
System.out.println("Rinsing");
}
},
BLOWDRY {
@Override
void action() {
System.out.println("Blowing dry");
}
```

```
};
abstract void action();
}
EnumSet<Cycle> cycles =
EnumSet.of(Cycle.BASIC, Cycle.RINSE);
public void add(Cycle cycle) {
cycles.add(cycle);
}
public void washCar() {
for(Cycle c : cycles)
c.action();
}
@Override
public String toString() {
return cycles.toString();
}
public static void main(String[] args) {
CarWash wash = new CarWash();
System.out.println(wash);
wash.washCar();
```

```
// Order of addition is unimportant:
wash.add(Cycle.BLOWDRY);
wash.add(Cycle.BLOWDRY); // Duplicates ignored
wash.add(Cycle.RINSE);
wash.add(Cycle.HOTWAX);
System.out.println(wash);
wash.washCar();
}
}
/* Output:
[BASIC, RINSE]
The basic wash
Rinsing
[BASIC, HOTWAX, RINSE, BLOWDRY]
The basic wash
Applying hot wax
Rinsing
Blowing dry
*/
```

The syntax for defining a constant-specific method is effectively that of

an anonymous inner class, but more succinct.

This example also shows more characteristics of **EnumSet**s. Since it's a set, it will only hold one of each item, so duplicate calls to **add()** with the same argument are ignored (this makes sense, since you can only flip a bit "on" once). Also, the order you add **enum** instances is unimportant—the output order is determined by the declaration order of the **enum**.

Is it possible to override constant-specific methods, instead of implementing an **abstract** method? Yes, as seen here:

```
// enums/OverrideConstantSpecific.java
public enum OverrideConstantSpecific {
NUT, BOLT,
WASHER {
@Override
void f() {
System.out.println("Overridden method");
}
};
void f() {
System.out.println("default behavior");
```

```
}
public static void main(String[] args) {
for(OverrideConstantSpecific ocs : values()) {
System.out.print(ocs + ": ");
ocs.f();
}
}
}
```

```
/* Output:
NUT: default behavior
BOLT: default behavior
WASHER: Overridden method
*/
```

Although **enum**s do prevent certain types of code, in general, experiment with them as if they were classes.

Chain of Responsibility **with enums**

In the *Chain of Responsibility* design pattern, you create a number of different ways to solve a problem and chain them together. When a request occurs, it is passed along the chain until one of the solutions can handle the request.

You can easily implement a simple Chain of Responsibility with constant-specific methods. Consider a model of a post office, which tries to deal with each piece of mail in the most general way possible, but must keep trying until it ends up treating the mail as a dead letter. Each attempt can be thought of as a *Strategy* (another design pattern), and the entire list together is a Chain of Responsibility.

We start by describing a piece of mail. All the different characteristics of interest can be expressed using **enum**s. Because **Mail** objects are randomly generated, the easiest way to reduce the probability of (for example) a piece of mail being given a **YES** for **GeneralDelivery** is to create more non-**YES** instances, so the **enum** definitions look a little funny at first.

Within **Mail**, you'll see **randomMail()**, which creates random pieces of test mail. The **generator()** method produces an **Iterable** object that uses **randomMail()** to produce a number of mail objects, one each time you call **next()** via the iterator. This construct allows the simple creation of a *for-in* loop by calling

Mail.generator():

```
// enums/PostOffice.java
// Modeling a post office
import java.util.*;
import onjava.*;
class Mail {
// The NO's reduce probability of random selection:
enum GeneralDelivery {YES,NO1,NO2,NO3,NO4,NO5}
enum Scannability {UNSCANNABLE,YES1,YES2,YES3,YES4}
enum Readability {ILLEGIBLE,YES1,YES2,YES3,YES4}
enum Address {INCORRECT,OK1,OK2,OK3,OK4,OK5,OK6}
enum ReturnAddress {MISSING,OK1,OK2,OK3,OK4,OK5}
GeneralDelivery generalDelivery;
Scannability scannability;
Readability readability;
Address address;
ReturnAddress returnAddress;
static long counter = 0;
long id = counter++;
@Override
```

```
public String toString() { return "Mail " + id; }
public String details() {
return toString() +
", General Delivery: " + generalDelivery +
", Address Scanability: " + scannability +
", Address Readability: " + readability +
", Address Address: " + address +
", Return address: " + returnAddress;
}
// Generate test Mail:
public static Mail randomMail() {
Mail m = new Mail();
m.generalDelivery =
Enums.random(GeneralDelivery.class);
m.scannability =
Enums.random(Scannability.class);
m.readability =
Enums.random(Readability.class);
m.address = Enums.random(Address.class);
m.returnAddress =
```

```
Enums.random(ReturnAddress.class);
return m;
}
public static
Iterable<Mail> generator(final int count) {
return new Iterable<Mail>() {
int n = count;
@Override
public Iterator<Mail> iterator() {
return new Iterator<Mail>() {
@Override
public boolean hasNext() {
return n-- > 0;
}
@Override
public Mail next() {
return randomMail();
}
@Override
public void remove() { // Not implemented
```

```
throw new UnsupportedOperationException();
}
};
}
};
}
}
public class PostOffice {
enum MailHandler {
GENERAL_DELIVERY {
@Override
boolean handle(Mail m) {
switch(m.generalDelivery) {
case YES:
System.out.println(
"Using general delivery for " + m);
return true;
default: return false;
}
}
```

```
},
MACHINE_SCAN {
@Override
boolean handle(Mail m) {
switch(m.scannability) {
case UNSCANNABLE: return false;
default:
switch(m.address) {
case INCORRECT: return false;
default:
System.out.println(
"Delivering "+ m + " automatically");
return true;
}
}
}
},
VISUAL_INSPECTION {
@Override
boolean handle(Mail m) {
```

```
switch(m.readability) {
case ILLEGIBLE: return false;
default:
switch(m.address) {
case INCORRECT: return false;
default:
System.out.println(
"Delivering " + m + " normally");
return true;
}
}
}
},
RETURN_TO_SENDER {
@Override
boolean handle(Mail m) {
switch(m.returnAddress) {
case MISSING: return false;
default:
System.out.println(
```

```
"Returning " + m + " to sender");
return true;
}
}
};
abstract boolean handle(Mail m);
}
static void handle(Mail m) {
for(MailHandler handler : MailHandler.values())
if(handler.handle(m))
return;
System.out.println(m + " is a dead letter");
}
public static void main(String[] args) {
for(Mail mail : Mail.generator(10)) {
System.out.println(mail.details());
handle(mail);
System.out.println("*****");
}
}
```

}

/ Output:*

Mail 0, General Delivery: NO2, Address Scanability:

UNSCANNABLE, Address Readability: YES3, Address

Address: OK1, Return address: OK1

Delivering Mail 0 normally

*****

Mail 1, General Delivery: NO5, Address Scanability:

YES3, Address Readability: ILLEGIBLE, Address Address:

OK5, Return address: OK1

Delivering Mail 1 automatically

*****

Mail 2, General Delivery: YES, Address Scanability:

YES3, Address Readability: YES1, Address Address: OK1,

Return address: OK5

Using general delivery for Mail 2

*****

Mail 3, General Delivery: NO4, Address Scanability:

YES3, Address Readability: YES1, Address Address:

INCORRECT, Return address: OK4

Returning Mail 3 to sender

*****

Mail 4, General Delivery: NO4, Address Scanability:

UNSCANNABLE, Address Readability: YES1, Address

Address: INCORRECT, Return address: OK2

Returning Mail 4 to sender

*****

Mail 5, General Delivery: NO3, Address Scanability:

YES1, Address Readability: ILLEGIBLE, Address Address:

OK4, Return address: OK2

Delivering Mail 5 automatically

*****

Mail 6, General Delivery: YES, Address Scanability:

YES4, Address Readability: ILLEGIBLE, Address Address:

OK4, Return address: OK4

Using general delivery for Mail 6

*****

Mail 7, General Delivery: YES, Address Scanability:

YES3, Address Readability: YES4, Address Address: OK2,

Return address: MISSING

Using general delivery for Mail 7

*****

Mail 8, General Delivery: NO3, Address Scanability:

YES1, Address Readability: YES3, Address Address:

INCORRECT, Return address: MISSING

Mail 8 is a dead letter

*****

Mail 9, General Delivery: NO1, Address Scanability:

UNSCANNABLE, Address Readability: YES2, Address

Address: OK1, Return address: OK4

Delivering Mail 9 normally

*****

*/

The Chain of Responsibility is expressed in **enum MailHandler**, and the order of the **enum** definitions determines the order in which the strategies are attempted on each piece of mail. Each strategy is tried in turn until one succeeds or they all fail, in which case you have

a dead letter.

State Machines with enums

Enumerated types can be ideal for creating *state machines*. A state machine can be in a finite number of specific states. The machine

normally moves from one state to the next based on an input, but

there are also *transient states*; the machine moves out of these as soon

as their task is performed.

There are certain allowable inputs for each state, and different inputs

change the state of the machine to different new states. Because

enums restrict the set of possible cases, they are useful for

enumerating the different states and inputs.

Each state also typically has some kind of associated output.

A vending machine is a good example of a state machine. First, we

define the various inputs in an **enum**:

```
// enums/Input.java
import java.util.*;
public enum Input {
NICKEL(5), DIME(10), QUARTER(25), DOLLAR(100),
TOOTHPASTE(200), CHIPS(75), SODA(100), SOAP(50),
ABORT_TRANSACTION {
@Override
```

```
public int amount() { // Disallow
throw new RuntimeException("ABORT.amount()");
}
},
STOP { // This must be the last instance.
@Override
public int amount() { // Disallow
throw new
RuntimeException("SHUT_DOWN.amount()");
}
};
int value; // In cents
Input(int value) { this.value = value; }
Input() {}
int amount() { return value; }; // In cents
static Random rand = new Random(47);
public static Input randomSelection() {
// Don't include STOP:
return
values()[rand.nextInt(values().length - 1)];
```

}

}

Note that two of the **Input**s have an associated amount, so **amount()** is defined in the interface. However, it is inappropriate to call **amount()** for the other two **Input** types, so they throw an exception if you call **amount()**. Although this is a bit of an odd setup (define a method in an interface, then throw an exception if you call it for certain implementations), it is imposed upon us because of the constraints of **enum**s.

The **VendingMachine** reacts to these inputs by first categorizing them via the **Category enum**, so it can **switch** on the categories. This example shows how **enum**s make code clearer and easier to manage:

```
// enums/VendingMachine.java
// {java VendingMachine VendingMachineInput.txt}
import java.util.*;
import java.io.IOException;
import java.util.function.*;
import java.nio.file.*;
import java.util.stream.*;
```

```
enum Category {
MONEY(Input.NICKEL, Input.DIME,
Input.QUARTER, Input.DOLLAR),
ITEM_SELECTION(Input.TOOTHPASTE, Input.CHIPS,
Input.SODA, Input.SOAP),
QUIT_TRANSACTION(Input.ABORT_TRANSACTION),
SHUT_DOWN(Input.STOP);
private Input[] values;
Category(Input... types) { values = types; }
private static EnumMap<Input,Category> categories =
new EnumMap<>(Input.class);
static {
for(Category c : Category.class.getEnumConstants())
for(Input type : c.values)
categories.put(type, c);
}
public static Category categorize(Input input) {
return categories.get(input);
}
}
```

```
public class VendingMachine {
private static State state = State.RESTING;
private static int amount = 0;
private static Input selection = null;
enum StateDuration { TRANSIENT } // Tagging enum
enum State {
RESTING {
@Override
void next(Input input) {
switch(Category.categorize(input)) {
case MONEY:
amount += input.amount();
state = ADDING_MONEY;
break;
case SHUT_DOWN:
state = TERMINAL;
default:
}
}
},
```

```
ADDING_MONEY {
@Override
void next(Input input) {
switch(Category.categorize(input)) {
case MONEY:
amount += input.amount();
break;
case ITEM_SELECTION:
selection = input;
if(amount < selection.amount())
System.out.println(
"Insufficient money for " + selection);
else state = DISPENSING;
break;
case QUIT_TRANSACTION:
state = GIVING_CHANGE;
break;
case SHUT_DOWN:
state = TERMINAL;
default:
```

```
}
}
},
DISPENSING(StateDuration.TRANSIENT) {
@Override
void next() {
System.out.println("here is your " + selection);
amount -= selection.amount();
state = GIVING_CHANGE;
}
},
GIVING_CHANGE(StateDuration.TRANSIENT) {
@Override
void next() {
if(amount > 0) {
System.out.println("Your change: " + amount);
amount = 0;
}
state = RESTING;
}
```

```
},
TERMINAL {@Override
void output() { System.out.println("Halted"); } };
private boolean isTransient = false;
State() {}
State(StateDuration trans) { isTransient = true; }
void next(Input input) {
throw new RuntimeException("Only call " +
"next(Input input) for non-transient states");
}
void next() {
throw new RuntimeException(
"Only call next() for " +
"StateDuration.TRANSIENT states");
}
void output() { System.out.println(amount); }
}
static void run(Supplier<Input> gen) {
while(state != State.TERMINAL) {
state.next(gen.get());
```

```
while(state.isTransient)
state.next();
state.output();
}
}
public static void main(String[] args) {
Supplier<Input> gen = new RandomInputSupplier();
if(args.length == 1)
gen = new FileInputSupplier(args[0]);
run(gen);
}
}
// For a basic sanity check:
class RandomInputSupplier implements Supplier<Input> {
@Override
public Input get() {
return Input.randomSelection();
}
}
// Create Inputs from a file of ';'-separated strings:
```

```
class FileInputSupplier implements Supplier<Input> {
private Iterator<String> input;
FileInputSupplier(String fileName) {
try {
input = Files.lines(Paths.get(fileName))
.skip(1) // Skip the comment line
.flatMap(s -> Arrays.stream(s.split(";")))
.map(String::trim)
.collect(Collectors.toList())
.iterator();
} catch(IOException e) {
throw new RuntimeException(e);
}
}
@Override
public Input get() {
if(!input.hasNext())
return null;
return Enum.valueOf(
Input.class, input.next().trim());
```

}

}

/ Output:*

25

50

75

here is your CHIPS

0

100

200

here is your TOOTHPASTE

0

25

35

Your change: 35

0

25

35

Insufficient money for SODA

35

60

70

75

Insufficient money for SODA

75

Your change: 75

0

Halted

**/*

Because selecting among **enum** instances is most often accomplished with a **switch** statement (notice the extra effort that the language goes to make a **switch** on **enum**s easy), one of the most common questions to ask when you are organizing multiple **enum**s is "What do I want to **switch** on?" Here, it's easiest to work back from the **VendingMachine** by noting that in each **State**, you **switch** on the basic categories of input action: inserting money, item selection, aborting the transaction, and turning off the machine. However, within those categories, you have different types of money that can be inserted and different items that can be selected. The **Category enum** groups the different types of **Input** so the **categorize()** method can produce the appropriate **Category** inside a **switch**.

This method uses an **EnumMap** to efficiently and safely perform the lookup.

If you study **class VendingMachine**, you see how each state is different, and responds differently to input. Also note the two transient states; in **run()** the machine waits for an **Input** and doesn't stop moving through states until it is no longer in a transient state.

The **VendingMachine** can be tested in two ways, by using two different **Supplier** objects. The **RandomInputSupplier** just keeps producing inputs, everything except **SHUT_DOWN**. By running this for a long time you get a kind of sanity check to help ensure that the machine will not wander into a bad state. The **FileInputSupplier** takes a file describing inputs in text form, turns them into **enum** instances, and creates **Input** objects. Here's the text file used to produce the output shown above:

// enums/VendingMachineInput.txt

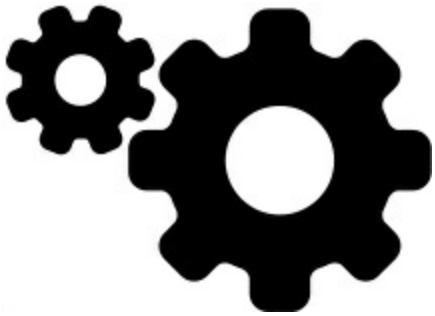
QUARTER; QUARTER; QUARTER; CHIPS;

DOLLAR; DOLLAR; TOOTHPASTE;

QUARTER; DIME; ABORT_TRANSACTION;

QUARTER; DIME; SODA;

QUARTER; DIME; NICKEL; SODA;



ABORT_TRANSACTION;

STOP;

The **FileInputSupplier** constructor turns this file into a **Stream** of lines, skipping the comment line. Then it uses **String.split()** to break each line into parts at the semicolons. This produces an array of **String**, which can be fed into the **Stream** by first converting it to a **Stream**, then applying **flatMap()**. The results have any spaces trimmed off and are turned into a **List<String>** from which an **Iterator<String>** is procured.

One limitation to this design is that the fields in **VendingMachine** accessed by **enum State** instances *must* be **static**, which means you can only have a single **VendingMachine** instance. This might not be that big of an issue if you think about an actual (embedded Java) implementation, since you are likely to have only one application per machine.

Multiple Dispatching

When you are dealing with multiple interacting types, a program can get particularly messy. For example, consider a system that parses and executes mathematical expressions. You want to say **Number.plus(Number)**, **Number.multiply(Number)**, etc., where **Number** is the base class for a family of numerical objects. But when you say **a.plus(b)**, and you don't know the exact type of either **a** or **b**, how can you get them to interact properly?

The answer starts with something you probably don't think about: Java only performs *single dispatching*. That is, if you are performing an operation on more than one object whose type is unknown, Java can invoke the dynamic binding mechanism on only one of those types. This doesn't solve the problem described here, so you end up detecting some types manually and effectively producing your own dynamic binding behavior.

The solution is *multiple dispatching* (here called *double dispatching* because there are only two dispatches). Polymorphism can only occur via method calls, so if you want double dispatching, there must be two method calls: the first to determine the first unknown type, and the second to determine the second unknown type. With multiple

dispatching, you must have a virtual call for each of the types—if you are working with two different interacting type hierarchies, you'll need a virtual call in each hierarchy. Generally, you'll set up a configuration such that a single method call produces more than one virtual method call and thus services more than one type in the process. To get this effect, you work with more than one method: You'll need a method call for each dispatch. The methods in the following example (which implements the "paper, scissors, rock" game, traditionally called *RoShamBo*) are called **compete()** and **eval()** and are both members of the same type. They produce one of three possible outcomes:

```
// enums/Outcome.java
package enums;
public enum Outcome { WIN, LOSE, DRAW }
// enums/RoShamBo1.java
// Demonstration of multiple dispatching
// {java enums.RoShamBo1}
package enums;
import java.util.*;
import static enums.Outcome.*;
```

```
interface Item {
Outcome compete(Item it);
Outcome eval(Paper p);
Outcome eval(Scissors s);
Outcome eval(Rock r);
}
class Paper implements Item {
@Override
public Outcome compete(Item it) {
return it.eval(this);
}
@Override
public Outcome eval(Paper p) { return DRAW; }
@Override
public Outcome eval(Scissors s) { return WIN; }
@Override
public Outcome eval(Rock r) { return LOSE; }
@Override
public String toString() { return "Paper"; }
}
```

```
class Scissors implements Item {
@Override
public Outcome compete(Item it) {
return it.eval(this);
}
@Override
public Outcome eval(Paper p) { return LOSE; }
@Override
public Outcome eval(Scissors s) { return DRAW; }
@Override
public Outcome eval(Rock r) { return WIN; }
@Override
public String toString() { return "Scissors"; }
}
class Rock implements Item {
@Override
public Outcome compete(Item it) {
return it.eval(this);
}
@Override
```

```
public Outcome eval(Paper p) { return WIN; }
@Override
public Outcome eval(Scissors s) { return LOSE; }
@Override
public Outcome eval(Rock r) { return DRAW; }
@Override
public String toString() { return "Rock"; }
}
public class RoShamBo1 {
static final int SIZE = 20;
private static Random rand = new Random(47);
public static Item newItem() {
switch(rand.nextInt(3)) {
default:
case 0: return new Scissors();
case 1: return new Paper();
case 2: return new Rock();
}
}
public static void match(Item a, Item b) {
```

```
System.out.println(
a + " vs. " + b + ": " + a.compete(b));
}
public static void main(String[] args) {
for(int i = 0; i < SIZE; i++)
match(newItem(), newItem());
}
}
/* Output:
Rock vs. Rock: DRAW
Paper vs. Rock: WIN
Paper vs. Rock: WIN
Paper vs. Rock: WIN
Scissors vs. Paper: WIN
Scissors vs. Scissors: DRAW
Scissors vs. Paper: WIN
Rock vs. Paper: LOSE
Paper vs. Paper: DRAW
Rock vs. Paper: LOSE
Paper vs. Scissors: LOSE
```

Paper vs. Scissors: LOSE

Rock vs. Scissors: WIN

Rock vs. Paper: LOSE

Paper vs. Rock: WIN

Scissors vs. Paper: WIN

Paper vs. Scissors: LOSE

Paper vs. Scissors: LOSE

Paper vs. Scissors: LOSE

Paper vs. Scissors: LOSE

*/

Item is the interface for the multiply-dispatched types.

RoShamBo1.match() takes two **Item** objects and begins the double-dispatching process by calling the **Item.compete()** function. The virtual mechanism determines the type of **a**, so it wakes up inside the **compete()** function of **a**s concrete type. The **compete()** function performs the second dispatch by calling **eval()** on the remaining type. Passing itself (**this**) as an argument

to **eval()** produces a call to the overloaded **eval()** function, thus preserving the type information of the first dispatch. When the second dispatch is completed, you know the exact types of both **Item** objects. It requires a lot of ceremony to set up multiple dispatching, but keep in mind that the benefit is the syntactic elegance achieved when making the call—instead of writing awkward code to determine the type of one or more objects during a call, you simply say, “You two! I don’t care what types you are, interact properly with each other!” Make sure this kind of elegance is important to you before embarking on multiple dispatching, however.

Dispatching with enums

Performing a straight translation of **RoShamBo1.java** into an **enum**-based solution is problematic because **enum** instances are not types, so the overloaded **eval()** methods won’t work—you can’t use **enum** instances as argument types. However, there are a number of different approaches to implementing multiple dispatching which benefit from **enum**s.

One approach uses a constructor to initialize each **enum** instance with a “row” of outcomes; taken together this produces a kind of lookup table:

```
// enums/RoShamBo2.java
// Switching one enum on another
// {java enums.RoShamBo2}
package enums;
import static enums.Outcome.*;
public enum RoShamBo2 implements Competitor<RoShamBo2> {
PAPER(DRAW, LOSE, WIN),
SCISSORS(WIN, DRAW, LOSE),
ROCK(LOSE, WIN, DRAW);
private Outcome vPAPER, vSCISSORS, vROCK;
RoShamBo2(Outcome paper,
Outcome scissors, Outcome rock) {
this.vPAPER = paper;
this.vSCISSORS = scissors;
this.vROCK = rock;
}
@Override
public Outcome compete(RoShamBo2 it) {
switch(it) {
default:
```

```
case PAPER: return vPAPER;
case SCISSORS: return vSCISSORS;
case ROCK: return vROCK;
}
}
public static void main(String[] args) {
RoShamBo.play(RoShamBo2.class, 20);
}
}
/* Output:
ROCK vs. ROCK: DRAW
SCISSORS vs. ROCK: LOSE
SCISSORS vs. ROCK: LOSE
SCISSORS vs. ROCK: LOSE
PAPER vs. SCISSORS: LOSE
PAPER vs. PAPER: DRAW
PAPER vs. SCISSORS: LOSE
ROCK vs. SCISSORS: WIN
SCISSORS vs. SCISSORS: DRAW
ROCK vs. SCISSORS: WIN
```

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

ROCK vs. PAPER: LOSE

ROCK vs. SCISSORS: WIN

SCISSORS vs. ROCK: LOSE

PAPER vs. SCISSORS: LOSE

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

*/

Once both types are determined in **compete()**, the only action is the return of the resulting **Outcome**. However, you can also call another method, even (for example) via a *Command* object that was assigned in the constructor.

RoShamBo2.java is much smaller and more straightforward than the original example, and thus easier to keep track of. Notice that you're still using two dispatches to determine the type of both objects. In **RoShamBo1.java**, both dispatches were performed using virtual method calls, but here, only the first dispatch uses a virtual method

call. The second dispatch uses a **switch**, but is safe because the **enum** limits the choices in the **switch** statement.

The code that drives the **enum** is separate so it can be used in the other examples. First, the **Competitor** interface defines a type that competes with another **Competitor**:

```
// enums/Competitor.java
// Switching one enum on another
package enums;
public interface Competitor<T extends Competitor<T>> {
Outcome compete(T competitor);
}
```

Then we define two **static** methods (**static** to avoid specifying the parameter type explicitly). First, **match()** calls **compete()** for one **Competitor** vs. another, and you see that here the type parameter need only be a **Competitor<T>** . But in **play()**, the type parameter must be both an **Enum<T>** because it is used in **Enums.random()**, and a **Competitor<T>** because it is passed to **match()**:

```
// enums/RoShamBo.java
// Common tools for RoShamBo examples
```

```
package enums;
import onjava.*;
public class RoShamBo {
public static <T extends Competitor<T>>
void match(T a, T b) {
System.out.println(
a + " vs. " + b + ": " + a.compete(b));
}
public static <T extends Enum<T> & Competitor<T>>
void play(Class<T> rsbClass, int size) {
for(int i = 0; i < size; i++)
match(
Enums.random(rsbClass),Enums.random(rsbClass));
}
}
```

The **play()** method does not have a return value that involves the type parameter **T**, so it seems like you might use wildcards inside the **Class<T>** type instead of using the leading parameter description. However, wildcards cannot extend more than one base type, so we

must use the above expression.

Using Constant-Specific

Methods

Because constant-specific methods allow you to provide different method implementations for each **enum** instance, they might seem like a perfect solution for setting up multiple dispatching. But even though they can be given different behavior in this way, **enum** instances are not types, so you cannot use them as argument types in method signatures. The best you can do for this example is to set up a **switch** statement:

// enums/RoShamBo3.java

// Using constant-specific methods

// {java enums.RoShamBo3}

package enums;

import static enums.Outcome.*;

public enum RoShamBo3 **implements** Competitor<RoShamBo3> {

PAPER {

```
@Override
public Outcome compete(RoShamBo3 it) {
switch(it) {
default: // To placate the compiler
case PAPER: return DRAW;
case SCISSORS: return LOSE;
case ROCK: return WIN;
}
}
},
SCISSORS {
@Override
public Outcome compete(RoShamBo3 it) {
switch(it) {
default:
case PAPER: return WIN;
case SCISSORS: return DRAW;
case ROCK: return LOSE;
}
}
```

```
},
ROCK {
@Override
public Outcome compete(RoShamBo3 it) {
switch(it) {
default:
case PAPER: return LOSE;
case SCISSORS: return WIN;
case ROCK: return DRAW;
}
}
};
@Override
public abstract Outcome compete(RoShamBo3 it);
public static void main(String[] args) {
RoShamBo.play(RoShamBo3.class, 20);
}
}
/* Output:
ROCK vs. ROCK: DRAW
```

SCISSORS vs. ROCK: LOSE

SCISSORS vs. ROCK: LOSE

SCISSORS vs. ROCK: LOSE

PAPER vs. SCISSORS: LOSE

PAPER vs. PAPER: DRAW

PAPER vs. SCISSORS: LOSE

ROCK vs. SCISSORS: WIN

SCISSORS vs. SCISSORS: DRAW

ROCK vs. SCISSORS: WIN

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

ROCK vs. PAPER: LOSE

ROCK vs. SCISSORS: WIN

SCISSORS vs. ROCK: LOSE

PAPER vs. SCISSORS: LOSE

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

*/

Although this is functional and not unreasonable, the solution of **RoShamBo2.java** seems to require less code when adding a new type, and thus seems more straightforward.

However, **RoShamBo3.java** can be simplified and compressed:

```
// enums/RoShamBo4.java
// {java enums.RoShamBo4}
package enums;
public enum RoShamBo4 implements Competitor<RoShamBo4> {
ROCK {
@Override
public Outcome compete(RoShamBo4 opponent) {
return compete(SCISSORS, opponent);
}
},
SCISSORS {
@Override
public Outcome compete(RoShamBo4 opponent) {
return compete(PAPER, opponent);
}
},
```

```
PAPER {
@Override
public Outcome compete(RoShamBo4 opponent) {
return compete(ROCK, opponent);
}
};
Outcome compete(RoShamBo4 loser, RoShamBo4 opponent) {
return ((opponent == this) ? Outcome.DRAW
: ((opponent == loser) ? Outcome.WIN
: Outcome.LOSE));
}
public static void main(String[] args) {
RoShamBo.play(RoShamBo4.class, 20);
}
}
/* Output:
```

```
PAPER vs. PAPER: DRAW
```

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

ROCK vs. SCISSORS: WIN

ROCK vs. ROCK: DRAW

ROCK vs. SCISSORS: WIN

PAPER vs. SCISSORS: LOSE

SCISSORS vs. SCISSORS: DRAW

PAPER vs. SCISSORS: LOSE

SCISSORS vs. ROCK: LOSE

SCISSORS vs. ROCK: LOSE

PAPER vs. ROCK: WIN

PAPER vs. SCISSORS: LOSE

SCISSORS vs. PAPER: WIN

ROCK vs. SCISSORS: WIN

SCISSORS vs. ROCK: LOSE

SCISSORS vs. ROCK: LOSE

SCISSORS vs. ROCK: LOSE

SCISSORS vs. ROCK: LOSE

*/

Here, the second dispatch is performed by the two-argument version of **compete()**, which performs a sequence of comparisons and is thus similar to the action of a **switch**. It's smaller, but a bit confusing. For a large system this confusion can become debilitating.

Dispatching with EnumMaps

It's possible to perform a "true" double dispatch using the **EnumMap** class, which is specifically designed to work very efficiently with **enum**s. Since the goal is to switch on two unknown types, an **EnumMap** of **EnumMap**s produces the double dispatch:

```
// enums/RoShamBo5.java
// Multiple dispatching using an EnumMap of EnumMaps
// {java enums.RoShamBo5}
package enums;
import java.util.*;
import static enums.Outcome.*;
enum RoShamBo5 implements Competitor<RoShamBo5> {
PAPER, SCISSORS, ROCK;
static EnumMap<RoShamBo5,EnumMap<RoShamBo5,Outcome>>
table = new EnumMap<>(RoShamBo5.class);
static {
```

```
for(RoShamBo5 it : RoShamBo5.values())
table.put(it, new EnumMap<>(RoShamBo5.class));
initRow(PAPER, DRAW, LOSE, WIN);
initRow(SCISSORS, WIN, DRAW, LOSE);
initRow(ROCK, LOSE, WIN, DRAW);
}
static void initRow(RoShamBo5 it,
Outcome vPAPER, Outcome vSCISSORS, Outcome vROCK) {
EnumMap<RoShamBo5,Outcome> row =
RoShamBo5.table.get(it);
row.put(RoShamBo5.PAPER, vPAPER);
row.put(RoShamBo5.SCISSORS, vSCISSORS);
row.put(RoShamBo5.ROCK, vROCK);
}
@Override
public Outcome compete(RoShamBo5 it) {
return table.get(this).get(it);
}
public static void main(String[] args) {
RoShamBo.play(RoShamBo5.class, 20);
```

}

}

/ Output:*

ROCK vs. ROCK: DRAW

SCISSORS vs. ROCK: LOSE

SCISSORS vs. ROCK: LOSE

SCISSORS vs. ROCK: LOSE

PAPER vs. SCISSORS: LOSE

PAPER vs. PAPER: DRAW

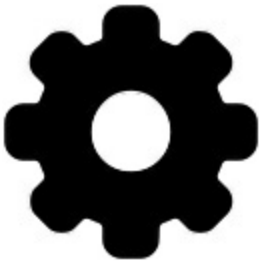
PAPER vs. SCISSORS: LOSE

ROCK vs. SCISSORS: WIN

SCISSORS vs. SCISSORS: DRAW

ROCK vs. SCISSORS: WIN

SCISSORS vs. PAPER: WIN



SCISSORS vs. PAPER: WIN

ROCK vs. PAPER: LOSE

ROCK vs. SCISSORS: WIN

SCISSORS vs. ROCK: LOSE

PAPER vs. SCISSORS: LOSE

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

*/

The **EnumMap** is initialized using a **static** clause; you see the table-like structure of the calls to **initRow()**. Notice the **compete()** method, where both dispatches happen in a single statement.

Using a 2-D Array

We can simplify the solution even more by noting that each **enum** instance has a fixed value (based on its declaration order) and that **ordinal()** produces this value. A two-dimensional array mapping the competitors onto the outcomes produces the smallest and most straightforward solution (and possibly the fastest, although remember that **EnumMap** uses an internal array):

// enums/RoShamBo6.java

// Enums using "tables" instead of multiple dispatch

// {java enums.RoShamBo6}

```
package enums;
import static enums.Outcome.*;
enum RoShamBo6 implements Competitor<RoShamBo6> {
PAPER, SCISSORS, ROCK;
private static Outcome[][] table = {
{ DRAW, LOSE, WIN }, // PAPER
{ WIN, DRAW, LOSE }, // SCISSORS
{ LOSE, WIN, DRAW }, // ROCK
};
@Override
public Outcome compete(RoShamBo6 other) {
return table[this.ordinal()][other.ordinal()];
}
public static void main(String[] args) {
RoShamBo.play(RoShamBo6.class, 20);
}
}
/* Output:
ROCK vs. ROCK: DRAW
SCISSORS vs. ROCK: LOSE
```

SCISSORS vs. ROCK: LOSE

SCISSORS vs. ROCK: LOSE

PAPER vs. SCISSORS: LOSE

PAPER vs. PAPER: DRAW

PAPER vs. SCISSORS: LOSE

ROCK vs. SCISSORS: WIN

SCISSORS vs. SCISSORS: DRAW

ROCK vs. SCISSORS: WIN

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

ROCK vs. PAPER: LOSE

ROCK vs. SCISSORS: WIN

SCISSORS vs. ROCK: LOSE

PAPER vs. SCISSORS: LOSE

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

SCISSORS vs. PAPER: WIN

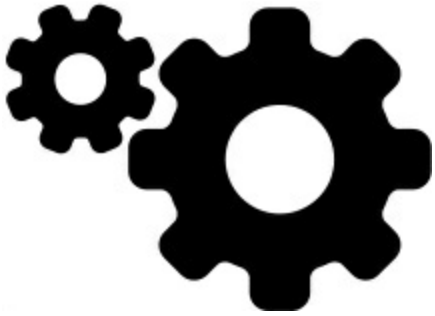
SCISSORS vs. PAPER: WIN

*/

The **table** has exactly the same order as the calls to **initRow()** in

the previous example.

The small size of this code holds great appeal over the previous examples, partly because it seems much easier to understand and modify but also because it just seems more straightforward. However, it’s not as “safe” as the previous examples because it uses an array. With a larger array, you might get the size wrong, and if your tests do not cover all possibilities something could slip through the cracks.



All these solutions are different types of tables, but it’s worth exploring the expression of the tables to find the one that fits best. Note that even though the above solution is the most compact, it is also fairly rigid because it can only produce a constant output given constant inputs. However, there’s nothing that prevents you from having **table** produce a function object. For certain types of problems, the concept of “table-driven code” can be very powerful.

Summary

Even though enumerated types are not terribly complex in themselves,

this chapter was postponed until later in the book because of what you can do with **enum**s in combination with features like polymorphism, generics, and reflection.

Although they are significantly more sophisticated than **enum**s in C or C++, **enum**s are still a “small” feature, something the language has survived (a bit awkwardly) without for many years. And yet this chapter shows the valuable impact that a “small” feature can have—sometimes it gives you just the right leverage to solve a problem elegantly and clearly, and as I say throughout this book, elegance is important, and clarity can make the difference between a successful solution and one that fails because others cannot understand it.

On the subject of clarity, an unfortunate source of confusion comes from the poor choice in Java 1.0 of the term “enumeration” instead of the common and well-accepted term “iterator” to indicate an object that selects each element of a sequence (as shown in Collections). Some languages even refer to enumerated data types as “enumerators!” This mistake has since been rectified in Java, but the **Enumeration** interface could not, of course, simply be removed and so is still hanging around in old (and sometimes new!) code, the library, and documentation.

1. Joshua Bloch was extremely helpful in developing this chapter.↩

Annotations

Annotations (also known as *metadata*)
provide a formalized way to add
information to your code so you can
easily use that data at some later point.1

Annotations are partly motivated by a general trend toward combining metadata with source-code files, instead of keeping it in external documents. They are also a response to feature pressure from other languages like C#.

Annotations are one of the fundamental language changes introduced in Java 5. They provide information that cannot be expressed in Java, but that you need to fully describe your program. Thus, annotations allow you to store extra information about your program in a format validated by the compiler. Annotations can generate descriptor files or even new class definitions and help ease the burden of writing "boilerplate" code. Using annotations, you can keep this metadata in the Java source code, and have the advantage of cleaner looking code,

compile-time type checking and the annotation API for building processing tools for your annotations. Although a few types of metadata come predefined in Java, in general the kind of annotations you add and what you do with them are entirely up to you.

The syntax of annotations is reasonably simple and consists mainly of the addition of the **@** symbol to the language. Java 5 introduced the first three general-purpose built-in annotations, defined in **java.lang**:

@Override, to indicate that a method definition is intended to override a method in the base class. This generates a compiler error if you accidentally misspell the method name or give an improper signature.2

@Deprecated, to produce a compiler warning if this element is used.

@SuppressWarnings, to turn off inappropriate compiler warnings.

@SafeVarargs, added in Java 7 to suppress warnings for callers of a method or constructor with a generics varargs parameter.

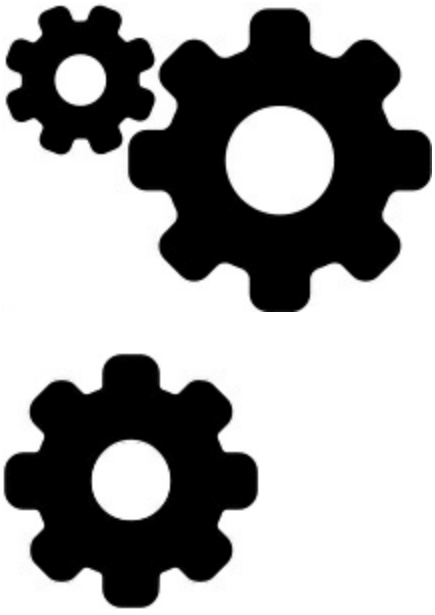
@FunctionalInterface, added in Java 8 to specify that the type declaration is a functional interface.

Five additional annotation types support the creation of new

annotations; you learn about these in this chapter.

Whenever you create classes or interfaces that involve repetitive work, you can usually use annotations to automate and simplify the process. Much of the extra work in *Enterprise JavaBeans* (EJBs), for example, is eliminated through annotations in EJB3.

Annotations can replace existing systems like XDoclet, an independent doclet tool that creates annotation-style doclets. In contrast, annotations are true language constructs and hence are structured and also type-checked at compile time. Keeping all the information in the actual source code and not in comments makes the code neater and easier to maintain. By using and extending the annotation API and tools, or with external bytecode manipulation libraries as you will see



in this chapter, you can perform powerful inspection and

manipulation of your source code as well as the bytecode.

Basic Syntax

In the example below, the method **testExecute()** is annotated with **@Test**. This doesn't do anything by itself, but the compiler ensures you have a definition for the **@Test** annotation in your CLASSPATH. Later in the chapter, we create a tool to run this method via reflection.

```
// annotations/Testable.java
package annotations;
import onjava.atunit.*;
public class Testable {
public void execute() {
System.out.println("Executing..");
}
@Test
void testExecute() { execute(); }
}
```

Annotated methods are no different from other methods. The **@Test** annotation in this example can be used in combination with any of the modifiers like **public** or **static** or **void**. Syntactically,

annotations are used in much the same way as modifiers.

Defining Annotations

Here is the definition of the annotation above. Annotation definitions look a lot like interface definitions. In fact, they compile to class files like any other Java interface:

```
// onjava/atunit/Test.java
// The @Test tag
package onjava.atunit;
import java.lang.annotation.*;
@Target(ElementType.METHOD)
@Retention(RetentionPolicy.RUNTIME)
public @interface Test {}
```

Apart from the **@** symbol, the definition of **@Test** is much like that of an empty interface. An annotation definition also requires the *meta-annotations* **@Target** and **@Retention**. **@Target** defines where you can apply this annotation (a method or a field, for example). **@Retention** defines whether the annotations are available in the source code (**SOURCE**), in the class files (**CLASS**), or at runtime (**RUNTIME**).

Annotations usually contain *elements* that specify values. A program

or tool can use these parameters when processing your annotations. Elements look like interface methods, except you can declare default values.

An annotation without any elements, such as **@Test** above, is called a *marker annotation*.

Here is a simple annotation that tracks use cases in a project. Programmers annotate each method or set of methods that fulfill the requirements of a particular use case. A project manager can get an idea of project progress by counting the implemented use cases, and developers maintaining the project can easily find use cases to update, or they can debug business rules within the system.

```
// annotations/UseCase.java
import java.lang.annotation.*;
@Target(ElementType.METHOD)
@Retention(RetentionPolicy.RUNTIME)
public @interface UseCase {
int id();
String description() default "no description";
}
```

Notice that **id** and **description** resemble method declarations.

Because **id** is type-checked by the compiler, it is a reliable way of linking a tracking database to the use case document and the source code. The element **description** has a **default** value picked up by the annotation processor if no value is specified when a method is annotated.

Here is a class with three methods annotated as use cases:

```
// annotations/PasswordUtils.java
import java.util.*;
public class PasswordUtils {
@UseCase(id = 47, description =
"Passwords must contain at least one numeric")
public boolean validatePassword(String passwd) {
return (passwd.matches("\\w*\\d\\w*"));
}
@UseCase(id = 48)
public String encryptPassword(String passwd) {
return new StringBuilder(passwd)
.reverse().toString();
}
@UseCase(id = 49, description =
```

"New passwords can't equal previously used ones")

public boolean checkForNewPassword(

List<String> prevPasswords, String passwd) {

return !prevPasswords.contains(passwd);

}

}

The values of the annotation elements are expressed as name-value pairs in parentheses after the **@UseCase** declaration. The annotation for **encryptPassword()** is not passed a value for the

description element here, so the default value defined in the **@interface UseCase** will appear when the class runs through an annotation processor.

Imagine using an approach like this to “sketch” out your system, then filling in the functionality as you build it.

Meta-Annotations

There are currently only five standard annotations (described earlier) and five meta-annotations defined in the Java language. The meta-

annotations are for annotating annotations:

Where this annotation can be

applied. The possible

ElementType arguments

are:

CONSTRUCTOR: Constructor

declaration

FIELD: Field declaration

(includes **enum** constants)

@Target

LOCAL_VARIABLE: Local

variable declaration

METHOD: Method declaration

PACKAGE: Package declaration

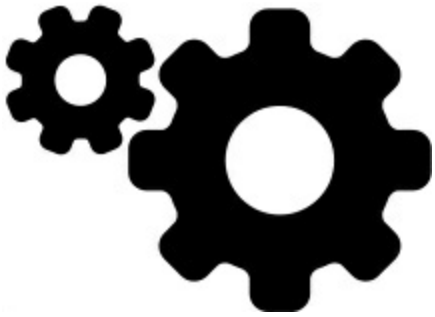
PARAMETER: Parameter

declaration

TYPE: Class, interface

(including annotation type), or

enum declaration



How long the annotation information is kept. The possible **RetentionPolicy** arguments are:

SOURCE: Annotations are discarded by the compiler.

CLASS: Annotations are

@Retention

available in the class file by the compiler but can be discarded by the VM.

RUNTIME: Annotations are retained by the VM at run time, so they can be read reflectively.

Include this annotation in the

@Documented

Javadocs.

Allow subclasses to inherit

@Inherited

parent annotations.

Can apply more than once to

@Repeatable

the same declaration (Java 8).

Most of the time, you define your own annotations and write your own processors to deal with them.

Writing Annotation

Processors

Without tools to read them, annotations are hardly more useful than comments. An important part of the process of using annotations is to create and use *annotation processors*. Java provides extensions to the reflection API to help you create these tools. It also provides a **javac** compiler hook to use annotations at compile time.

Here is a very simple annotation processor that reads the annotated **PasswordUtils** class and uses reflection to look for **@UseCase** tags. Given a list of **id** values, it lists the use cases it finds and reports any that are missing:

```
// annotations/UseCaseTracker.java
import java.util.*;
import java.util.stream.*;
import java.lang.reflect.*;
public class UseCaseTracker {
public static void
trackUseCases(List<Integer> useCases, Class<?> cl) {
for(Method m : cl.getDeclaredMethods()) {
UseCase uc = m.getAnnotation(UseCase.class);
if(uc != null) {
System.out.println("Found Use Case " +
uc.id() + "\n " + uc.description());
useCases.remove(Integer.valueOf(uc.id()));
}
}
useCases.forEach(i ->
System.out.println("Missing use case " + i));
}
public static void main(String[] args) {
List<Integer> useCases = IntStream.range(47, 51)
```

```
.boxed().collect(Collectors.toList());
trackUseCases(useCases, PasswordUtils.class);
}
}
/* Output:
Found Use Case 48
no description
Found Use Case 47
```

```
Passwords must contain at least one numeric
Found Use Case 49
New passwords can't equal previously used ones
Missing use case 50
*/
```

This uses both the reflection method **getDeclaredMethods()** and the method **getAnnotation()**, which comes from the **AnnotatedElement** interface (classes like **Class**, **Method** and **Field** all implement this interface). This method returns the

annotation object of the specified type, in this case "**UseCase**." If there are no annotations of that particular type on the annotated method, a **null** value is returned. The element values are extracted by calling **id()** and **description()**. Remember that no description was specified in the annotation for the **encryptPassword()** method, so the processor above finds the default value "**no description**" when it calls the **description()** method on that particular annotation.

Annotation Elements

The **@UseCase** tag defined in **UseCase.java** contains the **int** element **id** and **String** element **description**. Here is a list of the allowed types for annotation elements:

All primitives (**int**, **float**, **boolean** etc.)

String

Class

enums

Annotations

Arrays of any of the above

The compiler will report an error if you try to use any other types. Note you are not allowed to use any of the wrapper classes, but because of

autoboxing this isn’t really a limitation. You can also have elements that are themselves annotations. As you will see a bit later, nested annotations can be very helpful.

Default Value Constraints

The compiler is picky about default element values. No element can have an unspecified value. This means elements must either have default values or values provided by the class that uses the annotation. There is another restriction: none of the non-primitive type elements are allowed to take **null** as a value, either when declared in the source code or when defined as a default value in the annotation interface. This makes it hard to write a processor that acts on the presence or absence of an element, because every element is effectively present in every annotation declaration. You can get around this by checking for specific values, like empty **String**s or negative values:

```
// annotations/SimulatingNull.java
import java.lang.annotation.*;
@Target(ElementType.METHOD)
@Retention(RetentionPolicy.RUNTIME)
public @interface SimulatingNull {
int id() default -1;
```

String description() **default** "";

}

This is a typical idiom in annotation definitions.

Generating External Files

Annotations are especially useful when working with frameworks that require some sort of additional information to accompany your source code. Technologies like Enterprise JavaBeans (prior to EJB3) require numerous interfaces and deployment descriptors which are “boilerplate” code, defined in the same way for every bean. Web services, custom tag libraries and object/relational mapping tools like Toplink and Hibernate often require XML descriptors external to the code. After defining a Java class, the programmer must undergo the tedium of respecifying information like the name, package and so on—information that already exists in the original class. Whenever you use an external descriptor file, you end up with two separate sources of information about a class, which usually leads to code synchronization problems. This also requires that programmers working on the project

must know about editing the descriptor as well as how to write Java programs.

Suppose you want basic object/relational mapping functionality to automate the creation of a database table. You can use an XML descriptor file to specify the name of the class, each member, and information about its database mapping. Using annotations, however, you can keep all information in a single source-code file. To do this, you need annotations to define the name of the database table, the columns, and the SQL types to map to properties.

Here is an annotation that tells the annotation processor it should create a database table:

```
// annotations/database/DBTable.java
package annotations.database;
import java.lang.annotation.*;
@Target(ElementType.TYPE) // Applies to classes only
@Retention(RetentionPolicy.RUNTIME)
public @interface DBTable {
String name() default "";
}
```

Each **ElementType** you specify in the **@Target** annotation is a

restriction that tells the compiler that your annotation can only be applied to that particular type. You can specify a single value of the **enum ElementType**, or you can specify a comma-separated list of any combination of values. To apply the annotation to any **ElementType**, you can leave out the **@Target** annotation altogether, although this is uncommon.

Note that **@DBTable** has a **name()** element so the annotation can supply a name for the database table that the processor will create.

Here are the annotations for the fields:

```
// annotations/database/Constraints.java
package annotations.database;
import java.lang.annotation.*;
@Target(ElementType.FIELD)
@Retention(RetentionPolicy.RUNTIME)
public @interface Constraints {
boolean primaryKey() default false;
boolean allowNull() default true;
boolean unique() default false;
}
// annotations/database/SQLString.java
```

```
package annotations.database;
import java.lang.annotation.*;
@Target(ElementType.FIELD)
@Retention(RetentionPolicy.RUNTIME)
public @interface SQLString {
int value() default 0;
String name() default "";
Constraints constraints() default @Constraints;
}
// annotations/database/SQLInteger.java
package annotations.database;
import java.lang.annotation.*;
@Target(ElementType.FIELD)
@Retention(RetentionPolicy.RUNTIME)
public @interface SQLInteger {
String name() default "";
Constraints constraints() default @Constraints;
}
```

The **@Constraints** annotation allows the processor to extract the metadata about the database table. This represents a small subset of

the constraints generally offered by databases, but it gives you the general idea. The elements **primaryKey()**, **allowNull()** and **unique()** are given sensible default values so in most cases a user of the annotation won't have to type too much.

The other two **@interfaces** define SQL types. Again, for this framework to be more useful, you define an annotation for each additional SQL type. Here, two types are enough.

These types each have a **name()** element and a **constraints()** element. The latter makes use of the nested annotation feature to embed the information about the column type's database constraints.

Note that the default value for the **constraints()** element is **@Constraints**. Since there are no element values specified in parentheses after this annotation type, the default value of **constraints()** is actually a **@Constraints** annotation with its own default values set. To make a nested **@Constraints** annotation with uniqueness set to **true** by default, you can define its element like this:

```
// annotations/database/Uniqueness.java
// Sample of nested annotations
package annotations.database;
public @interface Uniqueness {
```

Constraints constraints()

default @Constraints(unique = **true**);

}

Here is a simple class that uses these annotations:

// annotations/database/Member.java

package annotations.database;

@DBTable(name = "MEMBER")

public class Member {

@SQLString(30) String firstName;

@SQLString(50) String lastName;

@SQLInteger Integer age;

@SQLString(value = 30,

constraints = @Constraints(primaryKey = **true**))

String reference;

static int memberCount;

public String getReference() { **return** reference; }

public String getFirstName() { **return** firstName; }

public String getLastName() { **return** lastName; }

@Override

public String toString() { **return** reference; }

public Integer getAge() { **return** age; }

}

The **@DBTable** class annotation is given the value **MEMBER**, which is used as the table name. The properties **firstName** and **lastName** are both annotated with **@SQLString**s and have element values of 30 and 50, respectively. These annotations are interesting for two reasons: First, they use the default value on the nested **@Constraints** annotation, and second, they use a shortcut feature.

If you define an element on an annotation with the name **value**, then as long as it is the only element type specified, you don't need the name-value pair syntax; you can just specify the value within parentheses. This can be applied to any of the legal element types. This limits you to naming your element "value" but in the case above, it does allow for the semantically meaningful and easy-to-read annotation specification:

@SQLString(30)

The processor will use this value to set the size of the SQL column it will create.

As neat as the default-value syntax is, it quickly becomes complex. Look at the annotation on the field **reference**. This has an

@SQLString annotation, but it must also be a primary key on the database, so the element type **primaryKey** must be set on the nested **@Constraint** annotation. This is where it gets messy. You are now forced to use the rather long-winded name-value pair form for this nested annotation, respecifying the element name *and* the **@interface** name. But because the specially named element **value** is no longer the only element value specified, you can't use the shortcut form. As you see, the result is not pretty.

Alternative Solutions

There are other ways of creating annotations for this task. You can, for example, have a single annotation class called **@TableColumn** with an **enum** element which defines values like **STRING**, **INTEGER**, **FLOAT**, etc. This eliminates the need for an **@interface** for each SQL type, but makes it impossible to qualify your types with additional

elements like *size*, or *precision*, which is probably more useful.

You can also use a **String** element to describe the actual SQL type, e.g., “VARCHAR(30)” or “INTEGER”. This does allow you to qualify the types, but it ties up the mapping from Java type to SQL type in your code, which is not good design. You don’t want to recompile classes if you change databases; it would be more elegant just to tell your annotation processor you use a different “flavor” of SQL, and it let it take that into account when processing the annotations.

A third workable solution is to use two annotation types together, **@Constraints** and the relevant SQL type (for example, **@SQLInteger**), to annotate the desired field. This is slightly messy but the compiler allows as many different annotations as you like on an annotation target. In Java 8, when using multiple annotations, you are allowed to use the same annotation more than once.

Annotations Don’t Support

Inheritance

You cannot use the **extends** keyword with **@interfaces**. This is a

pity, because an elegant solution would have been to define an annotation **@TableColumn**, as suggested above, with a nested annotation of type **@SQLType**. That way, you can inherit all your SQL types, like **@SQLInteger** and **@SQLString**, from **@SQLType**. This would reduce typing and neaten the syntax. There doesn't seem to be any suggestion of annotations supporting inheritance in future releases, so the examples above seem the best you can do under the circumstances.

Implementing the Processor

Here is an example of an annotation processor which reads in a class file, checks for its database annotations and generates the SQL command for making the database:

```
// annotations/database/TableCreator.java
// Reflection-based annotation processor
// {java annotations.database.TableCreator
// annotations.database.Member}
package annotations.database;
import java.lang.annotation.*;
import java.lang.reflect.*;
import java.util.*;
```

```
public class TableCreator {
public static void
main(String[] args) throws Exception {
if(args.length < 1) {
System.out.println(
"arguments: annotated classes");
System.exit(0);
}
for(String className : args) {
Class<?> cl = Class.forName(className);
DBTable dbTable = cl.getAnnotation(DBTable.class);
if(dbTable == null) {
System.out.println(
"No DBTable annotations in class " +
className);
continue;
}
String tableName = dbTable.name();
// If the name is empty, use the Class name:
if(tableName.length() < 1)
```

```
tableName = cl.getName().toUpperCase();
List<String> columnDefs = new ArrayList<>();
for(Field field : cl.getDeclaredFields()) {
String columnName = null;
Annotation[] anns =
field.getDeclaredAnnotations();
if(anns.length < 1)
continue; // Not a db table column
if(anns[0] instanceof SQLInteger) {
SQLInteger sInt = (SQLInteger) anns[0];
// Use field name if name not specified
if(sInt.name().length() < 1)
columnName = field.getName().toUpperCase();
else
columnName = sInt.name();
columnDefs.add(columnName + " INT" +
getConstraints(sInt.constraints()));
}
if(anns[0] instanceof SQLString) {
SQLString sString = (SQLString) anns[0];
```

```
// Use field name if name not specified.
if(sString.name().length() < 1)
columnName = field.getName().toUpperCase();
else
columnName = sString.name();
columnDefs.add(columnName + " VARCHAR(" +
sString.value() + ")" +
getConstraints(sString.constraints()));
}
StringBuilder createCommand = new StringBuilder(
"CREATE TABLE " + tableName + "(");
for(String columnDef : columnDefs)
createCommand.append(
"\n " + columnDef + ",");
// Remove trailing comma
String tableCreate = createCommand.substring(
0, createCommand.length() - 1) + ");";
System.out.println("Table Creation SQL for " +
className + " is:\n" + tableCreate);
}
```

```
}
}
private static
String getConstraints(Constraints con) {
String constraints = "";
if(!con.allowNull())
constraints += " NOT NULL";
if(con.primaryKey())
constraints += " PRIMARY KEY";
if(con.unique())
constraints += " UNIQUE";
return constraints;
}
}
/* Output:
Table Creation SQL for annotations.database.Member is:
CREATE TABLE MEMBER(
FIRSTNAME VARCHAR(30));
Table Creation SQL for annotations.database.Member is:
CREATE TABLE MEMBER(
```

FIRSTNAME VARCHAR(30),

LASTNAME VARCHAR(50));

Table Creation SQL for annotations.database.Member is:

CREATE TABLE MEMBER(

FIRSTNAME VARCHAR(30),

LASTNAME VARCHAR(50),

AGE INT);

Table Creation SQL for annotations.database.Member is:

CREATE TABLE MEMBER(

FIRSTNAME VARCHAR(30),

LASTNAME VARCHAR(50),

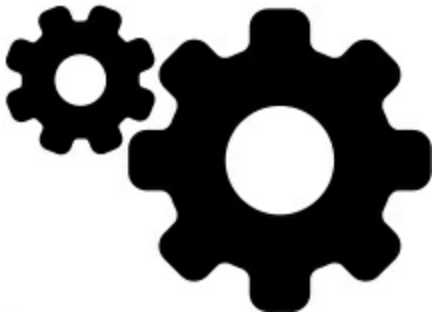
AGE INT,

REFERENCE VARCHAR(30) PRIMARY KEY);

**/*

The **main()** method cycles through each of the class names on the command line. Each class is loaded using **forName()** and checked to see if it has the **@DBTable** annotation on it with **getAnnotation(DBTable.class)**. If it does, then the table name is found and stored. All fields in the class are then loaded and checked using **getDeclaredAnnotations()**. This method

returns an array of all defined annotations for a particular method. The **instanceof** operator is used to determine if these annotations are of type **@SQLInteger** and **@SQLString**, and in each case the relevant **String** fragment is then created with the name of the table column. Note that because there is no inheritance of annotation interfaces, using **getDeclaredAnnotations()** is the only way you can approximate polymorphic behavior.



The nested @**Constraint** annotation is passed to the **getConstraints()** which builds up a **String** containing the SQL constraints.

It is worth mentioning that the technique shown above is a somewhat naïve way of defining an object/relational mapping. Having an annotation of type @**DBTable** which takes the table name as a parameter forces you to recompile your Java code to change the table name. This might not be desirable. There are many available frameworks for mapping objects to relational databases, and more and

more of them are making use of annotations.

Using javac to Process Annotations

Through **javac**, you can work with annotations on Java source files rather than compiled classes, by creating compile-time annotation processors. There's an important limitation, however: you cannot change the source code via the annotation processor. The only way to influence the outcome is by creating new files.

If your annotation processor creates a new source file, that file is itself checked for annotations in a new round of processing. The tool will continue round after round of processing until no more source files are created. It then compiles all the source files.

Each annotation you write will need its own processor, but **javac** can easily group several annotation processors together. You can specify multiple classes to be processed, and you can add listeners to receive notifications when an annotation processing round is complete.

The examples in this section will get you started but if you must go deeper, be ready to thrash around a bit, with plenty of visits to Google

and StackOverflow.

The Simplest Processor

Let’s start by defining the simplest processor we can imagine, just for something to compile and test. Here’s the annotation definition:

```
// annotations/simplest/Simple.java
// A bare-bones annotation
package annotations.simplest;
import java.lang.annotation.Retention;
import java.lang.annotation.RetentionPolicy;
import java.lang.annotation.Target;
import java.lang.annotation.ElementType;
@Retention(RetentionPolicy.SOURCE)
@Target({ElementType.TYPE, ElementType.METHOD,
ElementType.CONSTRUCTOR,
ElementType.ANNOTATION_TYPE,
ElementType.PACKAGE, ElementType.FIELD,
ElementType.LOCAL_VARIABLE})
```

```
public @interface Simple {
String value() default "-default-";
}
```

The **@Retention** is now **SOURCE**, which means the annotations do not survive into the compiled code. This is not necessary to manipulate annotations at compile time—it just makes the point that, here, **javac** is the only agent with the opportunity to process annotations.

The **@Target** declaration shows almost all the possible target types (except for **PACKAGE**), again just for demonstration.

Here's an example to test it:

```
// annotations/simplest/SimpleTest.java
// Test the "Simple" annotation
// {java annotations.simplest.SimpleTest}
package annotations.simplest;
@Simple
public class SimpleTest {
@Simple
int i;
@Simple
```

```
public SimpleTest() {}
@Simple
public void foo() {
System.out.println("SimpleTest.foo()");
}
@Simple
public void bar(String s, int i, float f) {
System.out.println("SimpleTest.bar()");
}
@Simple
public static void main(String[] args) {
@Simple
SimpleTest st = new SimpleTest();
st.foo();
}
}
/* Output:
SimpleTest.foo()
*/
```

Here, we annotate everything that **@Simple** is allowed by its

@Target declaration.

SimpleTest.java only requires **Simple.java** to compile successfully. Nothing happens when we compile it, though. **javac** allows the **@Simple** annotation (as long as it exists) but it doesn't do anything with it until we create an annotation processor and hook it into the compiler.

Here's a very simple processor. All it does is print information about the annotations:

```
// annotations/simplest/SimpleProcessor.java
// A bare-bones annotation processor
package annotations.simplest;
import javax.annotation.processing.*;
import javax.lang.model.SourceVersion;
import javax.lang.model.element.*;
import java.util.*;
@SupportedAnnotationTypes(
"annotations.simplest.Simple")
@SupportedSourceVersion(SourceVersion.RELEASE_8)
public class SimpleProcessor
extends AbstractProcessor {
```

```
@Override
public boolean process(
Set<? extends TypeElement> annotations,
RoundEnvironment env) {
for(TypeElement t : annotations)
System.out.println(t);
for(Element el :
env.getElementsAnnotatedWith(Simple.class))
display(el);
return false;
}
private void display(Element el) {
System.out.println("==== " + el + " ====");
System.out.println(el.getKind() +
" : " + el.getModifiers() +
" : " + el.getSimpleName() +
" : " + el.asType());
if(el.getKind().equals(ElementKind.CLASS)) {
TypeElement te = (TypeElement)el;
System.out.println(te.getQualifiedName());
```

```
System.out.println(te.getSuperclass());
System.out.println(te.getEnclosedElements());
}
if(el.getKind().equals(ElementKind.METHOD)) {
ExecutableElement ex = (ExecutableElement)el;
System.out.print(ex.getReturnType() + " ");
System.out.print(ex.getSimpleName() + "(");
System.out.println(ex.getParameters() + ")");
}
}
}
```

The (old, defunct) **apt** version of annotation processors required extra methods to establish which annotations were supported, and which Java version is supported. Now, however, you can simply use the annotations **@SupportedAnnotationTypes** and **@SupportedSourceVersion**. (This is a good example of how annotations simplify your code).

The only method you must implement is **process()**, where all the action happens. The first argument tells you which annotations are present, and the second argument contains all the rest of the

information. All we do here is print the annotations (there's only one) but see the **TypeElement** documentation for other actions.

Using the second **process()** argument, we loop through all the elements annotated with **@Simple**, and call our **display()** method on each one. Every **Element** can produce basic information about itself; for example, **getModifiers()** tells you if it's **public** and **static**.

Element can only do things common to all basic objects parsed by the compiler, whereas things like classes and methods have additional information to extract. So (and perhaps this was obvious if you read the right document, but it wasn't in any documentation I found—I had to find clues via StackOverflow) you check to see what **ElementKind** it is, then downcast it to the more specific type of element—here, **TypeElement** for **CLASS** and **ExecutableElement** for **METHOD**. At that point, you can call the additional methods for those **Element** types.

A dynamic downcast (which is not checked at compile-time) is a very un-Java-like way of doing things, thus un-intuitive and probably why I never thought of doing it. Instead, I spent several days cycling around trying to discover how you were supposed to access the information

that had seemed at least somewhat straightforward with the defunct **apt** approach. I still haven't come across anything that says the above is the canonical form, but it seems to me it is.

If you just compile **SimpleTest.java** the normal way, you won't get any results. To get the annotation output, you have to add the **–processor** flag and the annotation processor class:

javac -processor annotations.simplest.SimpleProcessor SimpleTest.java

Now the compiler produces:

annotations.simplest.Simple

==== annotations.simplest.SimpleTest ====

CLASS : [public] : SimpleTest : annotations.simplest.SimpleTest

annotations.simplest.SimpleTest

java.lang.Object

i,SimpleTest(),foo(),bar(java.lang.String,int,float),main(java.lang.String[]

==== i ====

FIELD : [] : i : int

==== SimpleTest() ====

CONSTRUCTOR : [public] : <init> : ()void

==== foo() ====

METHOD : [public] : foo : ()void

void foo()

==== bar(java.lang.String,int,float) ====

METHOD : [public] : bar : (java.lang.String,int,float)void

void bar(s,i,f)

==== main(java.lang.String[]) ====

METHOD : [public, static] : main : (java.lang.String[])void

void main(args)

This gives you a flavor of the kinds of things you can discover,

including argument names and types, return value, etc.

A More Complex Processor

When you create an annotation processor for use with **javac**, you

can't use the reflection features in Java because you are working with

source code, not compiled classes. The various **mirror**s[3] solve this problem by allowing you to view methods, fields and types in

uncompiled source code.

Here is an annotation for extracting the public methods from a class,

so they can be turned into an interface:

```
// annotations/ifx/ExtractInterface.java
// javac-based annotation processing
package annotations.ifx;
import java.lang.annotation.*;
@Target(ElementType.TYPE)
@Retention(RetentionPolicy.SOURCE)
public @interface ExtractInterface {
String interfaceName() default "-!!-";
}
```

The **RetentionPolicy** is **SOURCE** because there is no point in keeping this annotation in the class file after we have extracted the interface from the class. The following test class provides some public methods which can become part of an interface:

```
// annotations/ifx/Multiplier.java
// javac-based annotation processing
// {java annotations.ifx.Multiplier}
package annotations.ifx;
@ExtractInterface(interfaceName="IMultiplier")
public class Multiplier {
public boolean flag = false;
```

```
private int n = 0;
public int multiply(int x, int y) {
int total = 0;
for(int i = 0; i < x; i++)
total = add(total, y);
return total;
}
public int fortySeven() { return 47; }
private int add(int x, int y) {
return x + y;
}
public double timesTen(double arg) {
return arg * 10;
}
public static void main(String[] args) {
Multiplier m = new Multiplier();
System.out.println(
"11 * 16 = " + m.multiply(11, 16));
}
}
```

/ *Output:*

*11 * 16 = 176*

**/*

The **Multiplier** class (which only works with positive integers) has a **multiply()** method which calls the private **add()** method numerous times to perform multiplication. The **add()** method is not public, so is not part of the interface. The other methods provide some syntax variety. The annotation is given the **interfaceName** of **IMultiplier** as the name of the interface to create.

Here's a compile-time processor that extracts the methods of interest and creates the new interface source-code file (which will in turn be automatically compiled as part of the "rounds"):

```
// annotations/ifx/IfaceExtractorProcessor.java
// javac-based annotation processing
package annotations.ifx;
import javax.annotation.processing.*;
import javax.lang.model.SourceVersion;
import javax.lang.model.element.*;
import javax.lang.model.util.*;
import java.util.*;
```

```
import java.util.stream.*;
import java.io.*;
@SupportedAnnotationTypes(
"annotations.ifx.ExtractInterface")
@SupportedSourceVersion(SourceVersion.RELEASE_8)
public class IfaceExtractorProcessor
extends AbstractProcessor {
private ArrayList<Element>
interfaceMethods = new ArrayList<>();
Elements elementUtils;
private ProcessingEnvironment processingEnv;
@Override
public void init(
ProcessingEnvironment processingEnv) {
this.processingEnv = processingEnv;
elementUtils = processingEnv.getElementUtils();
}
@Override
public boolean process(
Set<? extends TypeElement> annotations,
```

```
RoundEnvironment env) {
for(Element elem:env.getElementsAnnotatedWith(
ExtractInterface.class)) {
String interfaceName = elem.getAnnotation(
ExtractInterface.class).interfaceName();
for(Element enclosed :
elem.getEnclosedElements()) {
if(enclosed.getKind()
.equals(ElementKind.METHOD) &&
enclosed.getModifiers()
.contains(Modifier.PUBLIC) &&
!enclosed.getModifiers()
.contains(Modifier.STATIC)) {
interfaceMethods.add(enclosed);
}
}
if(interfaceMethods.size() > 0)
writeInterfaceFile(interfaceName);
}
return false;
```

```
}
private void
writeInterfaceFile(String interfaceName) {
try(
Writer writer = processingEnv.getFiler()
.createSourceFile(interfaceName)
.openWriter()
) {
String packageName = elementUtils
.getPackageOf(interfaceMethods
.get(0)).toString();
writer.write(
"package " + packageName + ";\n");
writer.write("public interface " +
interfaceName + " {\n");
for(Element elem : interfaceMethods) {
ExecutableElement method =
(ExecutableElement)elem;
String signature = " public ";
signature += method.getReturnType() + " ";
```

```
signature += method.getSimpleName();
signature += createArgList(
method.getParameters());
System.out.println(signature);
writer.write(signature + ";\n");
}
writer.write("}");
} catch(Exception e) {
throw new RuntimeException(e);
}
}
private String createArgList(
List<? extends VariableElement> parameters) {
String args = parameters.stream()
.map(p -> p.asType() + " " + p.getSimpleName())
.collect(Collectors.joining(", "));
return "(" + args + ")";
}
}
```

The **Elements** object **elementUtils** is a collection of **static**

tools; we use it to find the package name within **writeInterfaceFile()**.

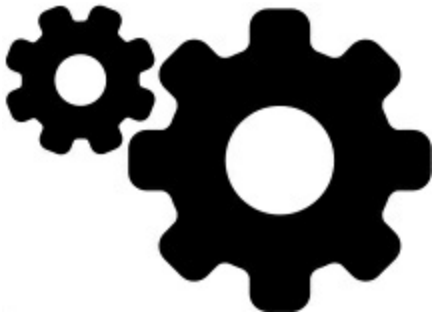
The **getEnclosedElements()** method produces all the elements "enclosed" by a particular element. Here, the class encloses all its components. Using **getKind()** we find all **public** and **static** methods, and add those to the **interfaceMethods** list. Then **writeInterfaceFile()** uses that list to produce the new interface definition. Note the downcast to **ExecutableElement** in **writeInterfaceFile()**, which enables us to extract all the method information. **createArgList()** is a helper method to generate the argument list.

The **Filer** (produced by **getFiler()**) is a kind of **PrintWriter** which creates new files. The reason you use a **Filer** object, rather than a plain **PrintWriter**, is that it allows **javac** to keep track of any new files you create, so it can check them for annotations and compile them in an additional "round."

Here's the command line to compile using the processor:

javac -processor annotations.ifx.IfaceExtractorProcessor Multiplier.java

The generated **IMultiplier.java** file, as you might guess by looking at the **println()** statements in the processor above, looks



like this:

```
package annotations.ifx;

public interface IMultiplier {

public int multiply(int x, int y);

public int fortySeven();

public double timesTen(double arg);

}
```

This file is also compiled by **javac** (as part of the “rounds”), so you see the file **IMultiplier.class** in the same directory.

Annotation-Based Unit Testing

Unit testing is the practice of creating one or more tests for each method in a class, to regularly test the portions of a class for correct behavior. The most popular tool used for unit testing in Java is called *JUnit* (see Validating Your Code). JUnit version 4 incorporates annotations. [4] One of the main problems with pre-annotation versions of JUnit is the amount of “ceremony” necessary to set up and run

JUnit tests. This has reduced over time, but annotations move testing closer to “the simplest unit testing system that can possibly work.” With pre-annotation versions of JUnit, you must create a separate class to hold your unit tests. With annotations we can include the unit tests inside the class to be tested, and thus reduce the time and trouble of unit testing to a minimum. This approach has the additional benefit of testing **private** methods as easily as **public** ones.

Since this example test framework is annotation-based, it’s called **@Unit**. The most basic form of testing, and one which you will probably use much of the time, only needs the **@Test** annotation to indicate which methods should be tested. One option is for the test methods to take no arguments and return a **boolean** to indicate success or failure. You can use any name you like for test methods. Also, **@Unit** test methods can have any access that you’d like, including **private**.

To use **@Unit**, you import **onjava.atunit**, mark the appropriate methods and fields with **@Unit** test tags (which you’ll learn about in the following examples), then have your build system run **@Unit** on the resulting class. Here’s a simple example:

// annotations/AtUnitExample1.java

```
// {java onjava.atunit.AtUnit
// build/classes/main/annotations/AtUnitExample1.class}
package annotations;
import onjava.atunit.*;
import onjava.*;
public class AtUnitExample1 {
public String methodOne() {
return "This is methodOne";
}
public int methodTwo() {
System.out.println("This is methodTwo");
return 2;
}
@Test
boolean methodOneTest() {
return methodOne().equals("This is methodOne");
}
@Test
boolean m2() { return methodTwo() == 2; }
@Test
```

```
private boolean m3() { return true; }
// Shows output for failure:
@Test
boolean failureTest() { return false; }
@Test
boolean anotherDisappointment() {
return false;
}
}
/* Output:
annotations.AtUnitExample1
. m3
. methodOneTest
. m2 This is methodTwo
. failureTest (failed)
. anotherDisappointment (failed)
(5 tests)
>>> 2 FAILURES <<<
annotations.AtUnitExample1: failureTest
annotations.AtUnitExample1: anotherDisappointment
```

*/

Classes to be **@Unit** tested must be placed in packages.

The **@Test** annotation preceding the methods **methodOneTest()**, **m2()**, **m3()**, **failureTest()** and **anotherDisappointment()** tells **@Unit** to run these methods as unit tests. It will also ensure that those methods take no arguments and return a **boolean** or **void**. Your only responsibility when you write the unit test is to determine whether the test succeeds or fails and returns **true** or **false**, respectively (for methods that return **boolean**).

If you're familiar with JUnit, you'll also note **@Unit**s more informative output—you see the test that's currently running so the output from that test is more useful, and at the end it tells you the classes and tests that caused failures.

You're not forced to embed test methods inside your classes, if that doesn't work for you. The easiest way to create non-embedded tests is with inheritance:

// annotations/AUExternalTest.java

// Creating non-embedded tests

// {java onjava.atunit.AtUnit

```
// build/classes/main/annotations/AUExternalTest.class}
package annotations;
import onjava.atunit.*;
import onjava.*;
public class
AUExternalTest extends AtUnitExample1 {
@Test
boolean tMethodOne() {
return methodOne().equals("This is methodOne");
}
@Test
boolean tMethodTwo() {
return methodTwo() == 2;
}
}
/* Output:
annotations.AUExternalTest
. tMethodOne
. tMethodTwo This is methodTwo
OK (2 tests)
```

*/

This example also demonstrates the value of flexible naming. Here, **@Test** methods that directly test another method are given the name of that method starting with an underscore (I’m not suggesting this is an ideal style, just showing a possibility).

You can also use composition to create non-embedded tests:

```
// annotations/AUComposition.java
// Creating non-embedded tests
// {java onjava.atunit.AtUnit
// build/classes/main/annotations/AUComposition.class}
package annotations;
import onjava.atunit.*;
import onjava.*;
public class AUComposition {
AtUnitExample1 testObject = new AtUnitExample1();
@Test
boolean tMethodOne() {
return testObject.methodOne()
.equals("This is methodOne");
}
```

```
@Test
boolean tMethodTwo() {
return testObject.methodTwo() == 2;
}
}
/* Output:
annotations.AUComposition
. tMethodTwo This is methodTwo
. tMethodOne
OK (2 tests)
*/
```

A new member **testObject** is created for each test, since an **AUComposition** object is created for each test.

There are no special “assert” methods as there are in JUnit, but the second form of the **@Test** method returns **void** (or **boolean**, if you still want to return **true** or **false** here). To test for success, you can use Java **assert** statements. Java assertions are normally enabled with the **-ea** flag on the **java** command line, but **@Unit** automatically enables them. To indicate failure, you can even use an exception. One of the **@Unit** design goals is to require as little

additional syntax as possible, and Java's **assert** and exceptions are all that is necessary to report errors. A failed **assert** or an exception that emerges from the test method is treated as a failed test, but **@Unit** does not halt here—it continues until all the tests are run. Here's an example:

```
// annotations/AtUnitExample2.java
// Assertions and exceptions can be used in @Tests
// {java onjava.atunit.AtUnit
// build/classes/main/annotations/AtUnitExample2.class}
package annotations;
import java.io.*;
import onjava.atunit.*;
import onjava.*;
public class AtUnitExample2 {
public String methodOne() {
return "This is methodOne";
}
public int methodTwo() {
System.out.println("This is methodTwo");
return 2;
```

```
}
@Test
void assertExample() {
assert methodOne().equals("This is methodOne");
}
@Test
void assertFailureExample() {
assert 1 == 2: "What a surprise!";
}
@Test
void exceptionExample() throws IOException {
try(FileInputStream fis =
new FileInputStream("nofile.txt")) {} // Throws
}
@Test
boolean assertAndReturn() {
// Assertion with message:
assert methodTwo() == 2: "methodTwo must equal 2";
return methodOne().equals("This is methodOne");
}
```

}

/ *Output:*

annotations.AtUnitExample2

. exceptionExample java.io.FileNotFoundException:

nofile.txt (The system cannot find the file specified)

(failed)

. assertExample

. assertAndReturn This is methodTwo

. assertFailureExample java.lang.AssertionError: What

a surprise!

(failed)

(4 tests)

>>> 2 FAILURES <<<

annotations.AtUnitExample2: exceptionExample

annotations.AtUnitExample2: assertFailureExample

**/*

Here’s an example using non-embedded tests with assertions,

performing some simple tests of **java.util.HashSet**:

// annotations/HashSetTest.java

// {java onjava.atunit.AtUnit

```
// build/classes/main/annotations/HashSetTest.class}
package annotations;
import java.util.*;
import onjava.atunit.*;
import onjava.*;
public class HashSetTest {
HashSet<String> testObject = new HashSet<>();
@Test
void initialization() {
assert testObject.isEmpty();
}
@Test
void tContains() {
testObject.add("one");
assert testObject.contains("one");
}
@Test
void tRemove() {
testObject.add("one");
testObject.remove("one");
```

```
assert testObject.isEmpty();
}
}
/* Output:
annotations.HashSetTest
. initialization
. tRemove
. tContains
OK (3 tests)
*/
```

The inheritance approach seems simpler, in the absence of other constraints.

For each unit test, **@Unit** creates an object of the class under test using the no-arg constructor. The test is called for that object, then the object is discarded to prevent side effects from leaking into other unit tests. This relies on the no-arg constructor to create the objects. If you don’t have a no-arg constructor or you need more sophisticated construction for objects, create a **static** method to build the object and attach the **@TestObjectCreate** annotation, like this:

```
// annotations/AtUnitExample3.java
```

```
// {java onjava.atunit.AtUnit
// build/classes/main/annotations/AtUnitExample3.class}
package annotations;
import onjava.atunit.*;
import onjava.*;
public class AtUnitExample3 {
private int n;
public AtUnitExample3(int n) { this.n = n; }
public int getN() { return n; }
public String methodOne() {
return "This is methodOne";
}
public int methodTwo() {
System.out.println("This is methodTwo");
return 2;
}
@TestObjectCreate
static AtUnitExample3 create() {
return new AtUnitExample3(47);
}
```

```
@Test
boolean initialization() { return n == 47; }
@Test
boolean methodOneTest() {
return methodOne().equals("This is methodOne");
}
@Test
boolean m2() { return methodTwo() == 2; }
}
/* Output:
annotations.AtUnitExample3
. initialization
. m2 This is methodTwo
. methodOneTest
OK (3 tests)
*/
```

The **@TestObjectCreate** method must be **static** and must return an object of the type that you're testing—the **@Unit** program will ensure this is true.

Sometimes you need additional fields to support unit testing. The

@TestProperty annotation can tag fields that are only used for unit testing (so they can be optionally removed before you deliver the product to the client). Here's an example that reads values from a **String** that is broken up using the **String.split()** method.

This input is used to produce test objects:

```
// annotations/AtUnitExample4.java
// {java onjava.atunit.AtUnit
// build/classes/main/annotations/AtUnitExample4.class}
// {VisuallyInspectOutput}
package annotations;
import java.util.*;
import onjava.atunit.*;
import onjava.*;
public class AtUnitExample4 {
static String theory = "All brontosauruses " +
"are thin at one end, much MUCH thicker in the " +
"middle, and then thin again at the far end.";
private String word;
private Random rand = new Random(); // Time-based seed
public AtUnitExample4(String word) {
```

```
this.word = word;
}
public String getWord() { return word; }
public String scrambleWord() {
List<Character> chars = Arrays.asList(
ConvertTo.boxed(word.toCharArray()));
Collections.shuffle(chars, rand);
StringBuilder result = new StringBuilder();
for(char ch : chars)
result.append(ch);
return result.toString();
}
@TestProperty
static List<String> input =
Arrays.asList(theory.split(" "));
@TestProperty
static Iterator<String> words = input.iterator();
@TestObjectCreate
static AtUnitExample4 create() {
if(words.hasNext())
```

```
return new AtUnitExample4(words.next());
else
return null;
}
@Test
boolean words() {
System.out.println("""" + getWord() + """");
return getWord().equals("are");
}
@Test
boolean scramble1() {
// Use specific seed to get verifiable results:
rand = new Random(47);
System.out.println("""" + getWord() + """");
String scrambled = scrambleWord();
System.out.println(scrambled);
return scrambled.equals("lAl");
}
@Test
boolean scramble2() {
```

```
rand = new Random(74);
System.out.println("""" + getWord() + """");
String scrambled = scrambleWord();
System.out.println(scrambled);
return scrambled.equals("tsaeborornussu");
}
}
/* Output:
annotations.AtUnitExample4
. words 'All'
(failed)
. scramble1 'brontosauruses'
ntsaueorosurbs
(failed)
. scramble2 'are'
are
(failed)
(3 tests)
>>> 3 FAILURES <<<
annotations.AtUnitExample4: words
```

annotations.AtUnitExample4: scramble1

annotations.AtUnitExample4: scramble2

/

@TestProperty can also be used to tag methods that can be used during testing, but are not tests themselves.

This program relies on the execution order of the tests, which is in general not a good practice.

If your test object creation performs initialization that requires later cleanup, you can optionally add a **static @TestObjectCleanup** method to perform cleanup when you are finished with the test object.

In this next example, **@TestObjectCreate** opens a file to create each test object, so the file must be closed before the test object is discarded:

```
// annotations/AtUnitExample5.java
// {java onjava.atunit.AtUnit
// build/classes/main/annotations/AtUnitExample5.class}
package annotations;
import java.io.*;
import onjava.atunit.*;
import onjava.*;
```

```
public class AtUnitExample5 {
private String text;
public AtUnitExample5(String text) {
this.text = text;
}
@Override
public String toString() { return text; }
@TestProperty
static PrintWriter output;
@TestProperty
static int counter;
@TestObjectCreate
static AtUnitExample5 create() {
String id = Integer.toString(counter++);
try {
output = new PrintWriter("Test" + id + ".txt");
} catch(IOException e) {
throw new RuntimeException(e);
}
return new AtUnitExample5(id);
```

```
}
@TestObjectCleanup
static void cleanup(AtUnitExample5 tobj) {
System.out.println("Running cleanup");
output.close();
}
@Test
boolean test1() {
output.print("test1");
return true;
}
@Test
boolean test2() {
output.print("test2");
return true;
}
```

```
@Test
```

```
boolean test3() {
output.print("test3");
return true;
}
}
/* Output:
annotations.AtUnitExample5
. test1
Running cleanup
. test3
Running cleanup
. test2
Running cleanup
OK (3 tests)
*/
```

The output shows that the cleanup method is automatically run after each test.

Using @Unit with Generics

Generics pose a special problem, because you can’t “test generically.” You must test for a specific type parameter or set of parameters. The

solution is simple: Inherit a test class from a specified version of the generic class.

Here's a simple implementation of a stack:

```
// annotations/StackL.java
// A stack built on a LinkedList
package annotations;
import java.util.*;
public class StackL<T> {
private LinkedList<T> list = new LinkedList<>();
public void push(T v) { list.addFirst(v); }
public T top() { return list.getFirst(); }
public T pop() { return list.removeFirst(); }
}
```

To test a **String** version, inherit a test class from **StackL<String>** :

```
// annotations/StackLStringTst.java
// Applying @Unit to generics
// {java onjava.atunit.AtUnit
// build/classes/main/annotations/StackLStringTst.class}
package annotations;
```

```
import onjava.atunit.*;
import onjava.*;
public class
StackLStringTst extends StackL<String> {
@Test
void tPush() {
push("one");
assert top().equals("one");
push("two");
assert top().equals("two");
}
@Test
void tPop() {
push("one");
push("two");
assert pop().equals("two");
assert pop().equals("one");
}
@Test
void tTop() {
```

```
push("A");
push("B");
assert top().equals("B");
assert top().equals("B");
}
}
/* Output:
annotations.StackLStringTst
. tTop
. tPush
. tPop
```

```
OK (3 tests)
*/
```

The only potential drawback to inheritance is that you lose the ability to access **private** methods in the class under test. If this is a problem, you can either make the method in question **protected**, or add a non-private **@TestProperty** method that calls the **private**

method (the **@TestProperty** method will then be stripped out of the production code by the **AtUnitRemover** tool that is shown later in this chapter).

@Unit searches for class files containing the appropriate annotations, then executes the **@Test** methods. Much of my goal with the **@Unit** testing system is to make it incredibly transparent, so people can begin using it by adding **@Test** methods, with no other special code or knowledge (modern versions of JUnit follow this practice). It's hard enough to write tests without adding any new hurdles, so **@Unit** tries to make it trivial. This way, you're more likely to actually write the tests.

Implementing @Unit

First, we define all the annotation types. These are simple tags, and have no fields. The **@Test** tag was defined at the beginning of the chapter, and here are the rest of the annotations:

```
// onjava/atunit/TestObjectCreate.java
// The @Unit @TestObjectCreate tag
package onjava.atunit;
import java.lang.annotation.*;
@Target(ElementType.METHOD)
```

```
@Retention(RetentionPolicy.RUNTIME)
public @interface TestObjectCreate {}
// onjava/atunit/TestObjectCleanup.java
// The @Unit @TestObjectCleanup tag
package onjava.atunit;
import java.lang.annotation.*;
@Target(ElementType.METHOD)
@Retention(RetentionPolicy.RUNTIME)
public @interface TestObjectCleanup {}
// onjava/atunit/TestProperty.java
// The @Unit @TestProperty tag
package onjava.atunit;
import java.lang.annotation.*;
// Both fields and methods can be tagged as properties:
@Target({ElementType.FIELD, ElementType.METHOD})
@Retention(RetentionPolicy.RUNTIME)
public @interface TestProperty {}
```

All the tests have **RUNTIME** retention because the **@Unit** system must discover the tests in compiled code.

To implement the system that runs the tests, we use reflection to

extract the annotations. The program uses this information to decide how to build the test objects and run tests on them. Annotations make the result surprisingly small and straightforward:

```
// onjava/atunit/AtUnit.java
// An annotation-based unit-test framework
// {java onjava.atunit.AtUnit}
package onjava.atunit;
import java.lang.reflect.*;
import java.io.*;
import java.util.*;
import java.nio.file.*;
import java.util.stream.*;
import onjava.*;
public class AtUnit implements ProcessFiles.Strategy {
static Class<?> testClass;
static List<String> failedTests= new ArrayList<>();
static long testsRun = 0;
static long failures = 0;
public static void
main(String[] args) throws Exception {
```

```
ClassLoader.getSystemClassLoader()
.setDefaultAssertionStatus(true); // Enable assert
new ProcessFiles(new AtUnit(), "class").start(args);
if(failures == 0)
System.out.println("OK (" + testsRun + " tests)");
else {
System.out.println("(" + testsRun + " tests)");
System.out.println(
"\n>>> " + failures + " FAILURE" +
(failures > 1 ? "S" : "") + " <<<");
for(String failed : failedTests)
System.out.println(" " + failed);
}
}
@Override
public void process(File cFile) {
try {
String cName = ClassNameFinder.thisClass(
Files.readAllBytes(cFile.toPath()));
if(!cName.startsWith("public:"))
```

```
return;
cName = cName.split(":")[1];
if(!cName.contains("."))
return; // Ignore unpackaged classes
testClass = Class.forName(cName);
} catch(IOException | ClassNotFoundException e) {
throw new RuntimeException(e);
}
TestMethods testMethods = new TestMethods();
Method creator = null;
Method cleanup = null;
for(Method m : testClass.getDeclaredMethods()) {
testMethods.addIfTestMethod(m);
if(creator == null)
creator = checkForCreatorMethod(m);
if(cleanup == null)
cleanup = checkForCleanupMethod(m);
}
if(testMethods.size() > 0) {
if(creator == null)
```

```
try {
if(!Modifier.isPublic(testClass
.getDeclaredConstructor()
.getModifiers())) {
System.out.println("Error: " + testClass +
" no-arg constructor must be public");
System.exit(1);
}
} catch(NoSuchMethodException e) {
// Synthesized no-arg constructor; OK
}
System.out.println(testClass.getName());
}
for(Method m : testMethods) {
System.out.print(" . " + m.getName() + " ");
try {
Object testObject = createTestObject(creator);
boolean success = false;
try {
if(m.getReturnType().equals(boolean.class))
```

```
success = (Boolean)m.invoke(testObject);
else {
m.invoke(testObject);
success = true; // If no assert fails
}
} catch(InvocationTargetException e) {
// Actual exception is inside e:
System.out.println(e.getCause());
}
System.out.println(success ? "" : "(failed)");
testsRun++;
if(!success) {
failures++;
failedTests.add(testClass.getName() +
": " + m.getName());
}
if(cleanup != null)
cleanup.invoke(testObject, testObject);
} catch(IllegalAccessException |
IllegalArgumentException |
```

```
InvocationTargetException e) {
throw new RuntimeException(e);
}
}
}
public static
class TestMethods extends ArrayList<Method> {
void addIfTestMethod(Method m) {
if(m.getAnnotation(Test.class) == null)
return;
if(!(m.getReturnType().equals(boolean.class) ||
m.getReturnType().equals(void.class)))
throw new RuntimeException("@Test method" +
" must return boolean or void");
m.setAccessible(true); // If it's private, etc.
add(m);
}
}
private static
Method checkForCreatorMethod(Method m) {
```

```
if(m.getAnnotation(TestObjectCreate.class) == null)
return null;
if(!m.getReturnType().equals(testClass))
throw new RuntimeException("@TestObjectCreate " +
"must return instance of Class to be tested");
if((m.getModifiers() &
java.lang.reflect.Modifier.STATIC) < 1)
throw new RuntimeException("@TestObjectCreate " +
"must be static.");
m.setAccessible(true);
return m;
}
private static
Method checkForCleanupMethod(Method m) {
if(m.getAnnotation(TestObjectCleanup.class) == null)
return null;
if(!m.getReturnType().equals(void.class))
throw new RuntimeException("@TestObjectCleanup " +
"must return void");
if((m.getModifiers() &
```

```
java.lang.reflect.Modifier.STATIC) < 1)
throw new RuntimeException("@TestObjectCleanup " +
"must be static.");
if(m.getParameterTypes().length == 0 ||
m.getParameterTypes()[0] != testClass)
throw new RuntimeException("@TestObjectCleanup " +
"must take an argument of the tested type.");
m.setAccessible(true);
return m;
}
private static Object
createTestObject(Method creator) {
if(creator != null) {
try {
return creator.invoke(testClass);
} catch(IllegalAccessException |
IllegalArgumentException |
InvocationTargetException e) {
throw new RuntimeException("Couldn't run " +
"@TestObject (creator) method.");
```

```
}
} else { // Use the no-arg constructor:
try {
return testClass.newInstance();
} catch(InstantiationException |
IllegalAccessException e) {
throw new RuntimeException(
"Couldn't create a test object. " +
"Try using a @TestObject method.");
}
}
}
}
```

Although it might be “premature refactoring,” (because it’s only used once in the book) **AtUnit.java** uses another tool called **ProcessFiles** to step through each argument on the command line, decide whether it’s a directory or a file, and act accordingly. It can be applied to different solutions because it contains a **Strategy** interface for customization:

```
// onjava/ProcessFiles.java
```

```
package onjava;
import java.io.*;
import java.nio.file.*;
public class ProcessFiles {
public interface Strategy {
void process(File file);
}
private Strategy strategy;
private String ext;
public ProcessFiles(Strategy strategy, String ext) {
this.strategy = strategy;
this.ext = ext;
}
public void start(String[] args) {
try {
if(args.length == 0)
processDirectoryTree(new File("."));
else
for(String arg : args) {
File fileArg = new File(arg);
```

```
if(fileArg.isDirectory())
processDirectoryTree(fileArg);
else {
// Allow user to leave off extension:
if(!arg.endsWith("." + ext))
arg += "." + ext;
strategy.process(
new File(arg).getCanonicalFile());
}
}
} catch(IOException e) {
throw new RuntimeException(e);
}
}
public void
processDirectoryTree(File root) throws IOException {
PathMatcher matcher = FileSystems.getDefault()
.getPathMatcher("glob:**/*.{" + ext + "}");
Files.walk(root.toPath())
.filter(matcher::matches)
```

```
.forEach(p -> strategy.process(p.toFile()));
}
}
```

The **AtUnit** class implements **ProcessFiles.Strategy**, containing the method **process()**. This way, an instance of **AtUnit** can be passed to the **ProcessFiles** constructor. The second constructor argument tells **ProcessFiles** to look for all files that have "**class**" extensions.

Here's a simple usage example:

```
// annotations/DemoProcessFiles.java
import onjava.ProcessFiles;
public class DemoProcessFiles {
public static void main(String[] args) {
new ProcessFiles(file -> System.out.println(file),
"java").start(args);
}
}
/* Output:
.\AtUnitExample1.java
.\AtUnitExample2.java
```

.*AtUnitExample3.java*

.*AtUnitExample4.java*

.*AtUnitExample5.java*

.*AUComposition.java*

.*AUExternalTest.java*

.*database\Constraints.java*

.*database\DBTable.java*

.*database\Member.java*

.*database\SQLInteger.java*

.*database\SQLString.java*

.*database\TableCreator.java*

.*database\Uniqueness.java*

.*DemoProcessFiles.java*

.*HashSetTest.java*

.*ifx\ExtractInterface.java*

.*ifx\IfaceExtractorProcessor.java*

.*ifx\Multiplier.java*

.*PasswordUtils.java*

.*simplest\Simple.java*

.*simplest\SimpleProcessor.java*

.\simplest\SimpleTest.java

.\SimulatingNull.java

.\StackL.java

.\StackLStringTst.java

.\Testable.java

.\UseCase.java

.\UseCaseTracker.java

/

With no command-line argument, the program traverses the current directory tree. You can also provide multiple arguments which can be either class files (with or without the **.class** extension) or directories.

Returning to our discussion of **AtUnit.java**, since **@Unit** automatically finds the testable classes and methods, no “suite” mechanism is necessary.5

One of the problems **AtUnit.java** must solve when it discovers class files is that the qualified class name (including package) is not evident from the class file name. To discover this information, the class file must be analyzed—not trivial, but not impossible, either.6

When a **.class** file is found, it is opened and its binary data is read

and handed to **ClassNameFinder.thisClass()**. Here, we are moving into the realm of “bytecode engineering,” because we are actually analyzing the contents of a class file:

```
// onjava/atunit/ClassNameFinder.java
// {java onjava.atunit.ClassNameFinder}
package onjava.atunit;
import java.io.*;
import java.nio.file.*;
import java.util.*;
import onjava.*;
public class ClassNameFinder {
public static String thisClass(byte[] classBytes) {
Map<Integer,Integer> offsetTable = new HashMap<>();
Map<Integer,String> classNameTable =
new HashMap<>();
try {
DataInputStream data = new DataInputStream(
new ByteArrayInputStream(classBytes));
int magic = data.readInt(); // 0xcafebabe
int minorVersion = data.readShort();
```

```
int majorVersion = data.readShort();
int constantPoolCount = data.readShort();
int[] constantPool = new int[constantPoolCount];
for(int i = 1; i < constantPoolCount; i++) {
int tag = data.read();
// int tableSize;
switch(tag) {
case 1: // UTF
int length = data.readShort();
char[] bytes = new char[length];
for(int k = 0; k < bytes.length; k++)
bytes[k] = (char)data.read();
String className = new String(bytes);
classNameTable.put(i, className);
break;
case 5: // LONG
case 6: // DOUBLE
data.readLong(); // discard 8 bytes
i++; // Special skip necessary
break;
```

```
case 7: // CLASS
int offset = data.readShort();
offsetTable.put(i, offset);
break;
case 8: // STRING
data.readShort(); // discard 2 bytes
break;
case 3: // INTEGER
case 4: // FLOAT
case 9: // FIELD_REF
case 10: // METHOD_REF
case 11: // INTERFACE_METHOD_REF
case 12: // NAME_AND_TYPE
case 18: // Invoke Dynamic
data.readInt(); // discard 4 bytes
break;
case 15: // Method Handle
data.readByte();
data.readShort();
break;
```

```
case 16: // Method Type
data.readShort();
break;
default:
throw
new RuntimeException("Bad tag " + tag);
}
}
short accessFlags = data.readShort();
String access = (accessFlags & 0x0001) == 0 ?
"nonpublic:" : "public:";
int thisClass = data.readShort();
int superClass = data.readShort();
return access + classNameTable.get(
offsetTable.get(thisClass)).replace('/', '.');
} catch(IOException | RuntimeException e) {
throw new RuntimeException(e);
}
}
// Demonstration:
```

```
public static void
main(String[] args) throws Exception {
PathMatcher matcher = FileSystems.getDefault()
.getPathMatcher("glob:**/*.class");
// Walk the entire tree:
Files.walk(Paths.get("."))
.filter(matcher::matches)
.map(p -> {
try {
return thisClass(Files.readAllBytes(p));
} catch(Exception e) {
throw new RuntimeException(e);
}
})
.filter(s -> s.startsWith("public:"))
// .filter(s -> s.indexOf('$') >= 0)
.map(s -> s.split(":")[1])
.filter(s -> !s.startsWith("enums."))
.filter(s -> s.contains("."))
.forEach(System.out::println);
```

}

}

/ Output:*

onjava.ArrayShow

onjava.atunit.AtUnit$TestMethods

onjava.atunit.AtUnit

onjava.atunit.ClassNameFinder

onjava.atunit.Test

onjava.atunit.TestObjectCleanup

onjava.atunit.TestObjectCreate

onjava.atunit.TestProperty

onjava.BasicSupplier

onjava.CollectionMethodDifferences

onjava.ConvertTo

onjava.Count$Boolean

onjava.Count$Byte

onjava.Count$Character

onjava.Count$Double

onjava.Count$Float

onjava.Count$Integer

onjava.Count$Long

onjava.Count$Pboolean

onjava.Count$Pbyte

onjava.Count$Pchar

onjava.Count$Pdouble

onjava.Count$Pfloat

onjava.Count$Pint

onjava.Count$Plong

onjava.Count$Pshort

onjava.Count$Short

onjava.Count

onjava.CountingIntegerList

onjava.CountMap

onjava.Countries

onjava.Enums

onjava.FillMap

onjava.HTMLColors

onjava.MouseClick

onjava.Nap

onjava.Null

onjava.Operations

onjava.OSExecute

onjava.OSExecuteException

onjava.Pair

onjava.ProcessFiles$Strategy

onjava.ProcessFiles

onjava.Rand$Boolean

onjava.Rand$Byte

onjava.Rand$Character

onjava.Rand$Double

onjava.Rand$Float

onjava.Rand$Integer

onjava.Rand$Long

onjava.Rand$Pboolean

onjava.Rand$Pbyte

onjava.Rand$Pchar

onjava.Rand$Pdouble

onjava.Rand$Pfloat

onjava.Rand$Pint

onjava.Rand$Plong

onjava.Rand$Pshort

onjava.Rand$Short

onjava.Rand$String

onjava.Rand

onjava.Range

onjava.Repeat

onjava.RmDir

onjava.Sets

onjava.Stack

onjava.Suppliers

onjava.TimedAbort

onjava.Timer

onjava.Tuple

onjava.Tuple2

onjava.Tuple3

onjava.Tuple4

onjava.Tuple5

onjava.TypeCounter

*/

Although it’s not possible to go into full detail here, each class file

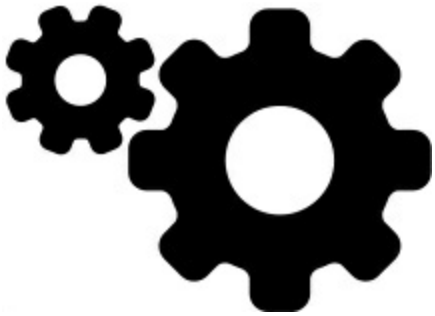
follows a particular format and I've tried to use meaningful field names for the pieces of data picked out of the **ByteArrayInputStream**; you can also see the size of each piece by the length of the read performed on the input stream. For example, the first 32 bits of any class file is always the "magic number" hex 0xcafebabe,[7] and the next two **short**s are version information. The constant pool contains the constants for the program and so is of variable size; the next **short** tells how big it is, so an appropriate-sized array can be allocated. Each entry in the constant pool can be a fixed-size or variable-sized value, so we must examine the tag that begins each one to find out what to do with it—that's the **switch** statement. Here, we are not trying to accurately analyze all the data in the class file, but merely to step through and store the pieces of interest, so you'll notice that a fair amount of data is discarded.

Information about classes is stored in the **classNameTable** and the **offsetTable**. After the constant pool is read, the **thisClass** information is found. It is an index into the **offsetTable**, which produces an index into the **classNameTable**, which produces the class name.

Back in **AtUnit.java**, **process()** now has the class name and can look to see if it contains a **.** , which means it's in a package.

Unpackaged classes are ignored. If a class is in a package, the standard class loader is used to load the class with **Class.forName()**. Now the class can be analyzed for **@Unit** annotations.

We only look for three things: **@Test** methods, which are stored in a **TestMethods** list, and whether there's an **@TestObjectCreate** and **@TestObjectCleanup** method. These are discovered through the associated method calls you see in the code, which look for the annotations.



If any **@Test** methods are found, the name of the class is displayed so the viewer can see what's happening, then each test is executed. This means printing the method name, then calling **createTestObject()**, which will use the **@TestObjectCreate** method if one exists, or will fall back to the no-arg constructor otherwise. Once the test object is created, the test method is invoked upon that object. If the test returns a **boolean**, the result is captured. If not, we assume success if there is no

exception (which would happen in the case of a failed **assert** or any other kind of exception). If an exception is thrown, the exception information is printed to show the cause. If any failure occurs, the failure count is increased and the class name and method are added to **failedTests** so these can be reported at the end of the run.

Summary

Annotations are a welcome addition to Java. They are a structured and type-checked means of adding metadata to your code without rendering it unreadable and messy. They can help remove the tedium of writing deployment descriptors and other generated files. The fact that the **@deprecated** Javadoc tag is superseded by the **@Deprecated** annotation is just one indication of how much better suited annotations are for describing information about code components than are comments.

Only a small handful of annotations come with Java. This means if you can’t find a library elsewhere, you create annotations and the associated logic. With annotation processors attached to **javac**, you can compile newly generated files in one step, easing the build process. Providers of APIs and frameworks will start including annotations as part of their toolkits. As you can imagine by seeing the **@Unit** system,

it is very likely that annotations will cause significant changes in our Java programming experience.

1. Jeremy Meyer came to Crested Butte and spent two weeks with me working on this chapter. His help was invaluable. ↩

2. This was no doubt inspired by a similar feature in C#. The C# feature is a keyword and not an annotation, and is enforced by the compiler. That is, when you override a method in C#, you must use the **override** keyword, whereas in Java the **@Override** annotation is optional. ↩

3. The Java designers coyly suggest that a mirror is where you find a reflection. ↩

4. I originally had thoughts of making a “better JUnit” based on the design shown here. However, it appears that JUnit4 also includes many of the ideas presented here, so it remains easier to go along with that.↩

5. It is not clear why the no-arg constructor for the class under test must be **public**, but if it isn’t, the call to **newInstance()** just hangs (doesn’t throw an exception). ↩

6. Jeremy Meyer and I spent most of a day figuring this out.↩

7. Various legends surround the meaning of this, but since Java was

predominantly created by male nerds we can make a reasonable guess it had something to do with fantasizing about a woman in a coffee shop. ↩

Concurrent

Programming

“But I don’t want to go among mad people,” Alice remarked. “Oh, you can’t help that,” said the Cat. “We’re all mad here. I’m mad. You’re mad.” “How do you know I’m mad?” said Alice. “You must be,” said the Cat, “or you wouldn’t have come here.” — *Alice’s Adventures in Wonderland*, Chapter 6.

Up to this point we’ve been programming in a fashion much like the *stream-of-consciousness* narrative device in literature: first one thing happens, then the next. We’re in complete control of all the steps and the order they occur. It would be very surprising if we were to set a value to 5, then at some point later come back and find it was 47.

We now enter the strange world of concurrency, where this result is not surprising at all. Everything you're comfortable believing is no longer reliable. It might work and it might not. Most likely it will work under some conditions and not in others, and you'll have to know and understand these situations in order to determine what works.

As an analogy, your normal life takes place in the world of Newtonian Mechanics. Objects have mass: they fall and transfer their momentum. Wires have resistance, and light travels in straight lines. But if you enter the world of the very small, very hot, very cold or very massive (where we can't exist) things change. We can't tell whether something is a particle or a wave, light is affected by gravity, and some things become superconductors.

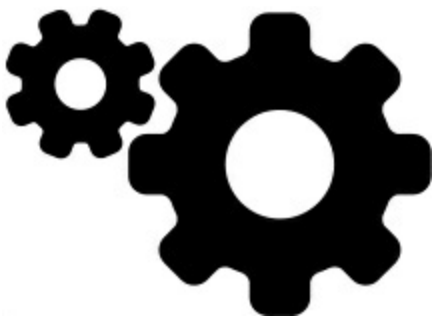
Rather than a single stream-of-consciousness narrative, we're inside a spy novel that has numerous stories running at the same time, one for each character. One spy leaves microfilm under a special rock, and when the second spy comes to retrieve the package, it might already have been taken by a third spy. But this particular novel doesn't neatly tie things up; you can easily get to the end and never figure out what happens.

Building concurrent applications is much like the game Jenga, where every time you pull out a block and place it on the tower, the whole

thing can come crashing down. Every tower, and every application, is unique, with its own requirements. What you learn from building one system might not apply to the next one.

This chapter is a very basic introduction to concurrency. Although I use the most modern Java 8 tools available to demonstrate the principles, the chapter is far from a comprehensive treatment of the topic. My goal is to give you enough of the fundamentals that you can grasp the complexity—and danger—of the issues, to engender a healthy respect for the difficulty of wading into these shark-infested waters.

For more of the messy, low-level details, see the Appendix: Low-Level Concurrency. To venture further into this domain, you must also read *Java Concurrency in Practice* by Brian Goetz et. al. Although at this writing, that book is over ten years old, it still contains essentials you must know and understand. Ideally, this chapter and the appendix is a good preparation for that book. Another valuable resource is Bill



Venners' *Inside the Java Virtual Machine*, which describes in detail the innermost workings of the JVM, including threads.

The Terminology Problem

The terms *concurrent*, *parallel*, *multitasking*, *multiprocessing*, *multithreading*, *distributed systems* (and probably others) are used in numerous conflicting ways throughout programming literature, and are often conflated. After pointing this out in his 2016 presentation From Concurrent to Parallel, Brian Goetz suggests a reasonable dichotomy:

Concurrency is about correctly and efficiently controlling access to shared resources.

Parallelism uses additional resources to produce an answer faster.

These are good definitions, but there are decades of confusion-producing history that fight against fixing the problem. In general, when people use the word "concurrency," they mean "everything, the entire mess," and I'll probably fall into that practice myself in many places—indeed, most books, including Brian Goetz' *Java Concurrency in Practice*, use the word in the title.

Concurrency often means "more than one task is making progress," while parallelism almost always means "more than one task is executing simultaneously." You can immediately see the problem with

these definitions: parallelism also has more than one task "making progress." The distinction is the details, in exactly *how* that "progress" is happening. Also, the overlap: a program written for parallelism can still sometimes run on a single processor, while some concurrent-programming systems can take advantage of more than one processor. Here's another approach, writing the definitions around where the slowdown occurs:

Concurrency

Accomplishing more than one task at the same time. One task doesn't need to complete before you start working on other tasks. Concurrency solves problems where *blocking* occurs—when a task can't progress further until something outside its control changes. The most common example is I/O, where a task must wait for some input (in which case it is said to be *blocked*). A problem like this is said to be *I/O bound*.

Parallelism

Accomplishing more than one task *in multiple places* at the same time. This solves so-called *compute-bound* problems, where a program can run faster if you split it into multiple parts and run those different parts on different processors.

The reason the terminology is confusing is shown in the definitions above: the core of both is “accomplishing more than one task at the same time.” Parallelism adds distribution across multiple processors. More importantly, the two solve different types of problems: taking an I/O-bound problem and parallelizing might not do you any good because the problem is not overall speed, it’s blocking. And taking a compute-bound problem and trying to solve it using concurrency on a single processor might be a similar waste of time. Both approaches try to accomplish more in less time, but the way they achieve speedup is different, and depends upon constraints imposed by the problem.

A major reason that the two concepts get mixed together is that many programming languages including Java use the same mechanism—the *thread*—to implement both concurrency and parallelism.

We can even try to add more granularity to the definitions (however, this is not standardized terminology):

Purely Concurrent: Tasks still run on a single CPU. A purely concurrent system produces results faster than a sequential system, but doesn’t run any faster if there are more processors.

Concurrent-Parallel: Using concurrency techniques, the resulting program takes advantage of more processors and

produces results faster.

Parallel-Concurrent: Written using parallel programming techniques, the resulting program can still run if there is only a single processor (Java 8 **Stream**s are a good example).

Purely Parallel: Won't run unless there is more than one processor.

This might be a useful taxonomy in some situations.

Language and library support for concurrency seem like perfect candidates for the term Leaky Abstraction. The goal of an abstraction is to "abstract away" pieces that are not essential to the idea at hand, to shield you from needless detail. If the abstraction is leaky, those pieces and details keep re-asserting themselves as important, regardless of how much you try to hide them.

I've started to wonder whether there's really any abstraction at all. When writing these kinds of programs you are never shielded from any of the underlying systems and tools, even details about how the CPU cache works. Ultimately, if you've been very careful, what you create works in a particular situation, but it won't work in other situations. Sometimes the difference is the way two machines are configured, or the estimated load for the program. This is not specific to Java per se—it is the nature of concurrent and parallel

programming.

You might argue that a pure functional language doesn't have these restrictions. Indeed, a pure functional language solves a large number of concurrency problems, so if you are tackling a difficult concurrency problem you might consider writing that portion in a pure functional language. But ultimately, if you write a system that uses a queue, for

example, if it isn't tuned properly and the input rate either isn't estimated correctly or throttled (and throttling means different things and has different impacts in different situations), that queue will either fill up and block, or overflow. In the end, you must understand all the details, and any issue can break your system. It's a very different kind of programming.

A New Definition of Concurrency

For decades, I have periodically grappled with concurrency in various forms, and one of the biggest challenges has always been simply defining it. While writing this chapter, I finally had an insight which I

think captures it:

Concurrency is a collection of
performance techniques focused on the
reduction of waiting.

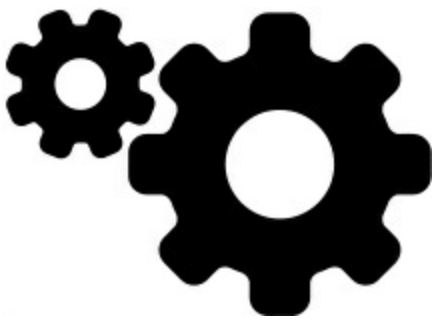
This is actually a rather dense statement, so I'll break it down:

It's a *collection*: there are many different approaches to solving the problem. This is one of the issues that makes defining concurrency so challenging, because the techniques vary widely.

These are *performance techniques*: That's it. The whole point of concurrency is to get your program to run faster. In Java, concurrency is very tricky and difficult, so absolutely do not use it unless you have a significant performance problem—and even then, use the easiest approach that produces the performance you need, because concurrency rapidly becomes unmanageable.

The "reduction of waiting" part is important and subtle.

Regardless of (for example) how many processors you are running



on, you can only produce a benefit when some kind of waiting is taking place. If you ask for I/O and instantly get a result, there's no delay and thus nothing to improve. If you are running multiple tasks on multiple processors and each is running at full capacity and no task is waiting on any other, there's no point in trying to increase your throughput. The only opportunity for concurrency is if some part of your program is forced to wait. That waiting can appear in many forms—which explains why there are so many different approaches to concurrency.

It's worth emphasizing that the effectiveness of this definition hinges on the word *waiting*. If nothing is waiting there's no opportunity for speedups. And if something is waiting, there are numerous approaches to speeding things up and these depend on multiple factors including the configuration of the system where it's running, the type of problem you're solving, and any number of other issues.

Concurrency

Superpowers

Imagine you're inside a science-fiction movie. You must search a tall building for a single item that is carefully and cleverly hidden in one of the ten million rooms of the building. You enter the building and move

down a corridor. The corridor divides.

By yourself it will take a hundred lifetimes to accomplish this task. Now suppose you have a strange superpower. You can split yourself in two, and send one of yourself down one corridor while you continue down the other. Every time you encounter a divide in a corridor or a staircase to the next level, you repeat this splitting-in-two trick. Eventually there is one of you for every terminating corridor in the entire building.

Each corridor contains a thousand rooms. Your superpower is getting stretched a little thin, so you only make 50 of yourself to search the rooms in parallel.

Once a clone enters a room, it must search through all the cracks and hidden pockets of the room. It switches to a second superpower. It divides into a million nanobots, each of which flies or crawls to some unseen spot in the room. You don’t understand this power—it just works, once you start it. Under their own control, the nanobots go, search the room and come back and reassemble into you, and suddenly, somehow, you just know whether the item is in the room or not.

I’d love to be able to say, “Your superpower in the science-fiction

movie? That's what concurrency is." That it's as simple as splitting yourself in two every time you have more tasks to solve. The problem is that any model we use to describe this phenomenon ends up being a leaky abstraction.

Here's one of those leaks: In an ideal world, every time you cloned yourself, you would also duplicate a hardware processor to run that clone. But of course that isn't what happens—you actually might have four or eight processors on your machine (typical when this was written). You might also have more, and there are still lots of situations where you have only one processor. In the abstraction under discussion, the way physical processors are allocated not only leaks through but can even dominate your decisions.

Let's change something in our science-fiction movie. Now when each clone searcher eventually reaches a door they must knock on it and wait until someone answers. If we have one processor per searcher, this is no problem—the processor just idles until the door is answered. But if we only have eight processors and thousands of searchers, we don't want a processor to be idle just because a searcher happens to be blocked, waiting for a door to be answered. Instead, we want that processor applied to a searcher where it can do some real work, so we

need mechanisms to switch processors from one task to another. Many models are able to effectively hide the number of processors and allow you to pretend you have a very large number. But there are situations where this breaks down, when you must know the number of processors so you can work around that number.

One of the biggest impacts depends on whether you have a single processor or more than one. If you only have one processor, then the cost of task-switching is also borne by that processor, and applying concurrency techniques to your system can make it run *slower*.

This might make you decide that, in the case of a single processor, it never makes sense to write concurrent code. However, there are situations where the *model* of concurrency produces much simpler code and it's actually worth having it run slower to achieve that.

In the case of the clones knocking on doors and waiting, even the single-processor system benefits from concurrency because it can switch from a task that is waiting (*blocked*) to one that is ready to go. But if all the tasks can run all the time, then the cost of switching will slow everything down, and in that case concurrency usually only makes sense if you *do* have multiple processors.

Suppose you are trying to crack some kind of encryption. The more

workers trying to crack it at the same time, the better chance you have of finding the answer sooner. Here, each worker can constantly use as much processor time as you can give it, and the best situation is when each worker has their own processor—in this case (a compute-bound problem), you should write the code so you *only* have as many workers as you have processors.

In a customer-service department that takes phone calls, you only have a certain number of people, but you can have lots of phone calls. Those people (the processors) must work on one phone call at a time until it is complete, and extra calls must be queued.

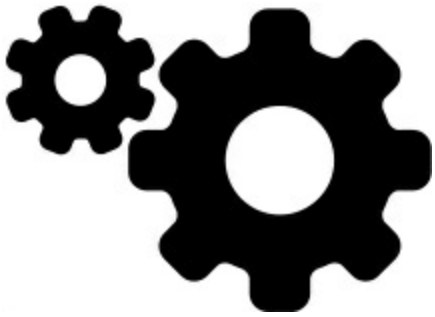
In the fairy tale of “The Shoemaker and the Elves,” the shoemaker had too much work to do and when he was asleep, a group of elves came and made shoes for him. Here the work is distributed, but even with a large number of physical processors the limitation comes when building certain parts of the shoe—if, for example, the sole takes the longest to make, that limits the rate of shoe creation and changes the way you design your solution.

Thus, the problem you’re trying to solve drives the design of the solution. There’s the lovely abstraction of breaking a problem into subtasks that “run independently,” then there’s the reality of how it’s actually going to happen. The physical reality keeps intruding upon, and shaking up, that abstraction.

That’s only part of the problem. Consider a factory that makes cakes. We’ve somehow distributed the cake-making task among workers, but now it’s time for a worker to put their cake in a box. There’s a box sitting there, ready to receive a cake. But before the worker can put the cake into the box, another worker darts in and puts *their* cake in the box instead! Our worker is already putting the cake in, and bam! The two cakes are smashed together and ruined. This is the common “shared memory” problem that produces what we call a *race*

condition, where the result depends on which worker can get their cake in the box first (you typically solve the problem using a locking mechanism so one worker can grab the box first and prevent cake-smashing).

The problem occurs when tasks that execute “at the same time” interfere with each other. This can happen in such a subtle and occasional manner it’s probably fair to say that concurrency is “arguably deterministic but effectively nondeterministic.” That is, you can hypothetically write concurrent programs that, through care and code inspection, work correctly. In practice, however, it’s much more common to write concurrent programs that only appear to work, but given the right conditions, will fail. These conditions might never actually occur, or occur so infrequently you never see them during testing. In fact, it’s often impossible to write test code to generate failure conditions for your concurrent program. The resulting failures often only occur occasionally, and as a result they appear in the form of customer complaints. This is one of the strongest arguments for studying concurrency: If you ignore it, you’re likely to get bitten.



Concurrency thus seems fraught with peril, and if that makes you a bit fearful, this is probably a good thing. Although Java 8 makes large improvements in concurrency, there are still no safety nets like compile-time verification or checked exceptions to tell you when you make a mistake. With concurrency, you're on your own, and only by being knowledgeable, suspicious and aggressive can you write reliable concurrent code in Java.

Concurrency is for

Speed

After hearing about the pitfalls of concurrent programming, you may rightly be wondering if it's worth the trouble. The answer is "no, unless your program isn't running fast enough." And you'll want to think carefully before deciding it isn't. Do not casually jump into the well of grief that is concurrent programming. If there's a way to run your program on a faster machine or if you can profile it and discover the bottleneck and swap in a faster algorithm in that spot, do that instead.

Only if there's clearly no other choice should you begin using concurrency, and then only in isolated places.

The speed issue sounds simple at first: If you want a program to run faster, break it into pieces and run each piece on a separate processor. With our ability to increase clock speeds running out of steam (at least for conventional chips), speed improvements are appearing in the form of multicore processors rather than faster chips. To make your programs run faster, you'll have to learn to take advantage of those extra processors, and that's one thing that concurrency gives you. With a multiprocessor machine, multiple tasks can be distributed across those processors, which can dramatically improve throughput. This is often the case with powerful multiprocessor Web servers, which can distribute large numbers of user requests across CPUs in a program that allocates one thread per request.

However, concurrency can often improve the performance of programs running on a *single* processor. This can sound a bit counterintuitive. If you think about it, a concurrent program running on a single processor should actually have *more* overhead than if all the parts of the program ran sequentially, because of the added cost of the *context switch* (changing from one task to another). On the

surface, it would appear cheaper to run all the parts of the program as a single task and save the cost of context switching.

The issue that can make a difference is *blocking*. If one task in your program is unable to continue because of some condition outside of the control of the program (typically I/O), we say that the task or the thread *blocks* (in our science-fiction story, the clone has knocked on the door and is waiting for it to open). Without concurrency, the whole program comes to a stop until the external condition changes. If the program is written using concurrency, however, the other tasks in the program can continue to execute when one task is blocked, so the program continues to move forward. In fact, from a performance standpoint, it makes no sense to use concurrency on a single-processor machine unless one of the tasks might block.

A common example of performance improvements in single-processor systems is *event-driven programming*, in particular user-interface programming. Consider a program that performs some long-running operation and thus ends up ignoring user input and being unresponsive. If you have a “quit” button, you don’t want to poll it in every piece of code you write. This produces awkward code, without any guarantee that a programmer won’t forget to perform the check.

Without concurrency, the only way to produce a responsive user interface is for all tasks to periodically check for user input. By creating a separate thread of execution to respond to user input, the program guarantees a certain level of responsiveness.

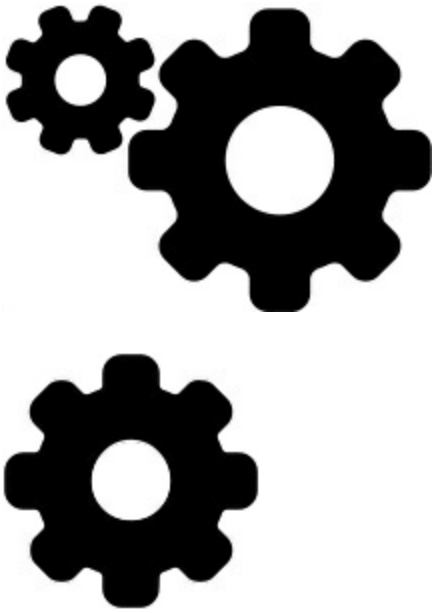
A straightforward way to implement concurrency is at the operating system level, using *processes*, which are different from threads. A process is a self-contained program running within its own address space. Processes are attractive because the operating system usually isolates one process from another so they cannot interfere with each other, which makes programming with processes relatively easy. In contrast, threads share resources like memory and I/O, so a fundamental difficulty in writing multithreaded programs is coordinating these resources between different thread-driven tasks, so they cannot be accessed by more than one task at a time.

Some people go so far as to advocate processes as the only reasonable approach to concurrency,[1] but unfortunately there are generally quantity and overhead limitations to processes that prevent their applicability across the concurrency spectrum. (Eventually you get used to the standard concurrency refrain, “That approach works in some cases but not in other cases”).

Some programming languages are designed to isolate concurrent tasks

from each other. These are generally called *functional languages*, where each function call produces no side effects (and so cannot interfere with other functions) and can thus be driven as an independent task. *Erlang* is one such language, and it includes safe mechanisms for one task to communicate with another. If you find that a portion of your program must make heavy use of concurrency and you are running into excessive problems trying to build that portion, you might consider creating that part of your program in a dedicated concurrency language.

Java took the more traditional approach of adding support for threading on top of a sequential language.2 Instead of forking external processes in a multitasking operating system, threading creates tasks *within* the single process represented by the executing program. Concurrency imposes costs, including complexity costs, but can be outweighed by improvements in program design, resource balancing, and user convenience. In general, concurrency enables you to create a more loosely coupled design; otherwise, parts of your code would be forced to pay explicit attention to operations that would normally be handled by concurrency.



The Four Maxims of

Java Concurrency

After grappling with Java concurrency over many years, I developed these four maxims:

1. Don’t do it

2. Nothing is true and everything matters

3. Just because it works doesn’t mean it’s

not broken

4. You must still understand it

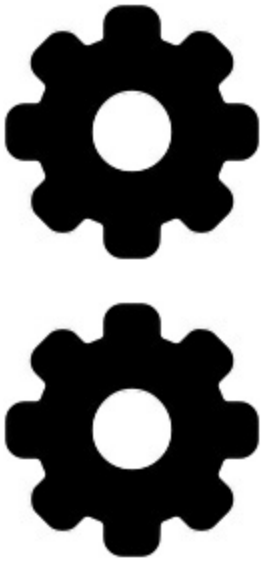
These are specifically about problems in the design of Java, although they can be applied to some other languages as well. However, there do exist languages that are designed to prevent these issues.

1. Don’t do it

(And don’t do it yourself).

The easiest way to avoid entangling yourself in the profound problems produced by concurrency is not to do it. Although it can be seductive and seem safe enough to try something simple, the pitfalls are myriad and subtle. If you can avoid it, your life will be much easier.

The *only* thing that justifies concurrency is speed. If your program isn’t running fast enough—and be careful here, because just *wanting* it to run faster isn’t justification—first apply a profiler (see Profiling and Optimizing) to discover whether there’s some other optimization you can perform.



If you’re compelled into concurrency, take the simplest, safest approach to the problem. Use well-known libraries and write as little of your own code as possible. With concurrency, there’s no such thing

as “too simple.” Cleverness is your enemy.

2. Nothing is true and

everything matters

Programming without concurrency, you’ve come to expect a certain order and consistency in your world. With something as simple as setting a variable to a value, it’s obvious it should always work properly.

In concurrency-land, some things might be true and others are not, to the point where you must assume that nothing is true. You must question everything. Even setting a variable to a value might or might not work the way you expect, and it goes downhill from there. I’ve become familiar with the feeling of discovering that something I thought should obviously work, actually doesn’t.

All kinds of things you can ignore in non-concurrent programming suddenly become important with concurrency. For example, you must now know about the processor cache and the problems of keeping the local cache consistent with main memory. You must understand the deep complexities of object construction so that your constructor doesn’t accidentally expose data to change by other threads. The list goes on.

Although these topics are too complex to give you expertise in this chapter (again, see *Java Concurrency in Practice*), you must be aware of them.

3. Just because it works

doesn’t mean it’s not broken

You can easily write a concurrent program that appears to work but is actually broken, and the problem only reveals itself under the rarest of conditions—inevitably as a user problem after you’ve deployed the program.

You can’t prove a concurrent program is correct, you can only (sometimes) prove it is incorrect.

Most of the time you can’t even do that: If it’s broken you probably won’t be able to detect it.

You can’t usually write useful tests, so you must rely on code inspection combined with deep knowledge of concurrency in order to discover bugs.

Even working programs only work under their design parameters. Most concurrent programs fail in some way when those design parameters are exceeded.

In other Java topics, we develop a sense of determinism. Everything

happens as promised (or implied) by the language, which is comforting and expected—after all, the point of a programming language is to get the machine to do what we want. Moving from the world of deterministic programming into the realm of concurrent programming, we encounter a cognitive bias called the Dunning-Kruger Effect which can be summed up as “the less you know, the more you think you know.” It means “…relatively unskilled persons suffer illusory superiority, mistakenly assessing their ability to be much higher than it really is.”

My own experience is that, no matter how certain you are that your code is thread-safe, it’s probably broken. It’s all too easy to be very sure you understand all the issues, then months or years later you discover some concept that makes you realize that most everything you’ve written is actually vulnerable to concurrency bugs. The

compiler doesn’t tell you when something is incorrect. To get it right you must hold all the issues of concurrency in your forebrain as you study your code.

In all the non-concurrent areas of Java, “no obvious bugs and no compiler complaints” seems to mean that everything is OK. With concurrency, it means nothing. The very worst thing you can be in this situation is “confident.”

4. You must still understand it.

After maxims 1-3 you might be properly frightened of concurrency, and think, “I’ve avoided it up until now, perhaps I can just continue avoiding it.”

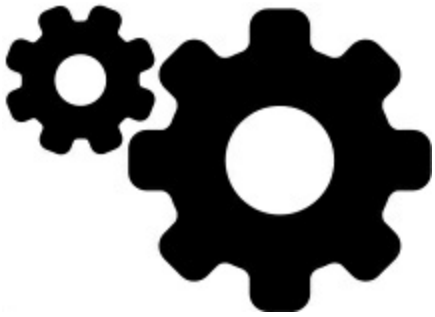
This is a rational reaction. You might know about other programming languages that are better designed to build concurrent programs—even ones that run on the JVM (and thus provide easy communication with Java) such as Clojure or Scala. Why not write the concurrent parts in those languages and use Java for everything else?

Alas, you cannot escape so easily:

Even if you never explicitly create a thread, frameworks you use might—for example, the Swing Graphical User Interface (GUI) library, or something as simple as the **Timer** class.

Here’s the worst thing: when you create components, you must assume those components might be reused in a multithreading

environment. Even if your solution is to give up and declare that your components are “not thread-safe,” you must still know enough to realize that such a statement is important and what it means.



People sometimes suggest that concurrency is too advanced to include in a book that introduces the language. They argue that concurrency is a discrete topic that can be treated independently, and the few cases where it appears in daily programming (such as graphical user interfaces) can be handled with special idioms. Why introduce such a complex topic if you can avoid it?

Alas, if only it were so. Unfortunately, you don’t get to choose when threads appear in your Java programs. Just because you never start a thread yourself doesn’t mean you can avoid writing threaded code. For example, Web systems are one of the most common Java applications, and are inherently multithreaded—Web servers typically contain multiple processors, and parallelism is an ideal way to utilize these

processors. As simple as such a system might seem, you must understand concurrency to write it properly.

Java is a multithreaded language, and concurrency issues are present whether you are aware of them or not. As a result, there are many Java programs in use that either just work by accident, or work most of the time and mysteriously break every now and again because of undiscovered flaws. Sometimes this breakage is relatively benign, but sometimes it means the loss of valuable data, and if you aren't at least aware of concurrency issues, you can end up assuming the problem is somewhere else rather than in your code. These kinds of issues can also be exposed or amplified if a program is moved to a multiprocessor system. Basically, knowing about concurrency makes you aware that apparently correct programs can exhibit incorrect behavior.

The Brutal Truth

When humans began cooking their food, they dramatically reduced the amount of energy their bodies required to break down and digest that food. Cooking created an "externalized stomach," thus freeing up that energy for other pursuits. The technology of fire enabled civilization.

We have now begun a second fundamental shift by creating an

“externalized brain” through the technology of computers and networks. We’ve only scratched the surface, but have already triggered other shifts such as the ability to design biological mechanisms, and have seen a dramatic acceleration in cultural evolution (in the past, people had to travel to mix cultures, but now they are beginning to mix on the Internet). The impact and benefits of these shifts have far exceeded the abilities of science-fiction writers to predict them (they have an especially hard time predicting cultural and personal changes, or even secondary effects from technology shifts).

With such a fundamental human change, it is unsurprising to see numerous disruptions and failed experiments. Indeed, evolution relies on myriad experiments, most of which fail. Those experiments are essential to move forward.

Java was created in an atmosphere of confidence, enthusiasm, and urgency. When inventing a programming language, it’s all too easy to feel like the initial plasticity of the language will persist, that you can try something out and if it doesn’t work out, fix it. Programming languages are unique this way—they go through water-like phase changes: gaseous, liquid and finally solid. During the gaseous phase the flexibility seems infinite, and it’s easy to think it will always be that

way. Once people start using your language, changes have bigger impacts and the environment becomes more viscous. The *process* of language design is itself an art.

The urgency came from the initial rise of the internet. It seemed like a race, and the first one to get through the starting gate would “win” (indeed, the popularity of languages like Java, JavaScript and PHP seem to bear this out). Alas, the cognitive load and technical debt produced by designing languages in a hurry eventually catches up with us.

Turing-completeness is not enough; languages need something more: they must enable creative expression, not weigh us down with needless detail. It is pointless to liberate our mental capacity only to turn around and bog it down again. I acknowledge that we have accomplished amazing things despite these issues, but also I see how much more we can do without them.

Enthusiasm caused the original Java designers to throw in features because they seemed necessary. Confidence (and the gaseousness of the original language) let them think that any problems could be fixed later. Somewhere along the timeline, someone decided that anything added to Java is fixed and permanent—this is confidence squared, to believe that the first decision would always be the right one, and so we

see the landscape of Java littered with poor decisions. Some of these decisions ultimately do have little consequence; you can tell people not to use **Vector**, for example, but leave it in the language to support old code.

Threads were included in Java 1.0. Certainly, concurrency is a fundamental language design decision that affects far corners of the language, and it's hard to imagine adding it later. To be fair, at the time it wasn't clear just how fundamental concurrency is. Other languages like C were able to treat threads as an add-on feature, so the Java designers followed suit, including a **Thread** class and the necessary JVM support (which is more complex than you might imagine).

The C language is primitive, and this limits your ambitions. These limits make add-on threading libraries reasonable. The much grander ambitions of Java rapidly exposed fundamental problems when taking a primitive model and pasting it into a sophisticated language. This mismatch is made obvious in the deprecation of many of the methods in the **Thread** class, and in subsequent waves of higher-level libraries that attempt to provide better abstractions for concurrency.

Unfortunately, to get concurrency right in a higher-level language, all

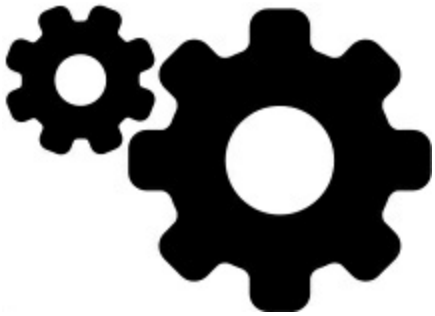
language features are affected, including the most basic ones like whether an identifier represents a changeable value. Making everything *invariant* and preventing *side-effects* in functions and methods produces a sea-change in the simplification of concurrent programming (these are foundations of pure functional programming languages), but at the time seemed like strange ideas for creators of a mainstream language. The original Java designers were either unaware of these choices or decided they were too different and would turn away many potential adopters of the language. We can be generous and say that the language-design community simply didn't have enough experience at the time to understand the impact of patching in a threading library.

The Java experiment has shown us that the results are quietly disastrous. Programmers easily fall into the trap of thinking that Java threads aren't that difficult. Programs that seem to work are riddled with subtle concurrency bugs.

To get concurrency right, language features must be designed from the ground up with concurrency in mind. That ship has sailed; Java will never be a language designed for concurrency, but simply a language that allows it.

What’s impressive is how far it has come despite these fundamental unfixable flaws. Subsequent versions of Java have added libraries to raise the level of abstraction when working with concurrency. In fact, I never would have thought it possible to make the improvements in Java 8: parallel streams and **CompletableFuture**s—this was a magic trick of epic proportions, the like of which I will be very surprised to see repeated[3].

These improvements are very helpful, and we will focus on parallel streams and **CompletableFuture**s in this chapter. Although they can greatly simplify the way you think about concurrency and the subsequent code, the fundamental issues still exist: all parts of your code are still vulnerable because of the original design of the Java language, and you must still understand these complicated and subtle issues. Threading in Java can never be simple or safe; that experience must be relegated to another, newer language.



The Rest of the

Chapter

Here's what we'll cover in the remainder of this chapter. Remember that the emphasis of this chapter is on using the most recent and high-level Java concurrency constructs. Using these makes your life much easier than the older alternatives. However, there are still some low-level tools that you will encounter in legacy code. On occasion, you might be forced to use some of these yourself. The Appendix: Low-Level Concurrency contains an introduction to some of the more primitive Java concurrency elements.

Parallel Streams

Up to this point in the book, I've emphasized the improved syntax provided by Java 8 **Stream**s. Now that you're comfortable with (and I hope, a fan of) that syntax, you can reap additional benefits: You can parallelize a stream by simply adding **parallel()** into the expression. This is a simple, powerful, and frankly rather amazing way to take advantage of multiple processors.

Adding **parallel()** to increase speed seems trivial, but alas, it can never be that simple, as you just learned in The Brutal Truth. I'll demonstrate and explain some of the pitfalls that come from blindly adding **parallel()** to a **Stream** expression.

Creating and Running Tasks

A task is a piece of code that can be run independently. In order to explain some of the basics of creating and running tasks, this section introduces a less-sophisticated mechanism than parallel streams or **CompletableFuture**s: the **Executor**. **Executor**s manage a pool of low-level **Thread** objects (the most primitive form of concurrency in Java). You create a task, then hand it to an **Executor** to be run.

There are multiple types of **Executor**s for different purposes. Here, we will show canonical forms representing the simplest and best approaches to creating and running tasks.

Terminating Long-Running Tasks

Tasks run independently and thus need a mechanism to shut them down. The typical approach uses a flag, and this introduces the problem of shared memory, which we'll sidestep using Java's "Atomic" library.

Completable Futures

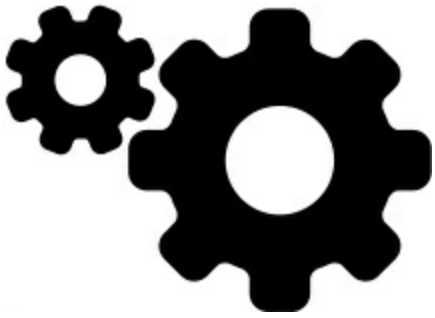
When you take clothing to a dry cleaner, they give you a receipt. You continue with other tasks, and eventually your clothing is clean and you can pick it up. The receipt is your connection to the task performed in the background by the dry cleaner. This is the approach

taken by the **Future** introduced in Java 5.

The **Future** was somewhat more convenient than the previous approach, but you must still show up and fetch your dry-cleaning with the ticket, and wait if the task hasn't completed. For a pipeline of operations, **Future**s don't really help that much.

The Java 8 **CompletableFuture** is a much better solution: it allows you to chain operations together so you don't have to write the code to interface sequenced operations. With **CompletableFuture**s it becomes much easier to do something like "procure ingredients, combine ingredients, cook food, serve food, clean up dishes, store dishes" as a sequence of chained operations.

Deadlock



Some tasks must wait— *block*—for results from other tasks. A blocked task has the potential of waiting for another blocked task, which is waiting for another one, etc. If the chain of blocked tasks loops around to the first one, no one can make any progress and you get *deadlock*.

The biggest problems happen if the deadlock doesn’t show up right away when you run the program. Your system can be *deadlock-prone*, and will only deadlock under certain conditions. A program might run just fine on a certain platform, for example your development machine, but then start deadlocking when you deploy it to different hardware.

Deadlock typically arises from subtle programming errors; a sequence of innocent decisions that ends up accidentally creating a dependency loop. This section contains a classic example that demonstrates the elusive nature of deadlocking.

Effort, Complexity, Cost

We’ll finish the chapter by simulating the process of creating a pizza, first implementing it using parallel streams, then **CompletableFuture**s. This is not just a comparison of the two approaches, but more importantly an exploration of how much work you should invest in trying to speed up a program.

Parallel Streams

One significant benefit of Java 8 streams is that, in some cases, they can be easily parallelized. This comes from careful library design, in particular the way streams use *internal iteration*—that is, they control

their own iterators. In particular, they use a special kind of iterator called a *Spliterator* which is constrained to be easily and automatically dividable. This produces the rather magical result of being able to simply say **.parallel()** and suddenly everything in your stream is running as a set of parallel tasks. If your code is written using **Stream**s, parallelizing to increase speed seems trivial.

For example, consider **Prime.java** from Streams. Finding prime numbers can be a time-consuming process, as we can see by timing a rewrite of that program:

```
// concurrent/ParallelPrime.java
import java.util.*;
import java.util.stream.*;
import static java.util.stream.LongStream.*;
import java.io.*;
import java.nio.file.*;
import onjava.Timer;
public class ParallelPrime {
static final int COUNT = 100_000;
public static boolean isPrime(long n) {
return rangeClosed(2, (long)Math.sqrt(n))
.noneMatch(i -> n % i == 0);
```

```
}
public static void main(String[] args)
throws IOException {
Timer timer = new Timer();
List<String> primes =
iterate(2, i -> i + 1)
.parallel() // [1]
.filter(ParallelPrime::isPrime)
.limit(COUNT)
.mapToObj(Long::toString)
.collect(Collectors.toList());
System.out.println(timer.duration());
Files.write(Paths.get("primes.txt"), primes,
StandardOpenOption.CREATE);
}
}
/* Output:
1224
*/
```

Notice this is not a microbenchmark, since we are timing the whole

program. We save the data on disk to guard against aggressive

optimization; if we didn't do anything with the result a wily compiler might observe that the program is pointless and eliminate the calculation (this is unlikely but not impossible). Note the simplicity of writing a file using the **nio2** library (described in the Files chapter).

When I comment out the **[1] parallel()** line, my results take roughly three times as long as with **parallel()** in place.

Parallel streams seem like a sweet deal. All you need do is cast your programming problems into streams, then insert **parallel()** to speed things up. Indeed, sometimes it's just that easy. But unfortunately there are numerous pitfalls.

parallel() is not a Panacea

As an exploration of the uncertainties of streams and parallel streams, let's look at a problem that seems simple: summing an incremental sequence of numbers. There turns out to be a surprising number of ways to do this, and I'll take the risk of comparing them through timing—trying to be careful, but acknowledging I might fall into one of

the many fundamental pitfalls when timing code execution. The results may have some flaws (there's no "warming up" of the JVM, for example), but I think it nonetheless gives some useful indications.

I'll start with a timing method **timeTest()** which takes a **LongSupplier**, measures the length of the **getAsLong()** call, compares the result with a **checkValue** and displays the results.

Note that everything must rigorously use **long**s; I spent a bit of time chasing down quiet overflows before realizing I had missed 'long's in important places.

All the numbers and discussions about time and memory refer to "my machine." Your experience will probably be different.

```
// concurrent/Summing.java
import java.util.stream.*;
import java.util.function.*;
import onjava.Timer;
public class Summing {
static void timeTest(String id, long checkValue,
LongSupplier operation) {
System.out.print(id + ": ");
Timer timer = new Timer();
```

```
long result = operation.getAsLong();
if(result == checkValue)
System.out.println(timer.duration() + "ms");
else
System.out.format("result: %d%ncheckValue: %d%n",
result, checkValue);
}
public static final int SZ = 100_000_000;
// This even works:
// public static final int SZ = 1_000_000_000;
public static final long CHECK =
(long)SZ * ((long)SZ + 1)/2; // Gauss's formula
public static void main(String[] args) {
System.out.println(CHECK);
timeTest("Sum Stream", CHECK, () ->
LongStream.rangeClosed(0, SZ).sum());
timeTest("Sum Stream Parallel", CHECK, () ->
LongStream.rangeClosed(0, SZ).parallel().sum());
timeTest("Sum Iterated", CHECK, () ->
LongStream.iterate(0, i -> i + 1)
```

```
.limit(SZ+1).sum());
// Slower & runs out of memory above 1_000_000:
// timeTest("Sum Iterated Parallel", CHECK, () ->
// LongStream.iterate(0, i -> i + 1)
// .parallel()
// .limit(SZ+1).sum());
}
}
/* Output:
5000000050000000
Sum Stream: 167ms
Sum Stream Parallel: 46ms
Sum Iterated: 284ms
*/
```

The **CHECK** value is calculated using the formula created by Carl Friedrich Gauss while still in primary school in the late 1700's.

This first version of **main()** uses the straightforward approach of generating a **Stream** and calling **sum()**. We see the benefits of streams in that a **SZ** of a billion is handled without overflow (I use a smaller number so the program doesn't take so long to run). Using the

basic range operation with **parallel()** is notably faster.

If **iterate()** is used to produce the sequence the slowdown is dramatic, probably because the lambda must be called each time a number is generated. But if we try to parallelize that, the result not only takes longer than the non-parallel version but it also runs out of memory (on some machines) when **SZ** gets above a million. Of course you wouldn't use **iterate()** when you could use **range()**, but if you're generating something other than a simple sequence you must use **iterate()**. Applying **parallel()** is a reasonable thing to attempt, but produces these surprising results. We shall explore the reason for the memory limitation in a later section, but we can make some initial observations regarding the stream parallel algorithms:

Stream parallelism divides the incoming data into pieces so the algorithm(s) can be applied to those separate pieces.

Arrays split cheaply, evenly and with perfect knowledge of split sizes.

Linked Lists have none of these properties; "splitting" a linked list only means dividing it into "first element" and "rest of list," which is relatively useless.

Stateless generators behave like arrays; the use of **range** above is stateless.

Iterative generators behave like linked lists; **iterate()** is an iterative generator.

Now let's try solving the problem by filling an array with values, then summing over the array. Because the array is only allocated once, it seems unlikely we'll run into garbage collection timing issues.

First we'll try an array filled with primitive **long**s:

```
// concurrent/Summing2.java
// {ExcludeFromTravisCI}
import java.util.*;
public class Summing2 {
static long basicSum(long[] ia) {
long sum = 0;
int size = ia.length;
for(int i = 0; i < size; i++)
sum += ia[i];
return sum;
}
// Approximate largest value of SZ before
// running out of memory on my machine:
public static final int SZ = 20_000_000;
```

```
public static final long CHECK =
(long)SZ * ((long)SZ + 1)/2;
public static void main(String[] args) {
System.out.println(CHECK);
long[] la = new long[SZ+1];
Arrays.parallelSetAll(la, i -> i);
Summing.timeTest("Array Stream Sum", CHECK, () ->
Arrays.stream(la).sum());
Summing.timeTest("Parallel", CHECK, () ->
Arrays.stream(la).parallel().sum());
Summing.timeTest("Basic Sum", CHECK, () ->
basicSum(la));
// Destructive summation:
Summing.timeTest("parallelPrefix", CHECK, () -> {
Arrays.parallelPrefix(la, Long::sum);
return la[la.length - 1];
});
}
}
/* Output:
```

200000010000000

Array Stream Sum: 104ms

Parallel: 81ms

Basic Sum: 106ms

parallelPrefix: 265ms

**/*

The first limitation is memory size; because the array is allocated up front, we can't create anything nearly as large as the previous version. Parallelizing speeds things up, even a bit faster than just looping through using **basicSum()**. Interestingly, **Arrays.parallelPrefix()** seems to actually slow things down. However, any of these techniques might be more useful under other conditions—that's why you can't make any deterministic statements about what to do, other than "you must try it out."

Finally, consider the effect of using boxed **Long**s instead:

```
// concurrent/Summing3.java
// {ExcludeFromTravisCI}
import java.util.*;
public class Summing3 {
static long basicSum(Long[] ia) {
```

```
long sum = 0;
int size = ia.length;
for(int i = 0; i < size; i++)
sum += ia[i];
return sum;
}
// Approximate largest value of SZ before
// running out of memory on my machine:
public static final int SZ = 10_000_000;
public static final long CHECK =
(long)SZ * ((long)SZ + 1)/2;
public static void main(String[] args) {
System.out.println(CHECK);
Long[] aL = new Long[SZ+1];
Arrays.parallelSetAll(aL, i -> (long)i);
Summing.timeTest("Long Array Stream Reduce",
CHECK, () ->
Arrays.stream(aL).reduce(0L, Long::sum));
Summing.timeTest("Long Basic Sum", CHECK, () ->
basicSum(aL));
```

```
// Destructive summation:
Summing.timeTest("Long parallelPrefix",CHECK, ()-> {
Arrays.parallelPrefix(aL, Long::sum);
return aL[aL.length - 1];
});
}
}
/* Output:
50000005000000
Long Array Stream Reduce: 1038ms
Long Basic Sum: 21ms
Long parallelPrefix: 3616ms
*/
```

Now the amount of memory available is approximately cut in half, and the amount of time required has exploded in all cases except **basicSum()**, which simply loops through the array. Surprisingly, **Arrays.parallelPrefix()** takes significantly longer than any other approach.

I separated the **parallel()** version because running it inside the above program caused a lengthy garbage collection, distorting the

results:

```
// concurrent/Summing4.java
// {ExcludeFromTravisCI}
import java.util.*;
public class Summing4 {
public static void main(String[] args) {
System.out.println(Summing3.CHECK);
Long[] aL = new Long[Summing3.SZ+1];
Arrays.parallelSetAll(aL, i -> (long)i);
Summing.timeTest("Long Parallel",
Summing3.CHECK, () ->
Arrays.stream(aL)
.parallel()
.reduce(0L,Long::sum));
}
}
/* Output:
50000005000000
Long Parallel: 1014ms
*/
```

It’s slightly faster than the non-**parallel()** version, but not significantly.

A big reason for this increase in time is the processor memory cache. With the primitive **long**s in **Summing2.java**, the array **la** is contiguous memory. The processor can more easily anticipate the use of this array and keep the cache filled with the array elements that are needed next. Accessing the cache is much, much faster than going out to main memory. It appears that the **Long parallelPrefix** calculation suffers because it reads two array elements for each calculation, plus writes the result back into the array, and each of these produces an out-of-cache reference for the **Long**.

With **Summing3.java** and **Summing4.java**, **aL** is an array of **Long**, which is not a contiguous array of data, but a contiguous array of references to **Long** objects. Even though that array will probably be kept in cache, the objects pointed to will almost always be out-of-cache.

These examples used different **SZ** values to show the memory limits.

To do a time comparison, here are the results with **SZ** set to the smallest value of 10 million:

Sum Stream: 69ms

Sum Stream Parallel: 18ms

Sum Iterated: 277ms

Array Stream Sum: 57ms

Parallel: 14ms

Basic Sum: 16ms

parallelPrefix: 28ms

Long Array Stream Reduce: 1046ms

Long Basic Sum: 21ms

Long parallelPrefix: 3287ms

Long Parallel: 1008ms

While Java 8's various built-in "parallel" tools are terrific, I've seen them treated as magical panaceas: "Just add **parallel()** and it will run faster!" I hope I've begun to show that this is not the case at all, and that blindly applying the built-in "parallel" operations can sometimes even make things run noticeably slower.

The parallel()/limit()

Intersection

There's a further complication when using **parallel()**. Streams, as taken from other languages, are designed around an *infinite* stream model. If you have a finite number of elements you use a collection and the associated algorithms designed for limited-sized collections. If you use infinite streams, you use those algorithms, optimized for streams.

Java 8 conflates the two. For example, **Collection**s have no built-in **map()** operation. The only stream-like batch operation in **Collection** and **Map** is **forEach()**. If you want to perform operations like **map()** and **reduce()**, you must first turn the **Collection** into a **Stream** where those operations exist:

```
// concurrent/CollectionIntoStream.java
import onjava.*;
import java.util.*;
import java.util.stream.*;
public class CollectionIntoStream {
public static void main(String[] args) {
List<String> strings =
Stream.generate(new Rand.String(5))
.limit(10)
```

```
.collect(Collectors.toList());
strings.forEach(System.out::println);
// Convert to a Stream for many more options:
String result = strings.stream()
.map(String::toUpperCase)
.map(s -> s.substring(2))
.reduce(":", (s1, s2) -> s1 + s2);
System.out.println(result);
}
}
/* Output:
btpen
pccux
szgvg
meinn
eeloz
tdvew
cippc
ygpoa
lkljl
```

bynxt

:PENCUXGVGINNLOZVEWPPCPOALJLNXT

**/*

Collections do have some batch operations like **removeAll()**, **removeIf()** and **retainAll()**, but these are destructive actions.

ConcurrentHashMap has special extensive support for **forEach**

and **reduce** operations.

In many cases, there's no problem with just calling **stream()** or

parallelStream() on a collection. Sometimes, however,

conflating **Stream** with **Collection** can produce surprises. Here's

an interesting puzzle:

// concurrent/ParallelStreamPuzzle.java

import java.util.*;

import java.util.function.*;

import java.util.stream.*;

public class ParallelStreamPuzzle {

static **class** IntGenerator

implements Supplier<Integer> {

private int current = 0;

public Integer get() {

return current++;

```
}
}
public static void main(String[] args) {
List<Integer> x =
Stream.generate(new IntGenerator())
.limit(10)
.parallel() // [1]
.collect(Collectors.toList());
System.out.println(x);
}
}
/* Output:
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
*/
```

If you run this with the **[1]** commented, it produces the expected:

[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]

Every time. But with the **.parallel()** included, it seems like a random-number generator, with outputs (that differ from one run to the next) like:

[0, 3, 6, 8, 11, 14, 17, 20, 23, 26]

How can such a simple program seem so broken? Let’s consider what we’re trying to achieve here: “parallel generation.”" What does that even mean? A bunch of threads all pulling at a single generator, then somehow selecting a limited set of the results? The code makes it look simple, but it turns out to be an especially messy problem.

To see it, we’ll add some instrumentation. Since we’re dealing with threads, we must capture any trace information into a concurrent data structure. Here I use a **ConcurrentLinkedDeque**:

```
// concurrent/ParallelStreamPuzzle2.java
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
import java.util.concurrent.*;
import java.util.concurrent.atomic.*;
import java.nio.file.*;
public class ParallelStreamPuzzle2 {
public static final Deque<String> trace =
new ConcurrentLinkedDeque<>();
static class
IntGenerator implements Supplier<Integer> {
```

```
private AtomicInteger current =
new AtomicInteger();
public Integer get() {
trace.add(current.get() + ": " +
Thread.currentThread().getName());
return current.getAndIncrement();
}
}
public static void
main(String[] args) throws Exception {
List<Integer> x =
Stream.generate(new IntGenerator())
.limit(10)
.parallel()
.collect(Collectors.toList());
System.out.println(x);
Files.write(Paths.get("PSP2.txt"), trace);
}
}
/* Output:
```

[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]

*/

current is defined using the thread-safe **AtomicInteger** class, to prevent race conditions; **parallel()** allows **get()** to be called by multiple threads.

You might be surprised when looking at **PSP2.txt**.

IntGenerator.get() is called **1024** times!

0: main

1: ForkJoinPool.commonPool-worker-1

2: ForkJoinPool.commonPool-worker-2

3: ForkJoinPool.commonPool-worker-2

4: ForkJoinPool.commonPool-worker-1

5: ForkJoinPool.commonPool-worker-1

6: ForkJoinPool.commonPool-worker-1

7: ForkJoinPool.commonPool-worker-1

8: ForkJoinPool.commonPool-worker-4

9: ForkJoinPool.commonPool-worker-4

10: ForkJoinPool.commonPool-worker-4

11: main

12: main

13: main

14: main

15: main

...

1017: ForkJoinPool.commonPool-worker-1

1018: ForkJoinPool.commonPool-worker-6

1019: ForkJoinPool.commonPool-worker-6

1020: ForkJoinPool.commonPool-worker-1

1021: ForkJoinPool.commonPool-worker-1

1022: ForkJoinPool.commonPool-worker-1

1023: ForkJoinPool.commonPool-worker-1

This block size appears to be part of the internal implementation (try different arguments to **limit()** to see different block sizes).

Combining **parallel()** with **limit()** tells it to prefetch a bunch of values, to be fed out as the stream.

Try to imagine what's happening here: a stream abstracts an infinite sequence, produced on-demand. When you ask it to produce the stream in parallel, you're asking all those threads to call **get()** whenever they can. Add in **limit()** and you're saying "just take *some* of these." Basically, you're *asking* for random output when you

combine **parallel()** with **limit()**—which might be just fine for the problem you're solving. But you must understand that when you do this. It's an experts-only feature, and not something to be thrown out to argue that "Java gets it wrong."

What's a more reasonable way to approach the problem? Well, if you want to produce a stream of **int**, you can use **IntStream.range()**, like this:

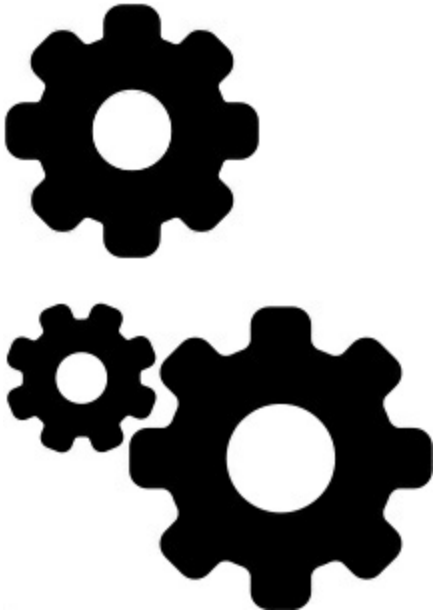
```
// concurrent/ParallelStreamPuzzle3.java
// {VisuallyInspectOutput}
import java.util.*;
import java.util.stream.*;
public class ParallelStreamPuzzle3 {
public static void main(String[] args) {
List<Integer> x = IntStream.range(0, 30)
.peek(e -> System.out.println(e + ": " +
Thread.currentThread().getName()))
.limit(10)
.parallel()
.boxed()
.collect(Collectors.toList());
```

```
System.out.println(x);
}
}
/* Output:
8: main
6: ForkJoinPool.commonPool-worker-5
3: ForkJoinPool.commonPool-worker-7
5: ForkJoinPool.commonPool-worker-5
1: ForkJoinPool.commonPool-worker-3
2: ForkJoinPool.commonPool-worker-6
4: ForkJoinPool.commonPool-worker-1
0: ForkJoinPool.commonPool-worker-4
7: ForkJoinPool.commonPool-worker-1
9: ForkJoinPool.commonPool-worker-2
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
*/
```

To show that **.parallel()** is indeed working, I've added a call to **peek()**, a stream function that is predominantly intended for debugging: it pulls a value out of the stream and does something with it, but doesn't affect the elements that are passed down the stream.

Note that this interferes with thread behavior, but I’m just trying to show something here, not actually debug anything.

You can also see the addition of **boxed()**, which takes the stream of **int** and turns it into a stream of **Integer**.



Now we get multiple threads producing the different values, but it’s also only producing 10 values as requested, rather than 1024 in order to produce 10.

Is it any faster? A better question is: When does it start to make sense? Certainly not with a set this small; the expense of context switching is likely to far outweigh any speedups from parallelism. It’s a little hard to imagine *when* a simple sequence of numbers will make sense to generate in parallel. If you’re using something with expensive generation, it might make sense—but that’s all speculation. The only

way to know is through testing. Remember the maxim: “First make it work, then make it fast—but only if you must.” Combining **parallel()** and **limit()** is for experts only (and to be clear, I don’t consider myself an expert here).

Parallel Streams Only *Look*

Easy

Actually, in many cases parallel streams do in fact effortlessly produce results faster. But as you’ve seen, just slapping **parallel()** onto your **Stream** operations is not necessarily a safe thing to do. Before you use **parallel()**, you must understand how parallelism might help or hurt your operations. The fundamental error here is thinking that parallelism is always a good idea. It’s not. Streams mean you don’t need to rewrite all your code in order to run it in parallel. What streams don’t do is replace the need to understand how parallelism works, and whether it will help achieve your goal.

Creating and Running

Tasks

If you cannot achieve concurrency with parallel streams then you must create and run your own tasks. Later you'll see that the ideal Java 8 approach for running tasks is the **CompletableFuture**, but we'll introduce the concepts using more basic tools.

The history of Java concurrency starts with very primitive and problematic mechanisms, and is littered with various attempts at improvement. Those are primarily relegated to the Appendix: Low-Level Concurrency. Here, we will show a canonical form representing the simplest and best approaches to creating and running tasks. As with everything in concurrency, there are all kinds of variations, but these are either relegated to that appendix or beyond the scope of this book.

Tasks and Executors

In early versions of Java you used threads by creating your own **Thread** objects directly, even subclassing them to create your own specific "task-thread" objects. You called constructors by hand and started the threads yourself.

The overhead of creating all those threads turned out to be significant, and the hands-on approach is now discouraged. In Java 5, classes were added to handle *thread pooling* for you. Instead of creating a new subtype of **Thread** for each different type of task, you create a task as

a separate type, then hand it to an **ExecutorService** to run that task. The **ExecutorService** manages the threads for you, and recycles threads rather than throwing them away after they've run a task.

To start, we'll create a task that does almost nothing. It "sleeps" (suspends execution) for 100 milliseconds, displays its identifier and the name of the **Thread** that's executing the task, then finishes:

```
// concurrent/NapTask.java
import onjava.Nap;
public class NapTask implements Runnable {
final int id;
public NapTask(int id) { this.id = id; }
@Override
public void run() {
new Nap(0.1); // Seconds
System.out.println(this + " " +
Thread.currentThread().getName());
}
@Override
public String toString() {
```

```
return "NapTask[" + id + "]";
}
}
```

This is simply a **Runnable**: a class containing a **run()** method. It doesn't include a mechanism for actually running the task.

We "sleep" using the **Nap** class:

```
// onjava/Nap.java
package onjava;
import java.util.concurrent.*;
public class Nap {
public Nap(double t) { // Seconds
try {
TimeUnit.MILLISECONDS.sleep((int)(1000 * t));
} catch(InterruptedException e) {
throw new RuntimeException(e);
}
}
public Nap(double t, String msg) {
this(t);
System.out.println(msg);
```

}

}

To eliminate the visual noise of the exception handling, this is defined as a utility. The second constructor displays a message when it times out.

The call to **TimeUnit.MILLISECONDS.sleep()** gets the "current thread" and puts it to sleep for the time in the argument, which means that thread is suspended. This does *not* mean that the underlying processor stops. The OS switches it to some other task, for example running another window on your computer. Periodically the OS *task manager* checks to see if the **sleep()** has timed out. When it does, the thread is "woken up" and given more processing time.

You can see that **sleep()** throws a checked **InterruptedException**; this is an artifact from the original Java design that terminated tasks by abruptly breaking out of them. Because it tends to produce unstable states, termination has subsequently been discouraged. However, we must catch the exception for situations when termination is required or still happens.

To execute tasks, we'll start with the simplest approach, the *SingleThreadExecutor*:

```
// concurrent/SingleThreadExecutor.java
import java.util.concurrent.*;
import java.util.stream.*;
import onjava.*;
public class SingleThreadExecutor {
public static void main(String[] args) {
ExecutorService exec =
Executors.newSingleThreadExecutor();
IntStream.range(0, 10)
.mapToObj(NapTask::new)
.forEach(exec::execute);
System.out.println("All tasks submitted");
exec.shutdown();
while(!exec.isTerminated()) {
System.out.println(
Thread.currentThread().getName() +
" awaiting termination");
new Nap(0.1);
}
}
```

}

/ Output:*

All tasks submitted

main awaiting termination

main awaiting termination

NapTask[0] pool-1-thread-1

main awaiting termination

NapTask[1] pool-1-thread-1

main awaiting termination

NapTask[2] pool-1-thread-1

main awaiting termination

NapTask[3] pool-1-thread-1

main awaiting termination

NapTask[4] pool-1-thread-1

main awaiting termination

NapTask[5] pool-1-thread-1

main awaiting termination

NapTask[6] pool-1-thread-1

main awaiting termination

NapTask[7] pool-1-thread-1

main awaiting termination

NapTask[8] pool-1-thread-1

main awaiting termination

NapTask[9] pool-1-thread-1

*/

First note there is no **SingleThreadExecutor** class. **newSingleThreadExecutor()** is a factory in **Executors** that creates that particular kind of **ExecutorService**. 4

I create ten **NapTask**s and submit them to the **ExecutorService**, which means they start running on their own. In the meantime, however, **main()** continues doing things. When I call **exec.shutdown()**, that tells the **ExecutorService** to finish tasks that have already been submitted, but not to accept any new tasks. At this point those tasks are still running, however, so we must wait until they complete before exiting **main()**. This is achieved by checking **exec.isTerminated()**, which becomes **true** after all the tasks complete.

Notice that the name of the thread in **main()** is **main**, and there is only one other thread, **pool-1-thread-1**. Also, the interleaved output shows that the two threads are indeed running concurrently.

If you simply call **exec.shutdown()**, the program will complete once all the tasks finish. That is, **while(!exec.isTerminated())** is not required:

```
// concurrent/SingleThreadExecutor2.java
import java.util.concurrent.*;
import java.util.stream.*;
public class SingleThreadExecutor2 {
public static void main(String[] args)
throws InterruptedException {
ExecutorService exec =
Executors.newSingleThreadExecutor();
IntStream.range(0, 10)
.mapToObj(NapTask::new)
.forEach(exec::execute);
exec.shutdown();
}
}
/* Output:
NapTask[0] pool-1-thread-1
NapTask[1] pool-1-thread-1
```

NapTask[2] pool-1-thread-1

NapTask[3] pool-1-thread-1

NapTask[4] pool-1-thread-1

NapTask[5] pool-1-thread-1

NapTask[6] pool-1-thread-1

NapTask[7] pool-1-thread-1

NapTask[8] pool-1-thread-1

NapTask[9] pool-1-thread-1

**/*

Once you call **exec.shutdown()**, trying to submit new tasks will throw a **RejectedExecutionException**:

```
// concurrent/MoreTasksAfterShutdown.java
import java.util.concurrent.*;
public class MoreTasksAfterShutdown {
public static void main(String[] args) {
ExecutorService exec =
Executors.newSingleThreadExecutor();
```

```
exec.execute(new NapTask(1));
exec.shutdown();
try {
exec.execute(new NapTask(99));
} catch(RejectedExecutionException e) {
System.out.println(e);
}
}
}
/* Output:
java.util.concurrent.RejectedExecutionException: Task
NapTask[99] rejected from java.util.concurrent.ThreadPo
olExecutor@4e25154f[Shutting down, pool size = 1,
active threads = 1, queued tasks = 0, completed tasks =
0]
NapTask[1] pool-1-thread-1
*/
```

The alternative to **exec.shutdown()** is **exec.shutdownNow()**, which, in addition to not accepting new tasks, will also try to stop any currently-running tasks by interrupting them. Again, interruption is

messy, error-prone and discouraged.

Using More Threads

The point of using threads is (almost always) to get things done faster, so why should we limit ourselves to the *SingleThreadExecutor*? Look at the Javadoc for **Executors** and you'll see more options. For example *CachedThreadPool*:

```
// concurrent/CachedThreadPool.java
import java.util.concurrent.*;
import java.util.stream.*;
public class CachedThreadPool {
public static void main(String[] args) {
ExecutorService exec =
Executors.newCachedThreadPool();
IntStream.range(0, 10)
.mapToObj(NapTask::new)
.forEach(exec::execute);
exec.shutdown();
}
}
/* Output:
```

NapTask[7] pool-1-thread-8

NapTask[4] pool-1-thread-5

NapTask[1] pool-1-thread-2

NapTask[3] pool-1-thread-4

NapTask[0] pool-1-thread-1

NapTask[8] pool-1-thread-9

NapTask[2] pool-1-thread-3

NapTask[9] pool-1-thread-10

NapTask[6] pool-1-thread-7

NapTask[5] pool-1-thread-6

**/*

When you run this program, you'll notice it finishes more quickly. This makes sense because, instead of using the same thread to sequentially run each task, every task gets its own thread so they all run in parallel. There seems to be no downside and it's hard to see why anyone would use a *SingleThreadExecutor*.

To understand the problem, we need a more complex task:

// concurrent/InterferingTask.java

public class InterferingTask **implements** Runnable {

final int id;

```
private static Integer val = 0;
public InterferingTask(int id) { this.id = id; }
@Override
public void run() {
for(int i = 0; i < 100; i++)
val++;
System.out.println(id + " " +
Thread.currentThread().getName() + " " + val);
}
}
```

Each task increments **val** one hundred times. This seems simple enough. Let's try it with a *CachedThreadPool*:

```
// concurrent/CachedThreadPool2.java
import java.util.concurrent.*;
import java.util.stream.*;
public class CachedThreadPool2 {
public static void main(String[] args) {
ExecutorService exec =
Executors.newCachedThreadPool();
IntStream.range(0, 10)
```

```
.mapToObj(InterferingTask::new)
.forEach(exec::execute);
exec.shutdown();
}
}
/* Output:
0 pool-1-thread-1 200
1 pool-1-thread-2 200
4 pool-1-thread-5 300
5 pool-1-thread-6 400
8 pool-1-thread-9 500
9 pool-1-thread-10 600
2 pool-1-thread-3 700
7 pool-1-thread-8 800
3 pool-1-thread-4 900
6 pool-1-thread-7 1000
*/
```

The output is not what we expect *and* it varies from one run to the next. The problem is that all the tasks are trying to write to the single instance of **val**, and they are stepping on each other's toes. We say

that such a class is *not thread-safe*. Let's see what happens with a *SingleThreadExecutor*:

```
// concurrent/SingleThreadExecutor3.java
import java.util.concurrent.*;
import java.util.stream.*;
public class SingleThreadExecutor3 {
public static void main(String[] args)
throws InterruptedException {
ExecutorService exec =
Executors.newSingleThreadExecutor();
IntStream.range(0, 10)
.mapToObj(InterferingTask::new)
.forEach(exec::execute);
exec.shutdown();
}
}
/* Output:
0 pool-1-thread-1 100
1 pool-1-thread-1 200
2 pool-1-thread-1 300
```

3 pool-1-thread-1 400

4 pool-1-thread-1 500

5 pool-1-thread-1 600

6 pool-1-thread-1 700

7 pool-1-thread-1 800

8 pool-1-thread-1 900

9 pool-1-thread-1 1000

**/*

Now we get consistent results, every time, despite the lack of thread-safety in **InterferingTask**. This is the primary benefit of a *SingleThreadExecutor*—because it runs one task at a time, those tasks never interfere with each other so thread safety is imposed. This

phenomenon is called *thread confinement* because running tasks on a single thread confines their effects. Thread confinement limits speedup but can save a lot of difficult debugging and rewriting.

Producing Results

Because **InterferingTask** is a **Runnable**, it has no return value

and can thus only produce results using *side effects*—manipulating its environment rather than returning a result. Side effects are one of the main problems in concurrent programming, for the reason we saw in **CachedThreadPool2.java**. The **val** in **InterferingTask** is called *mutable shared state*, and that's what gives you trouble: multiple tasks modifying the same variable at the same time produce what is called a *race condition*. The result depends on which task races to the finish line first and modifies the variable (and the myriad variations of other possibilities).

The best way to avoid race conditions is to avoid mutable shared state. We might call this the *selfish child principle*: Share nothing.

With **InterferingTask**, it would be nice to remove the side effects and just return a result from the task. To do this, we create a **Callable** rather than a **Runnable**:

```
// concurrent/CountingTask.java
import java.util.concurrent.*;
public class CountingTask implements Callable<Integer> {
final int id;
public CountingTask(int id) { this.id = id; }
@Override
```

```
public Integer call() {
Integer val = 0;
for(int i = 0; i < 100; i++)
val++;
System.out.println(id + " " +
Thread.currentThread().getName() + " " + val);
return val;
}
}
```

call() produces its result entirely

independently of all other CountingTasks, which

means there is no mutable shared state.

An **ExecutorService** allows you to start every **Callable** in a

collection using **invokeAll()**:

```
// concurrent/CachedThreadPool3.java
import java.util.*;
import java.util.concurrent.*;
import java.util.stream.*;
public class CachedThreadPool3 {
public static Integer
```

```
extractResult(Future<Integer> f) {
try {
return f.get();
} catch(Exception e) {
throw new RuntimeException(e);
}
}
public static void main(String[] args)
throws InterruptedException {
ExecutorService exec =
Executors.newCachedThreadPool();
List<CountingTask> tasks =
IntStream.range(0, 10)
.mapToObj(CountingTask::new)
.collect(Collectors.toList());
List<Future<Integer>> futures =
exec.invokeAll(tasks);
Integer sum = futures.stream()
.map(CachedThreadPool3::extractResult)
.reduce(0, Integer::sum);
```

```
System.out.println("sum = " + sum);
exec.shutdown();
}
}
/* Output:
1 pool-1-thread-2 100
0 pool-1-thread-1 100
4 pool-1-thread-5 100
5 pool-1-thread-6 100
8 pool-1-thread-9 100
9 pool-1-thread-10 100
2 pool-1-thread-3 100
3 pool-1-thread-4 100
6 pool-1-thread-7 100
7 pool-1-thread-8 100
sum = 1000
*/
```

Only after all the tasks are complete does **invokeAll()** return a **List** of **Future**, one **Future** for each task. A **Future** is a mechanism introduced in Java 5 that allows you to submit a task

without waiting for it to complete. Here, we use

ExecutorService.submit():

```
// concurrent/Futures.java
import java.util.*;
import java.util.concurrent.*;
import java.util.stream.*;
public class Futures {
public static void main(String[] args)
throws InterruptedException, ExecutionException {
ExecutorService exec =
Executors.newSingleThreadExecutor();
Future<Integer> f =
exec.submit(new CountingTask(99));
System.out.println(f.get()); // [1]
exec.shutdown();
}
}
/* Output:
99 pool-1-thread-1 100
100
```

*/

[1] When you call **get()** on a **Future** whose task hasn't completed yet, the call blocks (waits) until the result is available. But this means, in **CachedThreadPool3.java**, that **Future** seems redundant because **invokeAll()** doesn't even return until all the tasks have completed. However, here the **Future** is not used for the delayed result, but rather to capture any exceptions that might happen.

Notice also the messiness of extracting the results in **CachedThreadPool3.java**. **get()** throws exceptions, so **extractResult()** performs this extraction within a **Stream**.

Because a **Future** blocks when you call **get()**, it only puts off the problem of waiting for tasks to finish. Ultimately, **Future**s were deemed an ineffective solution and are now discouraged, in favor of Java 8's **CompletableFuture**, which we explore later in this chapter. Of course, you'll still encounter **Future**s in legacy libraries.

We can solve this problem in a much simpler and more elegant fashion using parallel **Stream**s:

// concurrent/CountingStream.java

// {VisuallyInspectOutput}

```
import java.util.*;
import java.util.concurrent.*;
import java.util.stream.*;
public class CountingStream {
public static void main(String[] args) {
System.out.println(
IntStream.range(0, 10)
.parallel()
```

```
.mapToObj(CountingTask::new)
.map(ct -> ct.call())
.reduce(0, Integer::sum));
}
}
/* Output:
1 ForkJoinPool.commonPool-worker-3 100
8 ForkJoinPool.commonPool-worker-2 100
0 ForkJoinPool.commonPool-worker-6 100
```

2 ForkJoinPool.commonPool-worker-1 100

4 ForkJoinPool.commonPool-worker-5 100

9 ForkJoinPool.commonPool-worker-7 100

6 main 100

7 ForkJoinPool.commonPool-worker-4 100

5 ForkJoinPool.commonPool-worker-2 100

3 ForkJoinPool.commonPool-worker-3 100

1000

**/*

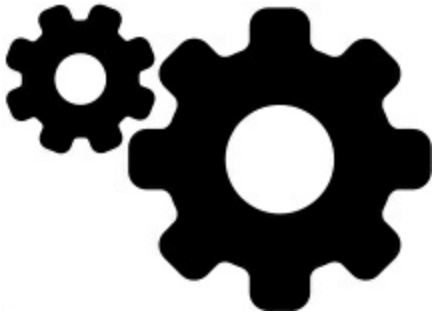
Not only is this much easier to understand, all we needed to do was insert **parallel()** into an otherwise sequential operation and suddenly everything is running concurrently.

Lambdas and Method References as Tasks

With lambdas and method references, you're not constrained to using only **Runnable**s and **Callable**s. Because Java 8 supports lambdas and method references by matching signatures (that is, it supports *structural conformance*), we can pass arguments that are *not* **Runnable**s or **Callable**s to an **ExecutorService**:

// concurrent/LambdasAndMethodReferences.java

```
import java.util.concurrent.*;

class NotRunnable {

public void go() {
```



```
System.out.println("NotRunnable");

}

}

class NotCallable {

public Integer get() {

System.out.println("NotCallable");

return 1;

}

}

public class LambdasAndMethodReferences {

public static void main(String[] args)

throws InterruptedException {

ExecutorService exec =
```

```
Executors.newCachedThreadPool();
exec.submit(() -> System.out.println("Lambda1"));
exec.submit(new NotRunnable()::go);
exec.submit(() -> {
System.out.println("Lambda2");
return 1;
});
exec.submit(new NotCallable()::get);
exec.shutdown();
}
}
/* Output:
Lambda1
NotCallable
NotRunnable
Lambda2
*/
```

Here, the first two **submit()** calls can instead be calls to **execute()**. All **submit()** calls return **Future**s, which you can use to extract the result in the case of the second two calls.

Terminating Long-Running Tasks

Concurrent programs commonly use long-running tasks. A **Callable** task returns a value upon completion; although this gives it a finite lifetime, that can still be long. **Runnable** tasks are sometimes set up as background processes that run forever. You often need a way to stop both **Runnable** and **Callable** tasks before their normal completion, such as when you're shutting down a program. The original Java design provided mechanisms (which, for backwards compatibility, still exist) to *interrupt* running tasks; the interruption mechanisms include issues around blocking. Interrupting tasks is messy and complicated because you must understand all possible states from which that interruption might occur, along with the possible resulting data loss. Using interruption is considered an antipattern, but we are still forced to catch **InterruptedException** because of the backward-compatibility residue of the design.

The best approach to task termination is to set a flag that the task periodically checks. Then the task can go through its own shutdown process and terminate gracefully. Instead of pulling the plug on a task

at some random time, you ask the task to terminate itself when it reaches a good point. This always produces better results than interruption, along with more sensible code that is easier to understand.

Terminating a task this way sounds simple enough: set a **boolean** flag that the task can see. Write the task so it periodically checks the flag and performs graceful termination. That is in fact what you do, but there's a complication: Our old nemesis, shared mutable state. If the flag can be manipulated by another task, then there are collision possibilities.

When studying Java literature you'll find numerous approaches to this problem, very often using the **volatile** keyword. We shall use a simpler technique and avoid all the vagaries of **volatile**, which are only covered in Appendix: Low-Level Concurrency.

Java 5 introduced the **Atomic** classes, which provide a set of types you can use without worrying about concurrency problems. We'll add an **AtomicBoolean** flag that tells a task to clean itself up and exit:

```
// concurrent/QuittableTask.java
import java.util.concurrent.atomic.AtomicBoolean;
import onjava.Nap;
```

```
public class QuittableTask implements Runnable {
final int id;
public QuittableTask(int id) { this.id = id; }
private AtomicBoolean running =
new AtomicBoolean(true);
public void quit() { running.set(false); }
@Override
public void run() {
while(running.get()) // [1]
new Nap(0.1);
System.out.print(id + " "); // [2]
}
}
```

Although multiple tasks can successfully call **quit()** at the same instant, the **AtomicBoolean** prevents more than one of those tasks from actually modifying **running** at the same time, rendering the **quit()** method thread-safe.

[1]: As long as the **running** flag is **true**, this task's **run()** method will continue.

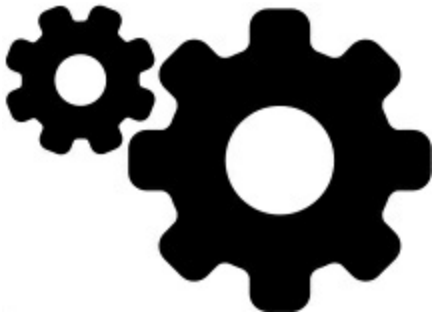
[2]: The display only happens as the task exits.

The need to make **running** an **AtomicBoolean** demonstrates one of the most fundamental difficulties when writing concurrent Java programs. If you make **running** an ordinary **boolean**, you might never see the problem in an executing program. Indeed, in this example the chances are that you'd never have any problems—and yet that code would still be unsafe. It can be difficult or impossible to write a test that demonstrates that problem. Thus you don't have any immediate feedback to tell you that you've done something wrong. Often, the only way for you to write thread-safe code is just by knowing all the subtle places where things can go wrong.

As a test, we'll start a lot of **QuittableTask**s and then shut them down. Try playing with larger values of COUNT:

```
// concurrent/QuittingTasks.java
import java.util.*;
import java.util.stream.*;
import java.util.concurrent.*;
import onjava.Nap;
public class QuittingTasks {
public static final int COUNT = 150;
public static void main(String[] args) {
```

```
ExecutorService es =
Executors.newCachedThreadPool();
List<QuittableTask> tasks =
IntStream.range(1, COUNT)
.mapToObj(QuittableTask::new)
.peek(qt -> es.execute(qt))
.collect(Collectors.toList());
new Nap(1);
tasks.forEach(QuittableTask::quit);
es.shutdown();
}
}
/* Output:
24 27 31 8 11 7 19 12 16 4 23 3 28 32 15 20 63 60 68 67
64 39 47 52 51 55 40 43 48 59 44 56 36 35 71 72 83 103
96 92 88 99 100 87 91 79 75 84 76 115 108 112 104 107
111 95 80 147 120 127 119 123 144 143 116 132 124 128
```



136 131 135 139 148 140 2 126 6 5 1 18 129 17 14 13 21

22 9 10 30 33 58 37 125 26 34 133 145 78 137 141 138 62

74 142 86 65 73 146 70 42 149 121 110 134 105 82 117

106 113 122 45 114 118 38 50 29 90 101 89 57 53 94 41

61 66 130 69 77 81 85 93 25 102 54 109 98 49 46 97

*/

I use **peek()** to pass the **QuittableTask**s to the **ExecutorService** before collecting those tasks into a **List**. **main()** prevents the program from exiting as long as any tasks remain running. The tasks don't shut down in the same order they were created, even though the **quit()** method *is* called for each task in order. Independently-running tasks don't respond to signals deterministically.

CompletableFutures

As an introduction, here's a translation of **QuittingTasks.java** using **CompletableFuture**s:

```
// concurrent/QuittingCompletable.java
import java.util.*;
import java.util.stream.*;
import java.util.concurrent.*;
import onjava.Nap;
public class QuittingCompletable {
public static void main(String[] args) {
List<QuittableTask> tasks =
IntStream.range(1, QuittingTasks.COUNT)
.mapToObj(QuittableTask::new)
.collect(Collectors.toList());
List<CompletableFuture<Void>> cfutures =
tasks.stream()
.map(CompletableFuture::runAsync)
.collect(Collectors.toList());
new Nap(1);
tasks.forEach(QuittableTask::quit);
cfutures.forEach(CompletableFuture::join);
}
}
```

/ *Output:*

7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

26 27 28 29 30 31 32 33 34 6 35 4 38 39 40 41 42 43 44

45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62

63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98

99 100 101 102 103 104 105 106 107 108 109 110 111 112

1 113 114 116 117 118 119 120 121 122 123 124 125 126

127 128 129 130 131 132 133 134 135 136 137 138 139 140

141 142 143 144 145 146 147 148 149 5 115 37 36 2 3

**/*

tasks is a **List<QuittableTask>** just as in **QuittingTasks.java**, but in this example, there's no **peek()** that submits each **QuittableTask** to an **ExecutorService**. Instead, during the creation of **cfutures** each task is handed to **CompletableFuture::runAsync**. This executes **QuittableTask.run()** and returns a **CompletableFuture<Void>** . Because **run()** doesn't return anything, I only use the **CompletableFuture** in this case to call **join()** to wait for it to finish.

The important thing to notice in this example is that no **ExecutorService** is required to run the tasks. This is managed by the **CompletableFuture** (although there are options to provide your own **ExecutorService**). You also don't need to call **shutdown()**; in fact, unless you explicitly call **join()** as I do here, the program will exit as soon as it can, without waiting for tasks to complete.

This example is just a starting point. You'll soon see that **CompletableFuture**s are capable of much more.

Basic Usage

Here's a class with a **static** method **work()** that performs some kind of work on objects of that class:

```
// concurrent/Machina.java
import onjava.Nap;
public class Machina {
public enum State {
START, ONE, TWO, THREE, END;
```

```
State step() {
if(equals(END)) return END;
return values()[ordinal() + 1];
}
}
private State state = State.START;
private final int id;
public Machina(int id) { this.id = id; }
public static Machina work(Machina m) {
if(!m.state.equals(State.END)){
new Nap(0.1);
m.state = m.state.step();
}
System.out.println(m);
return m;
}
@Override
public String toString() {
return "Machina" + id + ": " +
(state.equals(State.END)? "complete" : state);
```

```
}
}
```

This is a *finite state machine,* a trivial one because it has no branches…it just traverses a single path from beginning to end. The **work()** method moves the machine from one state to the next and requires 100 milliseconds to do that “work.”

One thing we can do with a **CompletableFuture** is to wrap it around an object of interest using **completedFuture()**:

```
// concurrent/CompletedMachina.java
import java.util.concurrent.*;
public class CompletedMachina {
public static void main(String[] args) {
CompletableFuture<Machina> cf =
CompletableFuture.completedFuture(
new Machina(0));
try {
Machina m = cf.get(); // Doesn't block
} catch(InterruptedException |
ExecutionException e) {
throw new RuntimeException(e);
```

}

}

}

completedFuture() creates a **CompletableFuture** which is

"already complete." The only useful thing to do with such a future is to

get() the object inside, so this doesn't seem that helpful at first.

Note that the **CompletableFuture** is typed to the object it

contains. This is important.

Normally, **get()** blocks the calling thread while it waits on the result.

This block can be broken out of via either an

InterruptedException or an **ExecutionException**. In this

case, the blocking never happens because the **CompletableFuture**

is already complete, so the answer is instantly available.

Things get much more interesting when, once we've wrapped our

Machina in a **CompletableFuture**, we discover that we can add operations onto that **CompletableFuture** to work on the

contained object:

// concurrent/CompletableApply.java

import java.util.concurrent.*;

public class CompletableApply {

public static void main(String[] args) {

```
CompletableFuture<Machina> cf =
CompletableFuture.completedFuture(
new Machina(0));
CompletableFuture<Machina> cf2 =
cf.thenApply(Machina::work);
CompletableFuture<Machina> cf3 =
cf2.thenApply(Machina::work);
CompletableFuture<Machina> cf4 =
cf3.thenApply(Machina::work);
CompletableFuture<Machina> cf5 =
cf4.thenApply(Machina::work);
}
}
/* Output:
Machina0: ONE
Machina0: TWO
Machina0: THREE
Machina0: complete
*/
```

thenApply() applies a **Function** that takes an input and

produces an output. In this case, the **work() Function** produces the same type that it takes in, so each resulting **CompletableFuture** is still typed as **Machina**, but (similar to **map()** in **Stream**s) the **Function** can also return different types, which would be reflected in the return type.

You see something essential about **CompletableFuture**s here: They automatically unwrap and re-wrap the object they are carrying when you perform an operation. This way you don't get caught up in messy details, which makes writing and understanding code much easier.

We can eliminate the intermediate variables and just chain the operations together, the way we do with **Stream**s:

```
// concurrent/CompletableApplyChained.java
import java.util.concurrent.*;
import onjava.Timer;
public class CompletableApplyChained {
public static void main(String[] args) {
Timer timer = new Timer();
CompletableFuture<Machina> cf =
CompletableFuture.completedFuture(
```

new Machina(0))

.thenApply(Machina::work)

.thenApply(Machina::work)

.thenApply(Machina::work)

.thenApply(Machina::work);

System.out.println(timer.duration());

}

}

/ *Output:*

Machina0: ONE

Machina0: TWO

Machina0: THREE

Machina0: complete

514

**/*

Here we've also added a **Timer** which shows us that each step adds 100 milliseconds, and there's some additional overhead.

One important benefit of **CompletableFuture**s is that they encourage the use of the *selfish child principle* (share nothing). By default, using **thenApply()** to apply a function doesn't

communicate with anyone—it just takes an argument and returns a result. This is a foundation of functional programming, and one reason it works so well for concurrency. [5] Parallel streams and **CompletableFuture**s are designed to support these principles. As long as you don't decide to share data anyway (sharing is very easy to do, even accidentally) you can write relatively safe concurrent programs.

Calling **thenApply()** starts the operation, and in this case the *creation* of the **CompletableFuture** isn't finished until all the tasks are completed. Although this is sometimes useful, it's typically more valuable to start all tasks so you can move on and do something else while they run. We accomplish this by adding **Async** to the end of the operation:

```
// concurrent/CompletableApplyAsync.java
import java.util.concurrent.*;
import onjava.*;
public class CompletableApplyAsync {
public static void main(String[] args) {
Timer timer = new Timer();
CompletableFuture<Machina> cf =
CompletableFuture.completedFuture(
```

```
new Machina(0))
.thenApplyAsync(Machina::work)
.thenApplyAsync(Machina::work)
.thenApplyAsync(Machina::work)
.thenApplyAsync(Machina::work);
System.out.println(timer.duration());
System.out.println(cf.join());
System.out.println(timer.duration());
}
}
/* Output:
116
Machina0: ONE
Machina0: TWO
Machina0: THREE
Machina0: complete
Machina0: complete
552
*/
```

A *synchronous* call (the kind we normally make) means “return when

you are finished working," whereas an *asynchronous* call means "return right away but keep working in the background." As you can see, the creation of **cf** happens much faster now. Each call to **thenApplyAsync()** returns immediately so the next call can be made, and the whole chaining sequence completes much more quickly than before.

So quickly, in fact, that without the call to **cf.join()** the program exits before finishing its work (try taking out that line). The call to **join()** blocks the **main()** thread from progressing until the **cf** operations complete, and we can see that most of the time was indeed spent there.

This *async* ability to "return right away" requires some undercover work by the **CompletableFuture** library. In particular, it must store the chain of operations you require as a set of *callbacks*. When the first background operation completes and returns, the second one must take the resulting **Machina** and begin work, and when that one completes, the next operation takes over, etc. But without our ordinary sequence of function calls, controlled via the program call stack, this order would be lost so it is instead stored using callbacks—a table of function addresses.

Fortunately, that's all you need to know about callbacks. Programmers refer to the mess you get into doing it by hand as "callback hell." With **Async** calls, the **CompletableFuture** manages all the callbacks for you. And unless you know something specific about your system that changes things, you'll probably want to use **Async** calls.

Other Operations

When you look at the Javadocs for **CompletableFuture**, you'll see it has many methods, but the majority of this number come from variations on the different operations. For example, there's **thenApply()**, **thenApplyAsync()**, and a second form of **thenApplyAsync()** that takes an **Executor** on which to run the tasks (in this book we ignore the **Executor** option).

Here's an example that shows all the "basic" operations, ones that don't involve either combining two **CompletableFuture**s or exceptions (we shall look at those later). First, here are two utilities we shall reuse to provide brevity and convenience:

// concurrent/CompletableUtilities.java

```
package onjava;
import java.util.concurrent.*;
public class CompletableUtilities {
// Get and show value stored in a CF:
public static void showr(CompletableFuture<?> c) {
try {
System.out.println(c.get());
} catch(InterruptedException
| ExecutionException e) {
throw new RuntimeException(e);
}
}
// For CF operations that have no value:
public static void voidr(CompletableFuture<Void> c) {
try {
c.get(); // Returns void
} catch(InterruptedException
| ExecutionException e) {
throw new RuntimeException(e);
}
```

}

}

showr() calls **get()** on a **CompletableFuture<Integer>** and displays the result, catching the two possible exceptions.

voidr() is a version of **showr()** for

CompletableFuture<Void> , that is, **CompletableFuture**s

that only exist to show when a task completes or fails.

For simplicity, the following **CompletableFuture**s just wrap

Integers. **cfi()** is a convenience method that wraps an **int** inside

a completed **CompletableFuture<Integer>** :

// concurrent/CompletableOperations.java

import java.util.concurrent.*;

import static onjava.CompletableUtilities.*;

public class CompletableOperations {

static CompletableFuture<Integer> cfi(int i) {

return

CompletableFuture.completedFuture(

Integer.valueOf(i));

}

public static void main(String[] args) {

showr(cfi(1)); *// Basic test*

```
voidr(cfi(2).runAsync(() ->
System.out.println("runAsync")));
voidr(cfi(3).thenRunAsync(() ->
System.out.println("thenRunAsync")));
voidr(CompletableFuture.runAsync(() ->
System.out.println("runAsync is static")));
showr(CompletableFuture.supplyAsync(() -> 99));
voidr(cfi(4).thenAcceptAsync(i ->
System.out.println("thenAcceptAsync: " + i)));
showr(cfi(5).thenApplyAsync(i -> i + 42));
showr(cfi(6).thenComposeAsync(i -> cfi(i + 99)));
CompletableFuture<Integer> c = cfi(7);
c.obtrudeValue(111);
showr(c);
showr(cfi(8).toCompletableFuture());
c = new CompletableFuture<>();
c.complete(9);
showr(c);
c = new CompletableFuture<>();
c.cancel(true);
```

```
System.out.println("cancelled: " +
c.isCancelled());
System.out.println("completed exceptionally: " +
c.isCompletedExceptionally());
System.out.println("done: " + c.isDone());
System.out.println(c);
c = new CompletableFuture<>();
System.out.println(c.getNow(777));
c = new CompletableFuture<>();
c.thenApplyAsync(i -> i + 42)
.thenApplyAsync(i -> i * 12);
System.out.println("dependents: " +
c.getNumberOfDependents());
c.thenApplyAsync(i -> i / 2);
System.out.println("dependents: " +
c.getNumberOfDependents());
}
}
/* Output:
1
```

runAsync

thenRunAsync

runAsync is static

99

thenAcceptAsync: 4

47

105

111

8

9

cancelled: true

completed exceptionally: true

done: true

java.util.concurrent.CompletableFuture@6d311334[Complet

ed exceptionally]

777

dependents: 1

dependents: 2

**/*

main() contains a sequence of tests that can be referred to by their **int** values. **cfi(1)** demonstrates that **showr()** works properly.

cfi(2) is an example of calling **runAsync()**. Since a **Runnable** produces no return value, the result is a **CompletableFuture<Void>** so **voidr()** is used.

Notice with **cfi(3)** that **thenRunAsync()** appears to be the same as **runAsync()**. The difference is shown in the subsequent test: **runAsync()** is a **static** method, so you normally wouldn't call it as in **cfi(2)**. Instead you'd use it as in **QuittingCompletable.java**. The subsequent test shows that **supplyAsync()** is also **static**, but requires a **Supplier** rather than a **Runnable** and produces a **CompletableFuture<Integer>** instead of a **CompletableFuture<Void>** .

The "**then**" methods apply further operations to an existing **CompletableFuture<Integer>** . Unlike **thenRunAsync()**, the "**then**" methods for **cfi(4)**, **cfi(5)** and **cfi(6)** are handed the unwrapped **Integer** as their argument. As you can see by the use of **voidr()**, **thenAcceptAsync()** takes a **Consumer** and so doesn't produce a result. **thenApplyAsync()** takes a **Function** and so produces a result (which can be of a different type than its argument). **thenComposeAsync()** is quite similar to

thenApplyAsync() except that its **Function** must produce a result that is *already wrapped* in a **CompletableFuture**.

The **cfi(7)** example demonstrates **obtrudeValue()**, which forces a value in as the result. **cfi(8)** uses

toCompletableFuture() which produces a **CompletableFuture** from this **CompletionStage**.

c.complete(9) shows how you can complete a future by giving it a result (versus **obtrudeValue()** which could then force its result in to replace this one).

If you **cancel()** a **CompletableFuture**, it also becomes *done* and is completed exceptionally.

The **getNow()** method returns either the completed value of the **CompletableFuture**, or the substitute argument of **getNow()** if the future hasn't yet completed.

Finally, we look at the concept of *dependents*. If we chain two **thenApplyAsync()** calls onto a **CompletableFuture**, the number of dependents is still one. But if we attach another

thenApplyAsync() directly to **c**, we now have two dependents:
The chain of two and the additional one. This shows that you can have a single **CompletionStage** that, when it completes, can fork multiple new tasks based on its result.

Combining CompletableFutures

The second category of **CompletableFuture** methods takes two **CompletableFuture**s and combines them in various ways. One **CompletableFuture** typically finishes before another, as if the two are in a race. These methods allow you to handle the results in different ways.

To test this, we'll create a task that takes as one of its arguments the amount of time to complete, so we can control which **CompletableFuture** finishes first:

```
// concurrent/Workable.java
import java.util.concurrent.*;
import onjava.Nap;
public class Workable {
String id;
final double duration;
public Workable(String id, double duration) {
```

```
this.id = id;
this.duration = duration;
}
@Override
public String toString() {
return "Workable[" + id + "]";
}
public static Workable work(Workable tt) {
new Nap(tt.duration); // Seconds
```

```
tt.id = tt.id + "W";
System.out.println(tt);
return tt;
}
public static CompletableFuture<Workable>
make(String id, double duration) {
return
CompletableFuture.completedFuture(
new Workable(id, duration))
.thenApplyAsync(Workable::work);
}
}
```

In **make()**, the **work()** method is applied to the **CompletableFuture**. **work()** takes **duration** to complete, then it attaches the letter **W** to **id** to indicate that work has been completed.

Now we can create multiple competing **CompletableFuture**s and connect them using the various methods in the **CompletableFuture** library:

// concurrent/DualCompletableOperations.java

```
import java.util.concurrent.*;
import static onjava.CompletableUtilities.*;
public class DualCompletableOperations {
static CompletableFuture<Workable> cfA, cfB;
static void init() {
cfA = Workable.make("A", 0.15);
cfB = Workable.make("B", 0.10); // Always wins
}
static void join() {
cfA.join();
cfB.join();
System.out.println("******************");
}
public static void main(String[] args) {
init();
voidr(cfA.runAfterEitherAsync(cfB, () ->
System.out.println("runAfterEither")));
join();
init();
voidr(cfA.runAfterBothAsync(cfB, () ->
```

```
System.out.println("runAfterBoth")));
join();
init();
showr(cfA.applyToEitherAsync(cfB, w -> {
System.out.println("applyToEither: " + w);
return w;
}));
join();
init();
voidr(cfA.acceptEitherAsync(cfB, w -> {
System.out.println("acceptEither: " + w);
}));
join();
init();
voidr(cfA.thenAcceptBothAsync(cfB, (w1, w2) -> {
System.out.println("thenAcceptBoth: "
+ w1 + ", " + w2);
}));
join();
init();
```

```
showr(cfA.thenCombineAsync(cfB, (w1, w2) -> {
System.out.println("thenCombine: "
+ w1 + ", " + w2);
return w1;
}));
join();
init();
CompletableFuture<Workable>
cfC = Workable.make("C", 0.08),
cfD = Workable.make("D", 0.09);
CompletableFuture.anyOf(cfA, cfB, cfC, cfD)
.thenRunAsync(() ->
System.out.println("anyOf"));
join();
init();
cfC = Workable.make("C", 0.08);
cfD = Workable.make("D", 0.09);
CompletableFuture.allOf(cfA, cfB, cfC, cfD)
.thenRunAsync(() ->
System.out.println("allOf"));
```

```
join();
}
}
/* Output:
Workable[BW]
runAfterEither
Workable[AW]
**********
Workable[BW]
Workable[AW]
runAfterBoth
**********
Workable[BW]
applyToEither: Workable[BW]
Workable[BW]
Workable[AW]
**********
Workable[BW]
acceptEither: Workable[BW]
Workable[AW]
```

****

Workable[BW]

Workable[AW]

thenAcceptBoth: Workable[AW], Workable[BW]

****

Workable[BW]

Workable[AW]

thenCombine: Workable[AW], Workable[BW]

Workable[AW]

****

Workable[CW]

anyOf

Workable[DW]

Workable[BW]

Workable[AW]

****

Workable[CW]

Workable[DW]

Workable[BW]

Workable[AW]

****

allOf

*/

For easy access, **cfA** and **cfB** are **static**. **init()** initializes the two with **"B"** always given the shorter delay and thus always

“winning.” **join()** is another convenience method to call **join()**

on both methods and display a border.

All of these “dual” methods take one **CompletableFuture** as the

object to call the method upon, and a second **CompletableFuture**

as the first argument, followed by the operation to perform.

You can see by the use of **showr()** and **voidr()** that “run” and

“accept” are terminal operations, while “apply” and “combine”

produce new payload-bearing **CompletableFuture**s.

The names of the methods are self-explanatory, and you can verify this

by looking at the output. One particularly interesting method is

combineAsync(), which waits for both **CompletableFuture**s

to complete and then hands *both* of them to a **BiFunction** which

can then join the results into the payload of the resulting **CompletableFuture**.

A Simulation

As an example of how you might wire together a sequence of operations using **CompletableFuture**s, let us simulate the process of making a cake. In the first stage, we prepare and combine the ingredients into a batter:

```
// concurrent/Batter.java
import java.util.concurrent.*;
import onjava.Nap;
public class Batter {
static class Eggs {}
static class Milk {}
static class Sugar {}
static class Flour {}
static <T> T prepare(T ingredient) {
new Nap(0.1);
return ingredient;
}
static <T> CompletableFuture<T> prep(T ingredient) {
```

```
return CompletableFuture
.completedFuture(ingredient)
.thenApplyAsync(Batter::prepare);
}
public static CompletableFuture<Batter> mix() {
CompletableFuture<Eggs> eggs = prep(new Eggs());
CompletableFuture<Milk> milk = prep(new Milk());
CompletableFuture<Sugar> sugar = prep(new Sugar());
CompletableFuture<Flour> flour = prep(new Flour());
CompletableFuture
.allOf(eggs, milk, sugar, flour)
.join();
new Nap(0.1); // Mixing time
return
CompletableFuture.completedFuture(new Batter());
}
}
```

Each ingredient takes some time to prepare. **allOf()** waits for all ingredients to be ready, then some more time is required to mix it into a batter.

Next we put the single batch of batter into four pans and bake it. The product is returned as a **Stream** of **CompletableFuture**s:

```
// concurrent/Baked.java
import java.util.concurrent.*;
import java.util.stream.*;
import onjava.Nap;
public class Baked {
static class Pan {}
static Pan pan(Batter b) {
new Nap(0.1);
return new Pan();
}
static Baked heat(Pan p) {
new Nap(0.1);
return new Baked();
}
static CompletableFuture<Baked>
bake(CompletableFuture<Batter> cfb) {
return cfb
.thenApplyAsync(Baked::pan)
```

```
.thenApplyAsync(Baked::heat);
}
public static
Stream<CompletableFuture<Baked>> batch() {
CompletableFuture<Batter> batter = Batter.mix();
return Stream.of(bake(batter), bake(batter),
bake(batter), bake(batter));
}
}
```

Finally, we create a batch of **Frosting** and frost our cakes with it:

```
// concurrent/FrostedCake.java
import java.util.concurrent.*;
import java.util.stream.*;
import onjava.Nap;
final class Frosting {
private Frosting() {}
static CompletableFuture<Frosting> make() {
new Nap(0.1);
return CompletableFuture
.completedFuture(new Frosting());
```

```
}
}
public class FrostedCake {
public FrostedCake(Baked baked, Frosting frosting) {
new Nap(0.1);
}
@Override
public String toString() { return "FrostedCake"; }
public static void main(String[] args) {
Baked.batch().forEach(baked -> baked
.thenCombineAsync(Frosting.make(),
(cake, frosting) ->
new FrostedCake(cake, frosting))
.thenAcceptAsync(System.out::println)
.join());
}
}
```

Once you’re comfortable with the ideas behind

CompletableFutures they are relatively easy to use.

Exceptions

The same way a **CompletableFuture** wraps the objects within the processing chain, it also buffers you from exceptions. These don’t appear to the caller while processing, but only when you try to extract the result. To show how they work, we’ll start by creating a class that throws an exception under certain conditions:

```
// concurrent/Breakable.java
import java.util.concurrent.*;
public class Breakable {
String id;
private int failcount;
public Breakable(String id, int failcount) {
this.id = id;
this.failcount = failcount;
}
@Override
```

```
public String toString() {
return "Breakable_" + id +
" [" + failcount + "]";
}
public static Breakable work(Breakable b) {
if(--b.failcount == 0) {
System.out.println(
"Throwing Exception for " + b.id + "");
throw new RuntimeException(
"Breakable_" + b.id + " failed");
}
System.out.println(b);
return b;
}
}
```

With a positive **failcount**, every time you pass the object to the

work() method it decrements that **failcount**. When it goes to zero, **work()** throws an exception. If you give it a **failcount** of

zero, it never throws an exception.

Notice that it reports throwing an exception as that exception is

thrown.

In the following **test()** method, **work()** is applied to a **Breakable** multiple times, so if **failcount** is within range the exception is thrown. However, in tests **A** through **E**, you can see from the output that the exceptions are thrown, but they never emerge:

```
// concurrent/CompletableExceptions.java
import java.util.concurrent.*;
public class CompletableExceptions {
static CompletableFuture<Breakable>
test(String id, int failcount) {
return
CompletableFuture.completedFuture(
new Breakable(id, failcount))
.thenApply(Breakable::work)
.thenApply(Breakable::work)
.thenApply(Breakable::work)
.thenApply(Breakable::work);
}
public static void main(String[] args) {
// Exceptions don't appear ...
test("A", 1);
```

```
test("B", 2);
test("C", 3);
test("D", 4);
test("E", 5);
// ... until you try to fetch the value:
try {
test("F", 2).get(); // or join()
} catch(Exception e) {
System.out.println(e.getMessage());
}
// Test for exceptions:
System.out.println(
test("G", 2).isCompletedExceptionally());
// Counts as "done":
System.out.println(test("H", 2).isDone());
// Force an exception:
CompletableFuture<Integer> cfi =
new CompletableFuture<>();
System.out.println("done? " + cfi.isDone());
cfi.completeExceptionally(
```

```
new RuntimeException("forced"));
try {
cfi.get();
} catch(Exception e) {
System.out.println(e.getMessage());
}
}
}
/* Output:
Throwing Exception for A
Breakable_B [1]
Throwing Exception for B
Breakable_C [2]
Breakable_C [1]
Throwing Exception for C
Breakable_D [3]
Breakable_D [2]
Breakable_D [1]
Throwing Exception for D
Breakable_E [4]
```

Breakable_E [3]

Breakable_E [2]

Breakable_E [1]

Breakable_F [1]

Throwing Exception for F

java.lang.RuntimeException: Breakable_F failed

Breakable_G [1]

Throwing Exception for G

true

Breakable_H [1]

Throwing Exception for H

true

done? false

java.lang.RuntimeException: forced

/

Tests **A** through **E** run up to the point they throw their exception, and then … nothing. Only when calling **get()** in test **F** do we see the thrown exception.

Test **G** shows that you can check first to see whether an exception was thrown during processing, without throwing that exception. However,

test **H** tells us that an exception still qualifies as being “done,” regardless of whether it was actually successful.

The last section of code shows how you can insert an exception into a **CompletableFuture**, regardless of whether there’s any failure. Rather than using a crude try-catch when joining or getting the result, we use the more sophisticated mechanisms provided by **CompletableFuture** to automatically respond to exceptions. You do this using the same form we’ve seen for all **CompletableFuture**s: Insert a **CompletableFuture** call in the chain. There are three options: **exceptionally()**, **handle()**, and **whenComplete()**:

```
// concurrent/CatchCompletableExceptions.java
import java.util.concurrent.*;
public class CatchCompletableExceptions {
static void handleException(int failcount) {
// Call the Function only if there's an
// exception, must produce same type as came in:
CompletableExceptions
.test("exceptionally", failcount)
.exceptionally((ex) -> { // Function
```

```
if(ex == null)
System.out.println("I don't get it yet");
return new Breakable(ex.getMessage(), 0);
})
.thenAccept(str ->
System.out.println("result: " + str));
// Create a new result (recover):
CompletableExceptions
.test("handle", failcount)
.handle((result, fail) -> { // BiFunction
if(fail != null)
return "Failure recovery object";
else
return result + " is good";
})
.thenAccept(str ->
System.out.println("result: " + str));
// Do something but pass the same result through:
CompletableExceptions
.test("whenComplete", failcount)
```

```
.whenComplete((result, fail) -> { // BiConsumer
if(fail != null)
System.out.println("It failed");
else
System.out.println(result + " OK");
})
.thenAccept(r ->
System.out.println("result: " + r));
}
public static void main(String[] args) {
System.out.println("**** Failure Mode ****");
handleException(2);
System.out.println("**** Success Mode ****");
handleException(0);
}
}
/* Output:
**** Failure Mode ****
Breakable_exceptionally [1]
Throwing Exception for exceptionally
```

result: Breakable_java.lang.RuntimeException:

Breakable_exceptionally failed [0]

Breakable_handle [1]

Throwing Exception for handle

result: Failure recovery object

Breakable_whenComplete [1]

Throwing Exception for whenComplete

It failed

***** Success Mode *****

Breakable_exceptionally [-1]

Breakable_exceptionally [-2]

Breakable_exceptionally [-3]

Breakable_exceptionally [-4]

result: Breakable_exceptionally [-4]

Breakable_handle [-1]

Breakable_handle [-2]

Breakable_handle [-3]

Breakable_handle [-4]

result: Breakable_handle [-4] is good

Breakable_whenComplete [-1]

Breakable_whenComplete [-2]

Breakable_whenComplete [-3]

Breakable_whenComplete [-4]

Breakable_whenComplete [-4] OK

result: Breakable_whenComplete [-4]

/

The **exceptionally()** argument only runs if there's been an exception up to that point. **exceptionally()** is restrictive in that the **Function** can only return a value of the same type that came in. **exceptionally()** recovers to a workable state by inserting a good object back into the stream.

handle() is always called, and you must check if **fail** is true to see whether an exception occurred. But **handle()** can produce any new type, so it allows you to perform processing and not just recover as with **exceptionally()**.

whenComplete() is like **handle()** in that you must test for failure, but the argument is a consumer and doesn't modify the **result** object that's being passed through.

Stream Exceptions

Let's see how **CompletableFuture** exceptions differ from those

for **Stream**s by modifying **CompletableExceptions.java**:

```
// concurrent/StreamExceptions.java
import java.util.concurrent.*;
import java.util.stream.*;
public class StreamExceptions {
static Stream<Breakable>
test(String id, int failcount) {
return
Stream.of(new Breakable(id, failcount))
.map(Breakable::work)
.map(Breakable::work)
.map(Breakable::work)
.map(Breakable::work);
}
public static void main(String[] args) {
// No operations are even applied ...
test("A", 1);
test("B", 2);
Stream<Breakable> c = test("C", 3);
test("D", 4);
```

```
test("E", 5);
// ... until there's a terminal operation:
System.out.println("Entering try");
try {
c.forEach(System.out::println); // [1]
} catch(Exception e) {
System.out.println(e.getMessage());
}
}
}
/* Output:
Entering try
Breakable_C [2]
Breakable_C [1]
Throwing Exception for C
Breakable_C failed
*/
```

With **CompletableFuture**s we saw progress in tests **A** through **E**, but with **Stream**s, nothing even begins until you apply a terminal operation, such as the **forEach()** at **[1]**. A **CompletableFuture**

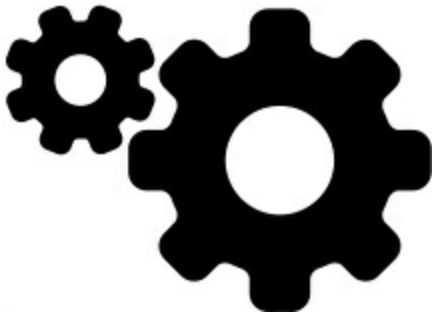
performs work and captures any exceptions for later retrieval. It’s not quite straightforward to compare the two, because of the way a **Stream** doesn’t do anything at all without a terminal operation—but a **Stream** definitely doesn’t store its exceptions.

Checked Exceptions

Neither **CompletableFuture**s nor parallel **Stream**s support operations containing checked exceptions. Instead, you must handle the checked exception at the point you invoke the operation, which produces much less elegant code:

```
// concurrent/ThrowsChecked.java
import java.util.stream.*;
import java.util.concurrent.*;
public class ThrowsChecked {
class Checked extends Exception {}
static ThrowsChecked nochecked(ThrowsChecked tc) {
return tc;
}
static ThrowsChecked
withchecked(ThrowsChecked tc) throws Checked {
return tc;
```

```
}
static void testStream() {
Stream.of(new ThrowsChecked())
.map(ThrowsChecked::nochecked)
// .map(ThrowsChecked::withchecked); // [1]
.map(tc -> {
try {
```



```
return withchecked(tc);
} catch(Checked e) {
throw new RuntimeException(e);
}
});
}
static void testCompletableFuture() {
CompletableFuture
.completedFuture(new ThrowsChecked())
```

```
.thenApply(ThrowsChecked::nochecked)
// .thenApply(ThrowsChecked::withchecked); // [2]
.thenApply(tc -> {
try {
return withchecked(tc);
} catch(Checked e) {
throw new RuntimeException(e);
}
});
}
}
```

The compiler complains at **[1]** and **[2]** if you try to use method references for **withchecked()** as you can with **nochecked()**.

Instead, you must write out the lambda expression (or write a wrapper method that doesn't throw the exception).

Deadlock

Because tasks can become blocked, it's possible for one task to get stuck waiting for another task, which in turn waits for another task, and so on, until the chain leads back to a task waiting on the first one. You get a continuous loop of tasks waiting on each other, and no one

can move. This is called *deadlock*. 6

If you try running a program and it deadlocks right away, you can immediately track down the bug. The real problem is when your program seems to be working fine but has the hidden potential to deadlock. Here, you might not get any indication that deadlocking is possible, so the flaw is latent in your program until it unexpectedly happens—typically to a customer (in a way almost certainly difficult to reproduce). Thus, preventing deadlock through careful program design is a critical part of developing concurrent systems.

The *Dining Philosophers* problem, invented by Edsger Dijkstra, is the classic demonstration of deadlock. The basic description specifies five philosophers (the example shown here allows any number). These philosophers spend part of their time thinking and part of their time eating. While they are thinking, they don’t need any shared resources, but they eat using a limited number of utensils. In the original problem description, the utensils are forks, and two forks are required to get spaghetti from a bowl in the middle of the table. A more convincing version uses chopsticks; clearly, each philosopher requires two chopsticks to eat.

A difficulty is introduced: As philosophers, they have very little money,

so they can only afford five chopsticks (more generally, the same number of chopsticks as philosophers). These are spaced around the table between them. When a philosopher wants to eat, that philosopher must pick up the chopstick to the left and the one to the right. If the philosopher on either side is using a desired chopstick, our philosopher must wait until the necessary chopsticks become available.

The **StickHolder** class manages a single **Chopstick** by keeping it in a **BlockingQueue** of size one. A **BlockingQueue** is a collection, designed to be safely used in concurrent programs, that blocks (waits) if you call **take()** and the queue is empty. Once a new element is placed in the queue, the block is released and that value is returned:

```
// concurrent/StickHolder.java
import java.util.concurrent.*;
public class StickHolder {
private static class Chopstick {}
private Chopstick stick = new Chopstick();
private BlockingQueue<Chopstick> holder =
new ArrayBlockingQueue<>(1);
```

```
public StickHolder() { putDown(); }
public void pickUp() {
try {
holder.take(); // Blocks if unavailable
} catch(InterruptedException e) {
throw new RuntimeException(e);
}
}
public void putDown() {
try {
holder.put(stick);
} catch(InterruptedException e) {
throw new RuntimeException(e);
}
}
}
```

For simplicity, the **Chopstick** is never actually produced by the **StickHolder**, but kept **private** within the class. If you call **pickUp()** and the stick is unavailable, **pickUp()** blocks until the stick is returned by another **Philosopher** calling **putDown()**.

Note that all thread safety in this class is achieved through the **BlockingQueue**.

Each **Philosopher** is a task that attempts to **pickUp()** the chopstick to both its right and left so it can eat, then releases those chopsticks with **putDown()**:

```
// concurrent/Philosopher.java
public class Philosopher implements Runnable {
private final int seat;
private final StickHolder left, right;
public Philosopher(int seat,
StickHolder left, StickHolder right) {
this.seat = seat;
this.left = left;
this.right = right;
}
@Override
public String toString() {
return "P" + seat;
}
@Override
```

```
public void run() {
while(true) {
// System.out.println("Thinking"); // [1]
right.pickUp();
left.pickUp();
System.out.println(this + " eating");
right.putDown();
left.putDown();
}
}
}
```

No two **Philosopher**s can successfully **take()** the same chopstick at the same time. In addition, if a chopstick has already been taken by one **Philosopher**, the next **Philosopher** trying to take that same chopstick will block, waiting for it to be released.

The result is a seemingly-innocent program that deadlocks. I've used arrays here instead of collections only because the resulting syntax is cleaner:

```
// concurrent/DiningPhilosophers.java
// Hidden deadlock
```

```
// {ExcludeFromGradle} Gradle has trouble
import java.util.*;
import java.util.concurrent.*;
import onjava.Nap;
public class DiningPhilosophers {
private StickHolder[] sticks;
private Philosopher[] philosophers;
public DiningPhilosophers(int n) {
sticks = new StickHolder[n];
Arrays.setAll(sticks, i -> new StickHolder());
philosophers = new Philosopher[n];
Arrays.setAll(philosophers, i ->
new Philosopher(i,
sticks[i], sticks[(i + 1) % n])); // [1]
// Fix by reversing stick order for this one:
// philosophers[1] = // [2]
// new Philosopher(0, sticks[0], sticks[1]);
Arrays.stream(philosophers)
.forEach(CompletableFuture::runAsync); // [3]
}
```

```
public static void main(String[] args) {
// Returns right away:
new DiningPhilosophers(5); // [4]
// Keeps main() from exiting:
new Nap(3, "Shutdown");
}
}
```

When you stop seeing output, the program is deadlocked. Depending on your machine configuration, however, you might not see deadlocking. It appears this depends on the number of cores[7] on your machine. Two cores don't seem to produce deadlocking, but more than two appear to readily produce deadlock. This behavior makes the example an even better demonstration of deadlock, because you might be writing your program on a machine that has two cores (if that is indeed what causes the issue) and become convinced that it is working correctly, only to have it start deadlocking when you install it on a different machine. And note that just because you can't easily see the deadlock doesn't mean the program can't deadlock on a two-core machine. The program is still deadlock-prone, it just happens rarely—arguably the worst situation because the problem doesn't present itself easily.

In the **DiningPhilosophers** constructor, each **Philosopher** is given a reference to a left and right **StickHolder**. Every **Philosopher** except the last one is initialized by situating that **Philosopher** between the next pair of chopsticks. The last **Philosopher** is given the zeroth chopstick for its right chopstick, so the round table is completed. That's because the last **Philosopher** is sitting right next to the first one, and they both share that zeroth chopstick. **[1]** shows the right-hand stick selected with a modulus of **n**, wrapping the last **Philosopher** around to be next to the first one.

Now all **Philosopher**s can try to eat, each waiting on the **Philosopher** next to them to put down its chopstick.

To start each **Philosopher** running at **[3]**, I call **runAsync()** which means that the **DiningPhilosophers** constructor returns right away at **[4]**. Without anything to keep **main()** from completing, the program simply exits and doesn't do much. The **Nap** object blocks **main()** from exiting, then after three seconds forces an exit from the (presumably) deadlocked program.

In the configuration as given, the **Philosopher**s spend virtually no time thinking. Thus they all compete for chopsticks while trying to eat, and deadlock tends to happen quickly. You can change this:

1. Add more **Philosopher**s by increasing the value at **[4]**.

2. Uncomment line **[1]** in **Philosopher.java**.

Either one will make deadlock less likely, which shows the danger of writing a concurrent program and believing it's safe because it seems to "run OK on my machine." You can easily convince yourself the program is deadlock free, even though it isn't. This example is interesting precisely because it demonstrates that a program can appear to run correctly while still prone to deadlock.

To repair the problem, we observe that deadlock occurs when four conditions are simultaneously met:

1. Mutual exclusion. At least one resource used by the tasks must not be shareable. Here, a chopstick can be used by only one **Philosopher** at a time.

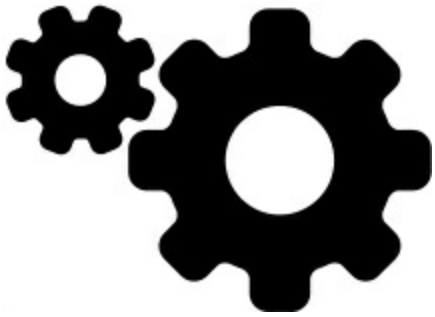
2. At least one task must hold a resource and wait to acquire a resource currently held by another task. That is, for deadlock to occur, a **Philosopher** must hold one chopstick and be waiting for a second one.

3. A resource cannot be preemptively taken away from a task. Tasks only release resources as a normal event. Our **Philosopher**s are polite and they don't grab chopsticks from other

Philosophers.

4. A circular wait can happen, whereby a task waits on a resource held by another task, which in turn is waiting on a resource held by another task, and so on, until one of the tasks is waiting on a resource held by the first task, thus gridlocking everything. In **DiningPhilosophers.java**, the circular wait happens because each **Philosopher** tries to get the right chopstick first, then the left.

Because *all* these conditions must be met to cause deadlock, you must only prevent one of them to prohibit deadlock. In this program, an easy way to prevent deadlock is to break the fourth condition. This condition happens because each **Philosopher** tries to pick up its chopsticks in a particular sequence: first right, then left. Because of that, it's possible for each **Philosopher** to hold its right chopstick while waiting for the left, causing the circular wait condition. However, if one of the **Philosopher**s tries instead to get the left chopstick first, that **Philosopher** never prevents the **Philosopher** on the immediate right from picking up a chopstick, precluding the circular



wait.

In **DiningPhilosophers.java**, uncomment the line at **[1]** and the one following it. This replaces the original **philosophers[1]** with a **Philosopher** that has its chopsticks reversed. By ensuring that the second **Philosopher** picks up and puts down the left chopstick before the right, we remove the potential for deadlock. This is only one solution to the problem. You can also solve it by preventing one of the other conditions.

There is no language support to help prevent deadlock; it's up to you to avoid it by careful design. These are not comforting words to the person who's trying to debug a deadlocking program. And of course the easiest and best way to avoid concurrency problems is *never share resources*—unfortunately that's not always possible.

Constructors are not

Thread-Safe

When you imagine the construction process, it can be easy to think

that it's thread-safe. After all, no one can even see the new object before it finishes initialization, so how could there be contention over that object? Indeed, the Java Language specification (JLS) confidently states:

"There is no practical need for a constructor to be synchronized, because it would lock the object under construction, which is normally not made available to other threads until all constructors for the object have completed their work."

Unfortunately, object construction is as vulnerable to shared-memory concurrency problems as anything else. The mechanisms can be more subtle, however.

Consider the automatic creation of a unique identifier for each object using a **static** field. To test different implementations, we'll start with an interface:

```
// concurrent/HasID.java
public interface HasID {
int getID();
}
```

Then implement that interface in an obvious way:

```
// concurrent/StaticIDField.java
public class StaticIDField implements HasID {
```

```
private static int counter = 0;
private int id = counter++;
public int getID() { return id; }
}
```

This is about as simple and innocuous a class as you can imagine. It doesn't even have an explicit constructor to cause problems. To see what happens when we make multiple concurrent tasks that create these objects, here's a test harness:

```
// concurrent/IDChecker.java
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
import java.util.concurrent.*;
import com.google.common.collect.Sets;
public class IDChecker {
public static final int SIZE = 100_000;
static class MakeObjects
implements Supplier<List<Integer>> {
private Supplier<HasID> gen;
MakeObjects(Supplier<HasID> gen) {
```

```
this.gen = gen;
}
@Override
public List<Integer> get() {
return
Stream.generate(gen)
.limit(SIZE)
.map(HasID::getID)
.collect(Collectors.toList());
}
}
public static void test(Supplier<HasID> gen) {
CompletableFuture<List<Integer>>
groupA = CompletableFuture
.supplyAsync(new MakeObjects(gen)),
groupB = CompletableFuture
.supplyAsync(new MakeObjects(gen));
groupA.thenAcceptBoth(groupB, (a, b) -> {
System.out.println(
Sets.intersection(
```

```
Sets.newHashSet(a),
Sets.newHashSet(b)).size());
}).join();
}
}
```

The **MakeObjects** class is a **Supplier** with a **get()** that produces a **List<Integer>** . This **List** is generated by extracting the **id** from each **HasID** object. The **test()** method creates two parallel **CompletableFuture**s that run **MakeObjects** suppliers, then takes the results of each and uses the Guava library **Sets.intersection()** to find out how many **id**s are common between the two **List<Integer>** (Guava is much faster than using **retainAll()**).

Now we can test the **StaticIDField**:

```
// concurrent/TestStaticIDField.java
public class TestStaticIDField {
public static void main(String[] args) {
IDChecker.test(StaticIDField::new);
}
}
```

```
/* Output:
13287
*/
```

That’s a rather large number of duplicates. Clearly, a plain **static** **int** is not safe to use for construction. Let’s make it thread-safe using an **AtomicInteger**:

```
// concurrent/GuardedIDField.java
import java.util.concurrent.atomic.*;
public class GuardedIDField implements HasID {
private static AtomicInteger counter =
new AtomicInteger();
private int id = counter.getAndIncrement();
public int getID() { return id; }
public static void main(String[] args) {
IDChecker.test(GuardedIDField::new);
}
}
/* Output:
0
*/
```

Constructors have an even more subtle way to share state: through constructor arguments:

```
// concurrent/SharedConstructorArgument.java
import java.util.concurrent.atomic.*;
interface SharedArg {
int get();
}
class Unsafe implements SharedArg {
private int i = 0;
public int get() { return i++; }
}
class Safe implements SharedArg {
private static AtomicInteger counter =
new AtomicInteger();
public int get() {
return counter.getAndIncrement();
}
}
class SharedUser implements HasID {
private final int id;
```

```
SharedUser(SharedArg sa) {
id = sa.get();
}
@Override
public int getID() { return id; }
}
public class SharedConstructorArgument {
public static void main(String[] args) {
Unsafe unsafe = new Unsafe();
IDChecker.test(() -> new SharedUser(unsafe));
Safe safe = new Safe();
IDChecker.test(() -> new SharedUser(safe));
}
}
/* Output:
24838
0
*/
```

Here, the **SharedUser** constructors share the same argument. Even though **SharedUser** is using its argument in a completely innocent

and reasonable fashion, *the way the constructor is called* causes collisions. **SharedUser** cannot even know it is being used this way, much less control it!

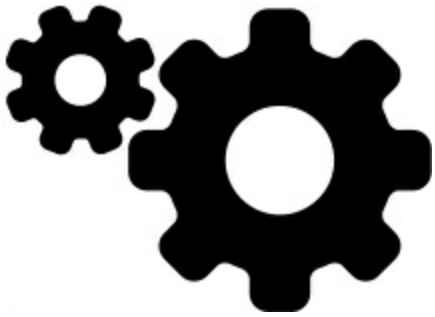
synchronized constructors are not supported by the language, but it's possible to create your own using a **synchronized** block (see the Appendix: Low-Level Concurrency to learn about the **synchronized** keyword). Although the JLS states that "… *it would lock the object under construction*", this is not true—the constructor is effectively a **static** method, so a **synchronized** constructor would actually lock the *class* object. We can reproduce this by creating our own **static** object and locking on that:

```
// concurrent/SynchronizedConstructor.java
import java.util.concurrent.atomic.*;
class SyncConstructor implements HasID {
private final int id;
private static Object
constructorLock = new Object();
SyncConstructor(SharedArg sa) {
synchronized(constructorLock) {
id = sa.get();
```

```
}
}
@Override
public int getID() { return id; }
}
public class SynchronizedConstructor {
public static void main(String[] args) {
Unsafe unsafe = new Unsafe();
IDChecker.test(() ->
new SyncConstructor(unsafe));
}
}
/* Output:
0
*/
```

The shared use of the **Unsafe** class is now safe.

An alternate approach is to make the constructors **private** (thus



preventing inheritance) and provide a **static** *Factory Method* to produce new objects:

```
// concurrent/SynchronizedFactory.java
import java.util.concurrent.atomic.*;
final class SyncFactory implements HasID {
private final int id;
private SyncFactory(SharedArg sa) {
id = sa.get();
}
@Override
public int getID() { return id; }
public static synchronized
SyncFactory factory(SharedArg sa) {
return new SyncFactory(sa);
}
}
```

```
public class SynchronizedFactory {
public static void main(String[] args) {
Unsafe unsafe = new Unsafe();
IDChecker.test(() ->
SyncFactory.factory(unsafe));
}
}
/* Output:
0
*/
```

By synchronizing the **static** *Factory Method* you lock on the class object during construction.

These examples emphasize how insidiously difficult it is to detect and manage shared state in concurrent Java programs. Even if you take the “share nothing” strategy, it’s remarkably easy for accidental sharing to take place.

Effort, Complexity,

Cost

Suppose you are making a pizza. The amount of work required to get from the current step in the process to the next one is represented here

as part of an enumeration:

```
// concurrent/Pizza.java
import java.util.function.*;
import onjava.Nap;
public class Pizza {
public enum Step {
DOUGH(4), ROLLED(1), SAUCED(1), CHEESED(2),
TOPPED(5), BAKED(2), SLICED(1), BOXED(0);
int effort; // Needed to get to the next step
Step(int effort) { this.effort = effort; }
Step forward() {
if(equals(BOXED)) return BOXED;
new Nap(effort * 0.1);
return values()[ordinal() + 1];
}
}
private Step step = Step.DOUGH;
private final int id;
public Pizza(int id) { this.id = id; }
public Pizza next() {
```

```
step = step.forward();
System.out.println("Pizza " + id + ": " + step);
return this;
}
public Pizza next(Step previousStep) {
if(!step.equals(previousStep))
throw new IllegalStateException("Expected " +
previousStep + " but found " + step);
return next();
}
public Pizza roll() { return next(Step.DOUGH); }
public Pizza sauce() { return next(Step.ROLLED); }
public Pizza cheese() { return next(Step.SAUCED); }
public Pizza toppings() { return next(Step.CHEESED); }
public Pizza bake() { return next(Step.TOPPED); }
public Pizza slice() { return next(Step.BAKED); }
public Pizza box() { return next(Step.SLICED); }
public boolean complete() {
return step.equals(Step.BOXED);
}
```

```
@Override
public String toString() {
return "Pizza" + id + ": " +
(step.equals(Step.BOXED)? "complete" : step);
}
}
```

This is another trivial state machine, like **Machina.java**. The endpoint is reached when the pizza is in a box.

If one person is making one pizza, all the steps happen linearly, one after the other:

```
// concurrent/OnePizza.java
import onjava.Timer;
public class OnePizza {
public static void main(String[] args) {
Pizza za = new Pizza(0);
System.out.println(
Timer.duration(() -> {
while(!za.complete())
za.next();
}));
```

```
}
}
/* Output:
Pizza 0: ROLLED
Pizza 0: SAUCED
Pizza 0: CHEESED
Pizza 0: TOPPED
Pizza 0: BAKED
Pizza 0: SLICED
Pizza 0: BOXED
1622
*/
```

The time is in milliseconds and agrees with what we'd expect by adding up the effort for all the steps.

If you made five pizzas this way, you'd expect it to take five times as long. But what if that isn't fast enough for you? We can start by trying the parallel stream approach:

```
// concurrent/PizzaStreams.java
import java.util.*;
import java.util.stream.*;
```

```
import onjava.Timer;
public class PizzaStreams {
static final int QUANTITY = 5;
public static void main(String[] args) {
Timer timer = new Timer();
IntStream.range(0, QUANTITY)
.mapToObj(Pizza::new)
.parallel() // [1]
.forEach(za -> {
while(!za.complete())
za.next();
});
System.out.println(timer.duration());
}
}
/* Output:
Pizza 2: ROLLED
Pizza 0: ROLLED
Pizza 1: ROLLED
Pizza 4: ROLLED
```

Pizza 3: ROLLED

Pizza 2: SAUCED

Pizza 1: SAUCED

Pizza 0: SAUCED

Pizza 4: SAUCED

Pizza 3: SAUCED

Pizza 2: CHEESED

Pizza 1: CHEESED

Pizza 0: CHEESED

Pizza 4: CHEESED

Pizza 3: CHEESED

Pizza 2: TOPPED

Pizza 1: TOPPED

Pizza 0: TOPPED

Pizza 4: TOPPED

Pizza 3: TOPPED

Pizza 2: BAKED

Pizza 1: BAKED

Pizza 0: BAKED

Pizza 4: BAKED

Pizza 3: BAKED

Pizza 2: SLICED

Pizza 1: SLICED

Pizza 0: SLICED

Pizza 4: SLICED

Pizza 3: SLICED

Pizza 2: BOXED

Pizza 1: BOXED

Pizza 0: BOXED

Pizza 4: BOXED

Pizza 3: BOXED

1739

**/*

Now we've created five pizzas in about the same amount of time as it took to create a single pizza. Try removing the line marked **[1]** to verify that it takes five times longer otherwise. Also try changing **QUANTITY** to 4, 8, 10, 16, and 17 to see the difference, and guess why it happens that way.

PizzaStreams.java does all the work inside its **forEach()**.

Would it make any difference if we mapped the individual steps?

```
// concurrent/PizzaParallelSteps.java
import java.util.*;
import java.util.stream.*;
import onjava.Timer;
public class PizzaParallelSteps {
static final int QUANTITY = 5;
public static void main(String[] args) {
Timer timer = new Timer();
IntStream.range(0, QUANTITY)
.mapToObj(Pizza::new)
.parallel()
.map(Pizza::roll)
.map(Pizza::sauce)
.map(Pizza::cheese)
.map(Pizza::toppings)
.map(Pizza::bake)
.map(Pizza::slice)
.map(Pizza::box)
.forEach(za -> System.out.println(za));
System.out.println(timer.duration());
```

```
}
}
/* Output:
Pizza 2: ROLLED
Pizza 0: ROLLED
Pizza 1: ROLLED
Pizza 4: ROLLED
Pizza 3: ROLLED
Pizza 1: SAUCED
Pizza 0: SAUCED
Pizza 2: SAUCED
Pizza 3: SAUCED
Pizza 4: SAUCED
Pizza 1: CHEESED
Pizza 0: CHEESED
Pizza 2: CHEESED
Pizza 3: CHEESED
Pizza 4: CHEESED
Pizza 0: TOPPED
Pizza 2: TOPPED
```

Pizza 1: TOPPED

Pizza 3: TOPPED

Pizza 4: TOPPED

Pizza 1: BAKED

Pizza 2: BAKED

Pizza 0: BAKED

Pizza 4: BAKED

Pizza 3: BAKED

Pizza 0: SLICED

Pizza 2: SLICED

Pizza 1: SLICED

Pizza 3: SLICED

Pizza 4: SLICED

Pizza 1: BOXED

Pizza1: complete

Pizza 2: BOXED

Pizza 0: BOXED

Pizza2: complete

Pizza0: complete

Pizza 3: BOXED

Pizza 4: BOXED

Pizza4: complete

Pizza3: complete

1738

/

The answer is “no,” and in hindsight this is not surprising because each pizza requires the steps to be executed in order, so there’s no opportunity for a further speedup by doing things in discrete steps as in **PizzaParallelSteps.java**.

We can rewrite the example using **CompletableFuture**s:

```
// concurrent/CompletablePizza.java
import java.util.*;
import java.util.concurrent.*;
import java.util.stream.*;
import onjava.Timer;
public class CompletablePizza {
static final int QUANTITY = 5;
public static CompletableFuture<Pizza>
makeCF(Pizza za) {
return CompletableFuture
```

```
.completedFuture(za)
.thenApplyAsync(Pizza::roll)
.thenApplyAsync(Pizza::sauce)
.thenApplyAsync(Pizza::cheese)
.thenApplyAsync(Pizza::toppings)
.thenApplyAsync(Pizza::bake)
.thenApplyAsync(Pizza::slice)
.thenApplyAsync(Pizza::box);
}
public static void
show(CompletableFuture<Pizza> cf) {
try {
System.out.println(cf.get());
} catch(Exception e) {
throw new RuntimeException(e);
}
}
public static void main(String[] args) {
Timer timer = new Timer();
List<CompletableFuture<Pizza>> pizzas =
```

```
IntStream.range(0, QUANTITY)
.mapToObj(Pizza::new)
.map(CompletablePizza::makeCF)
.collect(Collectors.toList());
System.out.println(timer.duration());
pizzas.forEach(CompletablePizza::show);
System.out.println(timer.duration());
}
}
/* Output:
169
Pizza 0: ROLLED
Pizza 1: ROLLED
Pizza 2: ROLLED
Pizza 4: ROLLED
Pizza 3: ROLLED
Pizza 1: SAUCED
Pizza 0: SAUCED
Pizza 2: SAUCED
Pizza 4: SAUCED
```

Pizza 3: SAUCED

Pizza 0: CHEESED

Pizza 4: CHEESED

Pizza 1: CHEESED

Pizza 2: CHEESED

Pizza 3: CHEESED

Pizza 0: TOPPED

Pizza 4: TOPPED

Pizza 1: TOPPED

Pizza 2: TOPPED

Pizza 3: TOPPED

Pizza 0: BAKED

Pizza 4: BAKED

Pizza 1: BAKED

Pizza 3: BAKED

Pizza 2: BAKED

Pizza 0: SLICED

Pizza 4: SLICED

Pizza 1: SLICED

Pizza 3: SLICED

Pizza 2: SLICED

Pizza 4: BOXED

Pizza 0: BOXED

Pizza0: complete

Pizza 1: BOXED

Pizza1: complete

Pizza 3: BOXED

Pizza 2: BOXED

Pizza2: complete

Pizza3: complete

Pizza4: complete

1797

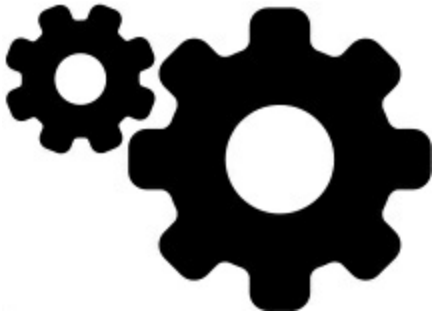
**/*

Parallel streams and **CompletableFuture**s are the most well-developed techniques in the Java concurrency toolbox. You should always choose one of these first. The parallel stream approach is most appropriate when a problem is *embarrassingly parallel*, that is, when it is trivially easy to break your data into identical, easy-to-process pieces (when doing this yourself you must roll up your sleeves and delve into the **Spliterator** documentation).

CompletableFutures work best when the pieces of *work* are distinct. **CompletableFuture** seems more task-oriented than data-oriented.

With the pizza problem, the results don't seem that different—in fact, the parallel stream approach looks cleaner, and for that reason alone I find parallel streams more attractive as a first attempt.

It takes a certain amount of time to make a pizza. No matter what



concurrency approach you use, the best you can do is create **n** pizzas in the same amount of time it takes to create one pizza. It's easy to see that here, but when you're working on a more sophisticated problem you can miss it. Often, a back-of-the-envelope calculation at the beginning of a project quickly shows the maximum possible throughput, which prevents you from spinning your wheels trying to make it faster.

If you really do need to use concurrency, parallel **Stream**s and **CompletableFuture**s might easily produce significant benefits,

but be careful when trying to push it further. The cost and effort can easily become far greater than any advantages you might wring out.

Summary

The only justification for concurrency is “too much waiting.” This can also include the responsiveness of user interfaces, but as Java is effectively not used to build user interfaces, [8] this simply means “your program isn’t running fast enough.”

If concurrency were easy, there would be no reason to avoid it. Because it is hard, you should consider carefully whether it’s worth the effort. Can you speed things up some other way? For example, move to faster hardware (which can be a lot less expensive than lost programmer time) or break your program into pieces and run those pieces on different machines?

Occam’s (or Ockham’s) razor is an oft-misunderstood principle. I’ve seen at least one movie where they define it as “the simplest solution is the correct one,” as if it’s some kind of law. It’s actually a guideline: When faced with a number of approaches, first try the one that requires the fewest assumptions. In the programming world, this has evolved into “try the simplest thing that could possibly work.” When you know something about a particular tool—as you now know

something about concurrency—it can be quite tempting to use it, or to specify ahead of time that your solution must “run fast,” to justify designing in concurrency from the beginning. But our programming version of Occam’s razor says that you should try the simplest approach first (which will also be cheaper to develop) and see if it’s good enough.

As I came from a low-level background (physics and computer engineering), I was prone to imagining the cost of all the little wheels turning. I can’t count the number of times I was certain the simplest approach could never be fast enough, only to discover upon trying that it was more than adequate.

Drawbacks

The main drawbacks to concurrency are:

1. Slowdown while threads wait for shared resources.

2. Additional CPU overhead for thread management.

3. Unrewarded complexity from poor design decisions.

4. Pathologies such as starving, racing, deadlock, and livelock

(multiple threads working individual tasks that the ensemble can't finish).

5. Inconsistencies across platforms. With some examples, I discovered race conditions that quickly appeared on some computers but not on others. If you develop a program on the latter, you might get badly surprised when you distribute it.

In addition, there's an art to the application of concurrency. Java is designed to allow you to create as many objects as necessary to solve your problem—at least in theory.9 However, **Thread**s are not typical objects: each has its own execution environment including a stack and other necessary elements, making it much larger than a normal object. In most environments it's only possible to create a few thousand **Thread** objects before running out of memory. You normally only need a handful of threads to solve a problem, so this is typically not much of a limit, but for some designs it becomes a constraint that might force you to use an entirely different scheme.

The Shared-Memory Pitfall

One of the main difficulties with concurrency occurs because more than one task might be sharing a resource—such as the memory in an object—and you must ensure that multiple tasks don't simultaneously read and change that resource.

I have spent years studying and struggling with concurrency. I've learned you can never believe that a program using shared-memory concurrency is working correctly. You can discover it's wrong, but you can never prove it's right. This is one of the well-know maxims of concurrency. 10

I've met numerous people who have an impressive amount of confidence in their ability to write correct threaded programs. I occasionally start thinking I can get it right, too. For one particular program, I initially wrote it when we only had single-CPU machines. I was able to convince myself that, because of the promises I thought I understood about Java tools, the program was correct. And it didn't fail on my single-CPU machine.

Fast forward to machines with multiple CPUs. I was surprised when the program broke, but that's one of the problems. It's not Java's fault; "write once, run everywhere" cannot possibly extend to concurrency on single vs. multicore machines. It's a fundamental problem with concurrency. You *can* actually discover some concurrency problems on a single-CPU machine, but there are other problems that won't appear until you try it on a multi-CPU machine, where your threads are actually running in parallel.

As another example, the dining philosophers problem can easily be adjusted so deadlock rarely happens, giving you the impression that everything is copacetic.

You can never let yourself become too confident about your programming abilities when it comes to shared-memory concurrency.

This Albatross is Big

If feel overwhelmed about Java concurrency, it turns out you're in good company. Go to the Javadoc page for the **Thread** class. Now look and see how many of the methods are **Deprecated**. These are things that the Java language designers *got wrong*, because they didn't understand enough about concurrency when they were designing the language.

A number of library solutions added in subsequent versions of Java have turned out to be ineffective or even useless. Fortunately, both

parallel **Stream**s and **CompletableFuture**s in Java 8 are quite valuable, but you will still encounter the old solutions when you work with legacy code.

Elsewhere in this book I've talked about one of the essential problems in Java: every failed experiment is forever embedded in the language or library. Java concurrency emphasizes this issue. It's not so much that there are lots of mistakes—although there are those—as there are lots of different attempts to solve the problem. The upside is that these attempts have yielded better and simpler designs. The downside is that you can easily get lost in the older designs before finding your way to the good stuff.

Other Libraries

This chapter focused on the relatively safe and easy tools of parallel

streams and **CompletableFuture**s and only touched on some of the more fine-grained tools in the Java standard library. To keep from overwhelming you, I didn't cover some libraries you might actually use in practice. We used a couple of the **Atomic** classes,

ConcurrentLinkedDeque, **ExecutorService** and **ArrayBlockingQueue**. The Appendix: Low-Level Concurrency covers a few others, but you'll also want to explore the **java.util.concurrent** Javadocs. Be wary, however, as some of the library components have been superseded with new and better ones.

Consider a Language Designed for Concurrency

In general, use concurrency carefully and sparingly. If you need to use it, try as hard as possible to use the most modern approaches: parallel streams or **CompletableFuture**s. These are designed to—as much as possible given Java's world—keep you out of trouble, assuming you don't attempt to share memory.

If your concurrency issues get larger and more complex than what high-level Java constructs can support, consider using a language designed for concurrency. It might be possible to use such a language only for the portions of your program that demand concurrency. At this writing, the purest functional languages on the JVM are Clojure (a version of Lisp) and Frege (an implementation of Haskell). These allow you to write the concurrent parts of your application in that

language and easily interact with your main Java code via the JVM.

Alternatively, you might choose the more complex approach of communicating off-JVM via a *foreign function interface* (FFI) to a different language that is designed for concurrency. 11

Its easy to become attached to a language and contort yourself trying

to do everything using that language. A common example is building HTML/JavaScript user interfaces; those tools are indeed ugly and unpleasant to use, and there are numerous libraries that allow you to generate those by writing code in your favorite language (for example, **Scala.js** allows you to do it in Scala).

Mental convenience is a valid consideration. However, I hope I've shown in this chapter (and the Appendix: Low-Level Concurrency) that Java concurrency is a deep hole from which you might not escape.

The knowledge required to visually inspect code while remembering all the pitfalls is more difficult than for any other part of the Java language.

Regardless of how simple concurrency can seem using a particular

language or library, consider it a black art. There's always something that can bite you when you least expect it.

Further Reading

Java Concurrency in Practice, by Brian Goetz, Tim Peierls, Joshua Bloch, Joseph Bowbeer, David Holmes, and Doug Lea (Addison-Wesley, 2006)—basically, the "who's who" in the Java concurrency world.

Concurrent Programming in Java, Second Edition, by Doug Lea (Addison-Wesley, 2000). Although this book significantly predates Java 5, much of Doug's work became the **java.util.concurrent** libraries, so this book is essential for a complete understanding of concurrency issues. It goes beyond Java and discusses concurrency across languages and technologies. Although it can be obtuse in places, it merits rereading several times (preferably with months in between to internalize the information). Doug is one of the few people in the world who actually understands concurrency, so this is a worthwhile endeavor.

1. Eric Raymond, for example, makes a strong case in *The Art of UNIX Programming* (Addison-Wesley, 2004). ↩

2. It could be argued that trying to bolt concurrency onto a

sequential language is a doomed approach, but you'll have to draw your own conclusions. ↩

3. There is talk of making some similarly fundamental improvements in Java 10 around generics, which would be quite amazing↩

4. This is an interesting, albeit inconsistent, approach. Normally we expect different behavior on a common interface to be expressed with an explicit class↩

5. And no, there can never be a pure functional Java. The best we can hope for is an entirely new language that runs on the JVM.↩

6. You can also have *livelock* when two tasks are able to change their state so that they don't block, but they never make any useful progress.↩

7. Not hyperthreads; there are often two hyperthreads per core and when asked for the number of cores, the version of Java used for this book would report the number of hyperthreads instead. Hyperthreads produce much faster context switching, but only actual cores do the work. ↩

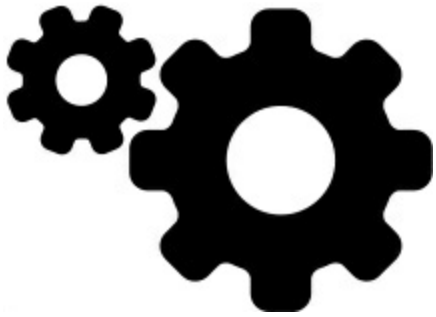
8. The libraries are there and the language was intended to be used for this purpose but in practice it happens so rarely as to be able

to say “never.” ↩

9. Creating millions of objects for finite-element analysis in engineering, for example, might not be practical in Java without the *Flyweight* design pattern.↩

10. In science, a theory is never proved, but to be valid it must be *falsifiable*. With concurrency, we can’t even get falsifiability most of the time.↩

11. Although the **Go** language shows promise with FFIs, at this writing it did not provide a solution across all platforms.↩



Patterns

The object-oriented *design patterns* movement is chronicled in the book *Design Patterns*, by Gamma, Helm, Johnson & Vlissides (Addison-Wesley

1995). 1

That book shows 23 different solutions to particular classes of problems. In this chapter, the basic concepts of design patterns are introduced through examples. This should whet your appetite to read *Design Patterns* (a source of what has become an important vocabulary for OOP programmers).

The latter part of this chapter contains an example of the design evolution process, starting with an initial solution and moving through the logic and process of evolving the solution to more appropriate designs. The program shown (a trash sorting simulation) has evolved over time, and you can look at that evolution as a prototype for the way your own design can start as an adequate solution to a particular problem and evolve into a flexible approach to a class of problems.

The Pattern Concept

Initially, you can think of a pattern as an especially clever and insightful way of solving a particular class of problems. That is, it looks like many people have worked out all the angles of a problem and have come up with the most general, flexible solution for it. The problem could be one you have seen and solved before, but your solution probably didn’t have the kind of completeness you’ll see embodied in a

pattern.

Although they're called "design patterns," they really aren't tied to the realm of design. A pattern seems to stand apart from the traditional way of thinking about analysis, design, and implementation. Instead, a pattern embodies a complete idea within a program, and thus it can sometimes appear at the analysis phase or high-level design phase. Because a pattern has a direct implementation in code, you might not expect it to show up before low-level design or implementation (and often you don't realize you need a particular pattern until you get to those phases).

The basic concept of a pattern can also be seen as the basic concept of program design: adding a layer of abstraction. Whenever you abstract something you're isolating particular details, and one of the most compelling motivations behind this is to:

Separate things that change from things

that stay the same.

Another way to put this is that once you find some part of your program that's likely to change for one reason or another, you'll keep those changes from propagating other changes throughout your code. If code is simpler to understand, it is cheaper to maintain.

Often, the most difficult part of developing an elegant and cheap-to-maintain design is in discovering what I call *the vector of change*. (Here, "vector" refers to the maximum gradient and not a collection class.) This means finding the most important thing that changes in your system, or put another way, discovering where your greatest cost is. Once you discover the vector of change, you have the focal point around which to structure your design.

So the goal of design patterns is to isolate changes in your code. If you look at it this way, you've already seen design patterns in this book. For example, inheritance can be thought of as a design pattern (albeit one implemented by the compiler). It allows you to express differences in behavior (that's the thing that changes) in objects that all have the same interface (that's what stays the same). Composition can also be considered a pattern, since it allows you to change—dynamically or statically—the objects that implement your class, and thus the way that class works.

You've also seen another pattern that appears in *Design Patterns*: the *iterator* (Java 1.0 and 1.1 capriciously called it the **Enumeration**; Java 2 collections use **Iterator**). This hides the particular implementation of the collection as you're stepping through and

selecting the elements one by one. The iterator allows you to write generic code that performs an operation on all elements in a sequence without regard to the way that sequence is built. Thus your generic code can be used with any collection that can produce an iterator.

Although patterns are very helpful, some people assert that:

Design patterns represent language failures.

This is an important insight. Just because a pattern makes sense in C++, for example it might not be necessary in Java or in another language. For that reason, just because a pattern appears in the *Design Patterns* book, it doesn't mean it is helpful when applied to your language.

I find the "language failure" observation useful, but I also think it's an oversimplification. If you're trying to solve a particular problem and the language doesn't have direct support for the technique you're using, you could argue that it's a failure of the language. But how often

do you actually use that particular technique? Perhaps the balance is

just right: while you must work harder when you use the technique, maybe you don’t need it enough to justify including support in the language. On the other hand, without language support, it might be too messy to use the technique on a regular basis, but with language support you might change the way you program (Java 8 streams achieve this, for example).

Singleton

Possibly the simplest design pattern is the *Singleton*, which is a way to provide one and only one instance of an object. This is used in the Java libraries, but here’s a more direct example:

```
// patterns/SingletonPattern.java
interface Resource {
int getValue();
void setValue(int x);
}
// Since this isn't inherited from a Cloneable
// base class and cloneability isn't added,
// making it final prevents cloneability from
// being added through inheritance. This also
// implements thread-safe lazy initialization:
```

```
final class Singleton {
private static final class
ResourceImpl implements Resource {
private int i;
private ResourceImpl(int i) {
this.i = i;
}
public synchronized int getValue() {
return i;
}
public synchronized void setValue(int x) {
i = x;
}
}
private static class ResourceHolder {
private static Resource resource =
new ResourceImpl(47);
}
public static Resource getResource() {
return ResourceHolder.resource;
```

```
}
}
public class SingletonPattern {
public static void main(String[] args) {
Resource r = Singleton.getResource();
System.out.println(r.getValue());
Resource s2 = Singleton.getResource();
s2.setValue(9);
System.out.println(r.getValue());
try {
// Can't do this: compile-time error.
// Singleton s3 = (Singleton)s2.clone();
} catch(Exception e) {
throw new RuntimeException(e);
}
}
}
/* Output:
47
9
```

*/

The key to creating a singleton is to prevent the client programmer from creating an object directly. Here, this is accomplished by making the implementation of **Resource** a private class inside **Singleton**.

At this point, you decide how you're going to create your object. Here, it's created on demand, the first time the client programmer asks for one. The object should be stored privately, accessed only through the **public getResource()** method.

The reason the object is created lazily is that the nested **private** class **resourceHolder** is not loaded until it is first referenced (within **getResource()**). When it loads, the **static** initializers are called. Because of the way the JVM works, this **static** initialization is thread-safe. To complete the thread-safety, the getters and setters in **Resource** are **synchronized**.

For non-lazy (a.k.a. *eager*) initialization, simply move the definition of **resource** outside of **ResourceHolder**.

Java also allows the creation of objects through cloning (see the

Appendix: Passing and Returning Objects). In this example, making the class **final** prevents cloning. Since **Singleton** is inherited directly from **Object**, the **clone()** method remains **protected** so it cannot be used (doing so produces a compile-time error). However, if you're inheriting from a class hierarchy that has overridden **clone()** as **public** and implemented **Cloneable**, the way to prevent cloning is to override **clone()** and throw a **CloneNotSupportedException** as described in the Appendix: Passing and Returning Objects. (You can also override **clone()** and simply return **this**, but that's deceiving since the client programmer thinks they are cloning the object, but instead are still dealing with the original.)

Note you aren't restricted to creating only one object. This is also a technique to create a limited pool of objects. In that situation, however, you can be confronted with the problem of sharing objects in the pool. If this is an issue, you can create a solution involving a check-out and check-in of the shared objects.

Classifying Patterns

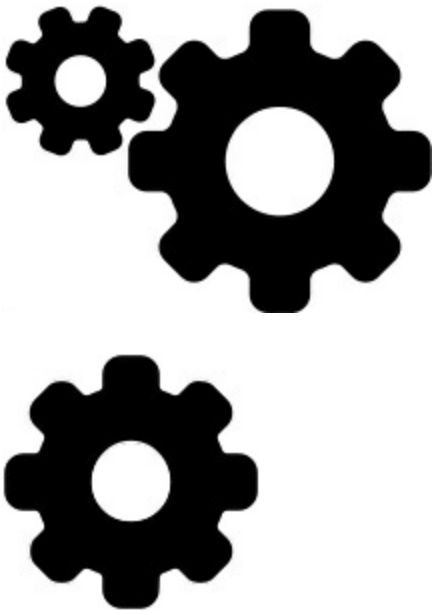
The *Design Patterns* book discusses 23 different patterns, classified under three purposes (all of which revolve around the particular aspect that can vary). The three purposes are:

1. **Creational**: How an object is created. This often involves isolating the details of object creation so your code isn't dependent on what types of objects there are and thus doesn't change when you add a new type of object. The *Singleton* is classified as a creational pattern, and later in this chapter you'll see examples of *Factory Method*.
2. **Structural**: Designing objects to satisfy particular project constraints. These work with the way objects are connected with other objects to ensure that changes in the system don't require changes to those connections.
3. **Behavioral**: Objects that handle particular types of actions within a program. These encapsulate processes to perform, such as interpreting a language, fulfilling a request, moving through a sequence (as in an iterator), or implementing an algorithm. This chapter contains examples of the *Observer* and the *Visitor* patterns.

The *Design Patterns* book has a section on each of its 23 patterns along with one or more examples for each, typically in C++ but sometimes in SmallTalk. This chapter does not repeat all the patterns shown in *Design Patterns* since that book stands on its own and

should be studied separately. Instead, you'll see some examples that should provide you with a decent feel for what patterns are about and why they are so important.

After years of looking at these things, it began to occur to me that the patterns themselves use basic principles of organization, other than (and more fundamental than) those described in *Design Patterns*. These principles are based on the structure of the implementations, which is where I have seen great similarities between patterns (more than those expressed in *Design Patterns*). Although we generally try to avoid implementation in favor of interface, I find it's often easier to



think about, and especially to learn about, the patterns in terms of these structural principles. This chapter will attempt to present the patterns based on their structure instead of the categories presented in

Design Patterns.

Building Application

Frameworks

An application framework allows you to start with a class or set of classes and create a new application, reusing most of the code in the existing classes and overriding one or more methods to customize the application to your needs.

Template Method

A fundamental concept in the application framework is the *Template Method*, which is typically hidden beneath the covers and drives the application by calling the various methods in the base class (some of which you have overridden to create the application).

An important characteristic of the Template Method is it is defined in the base class and cannot be changed. It's sometimes a **private** method but it's virtually always **final**. It calls other base-class methods (the ones you override) to do its job, but it is usually called only as part of an initialization process (and thus the client programmer isn't necessarily able to call it directly).

// patterns/TemplateMethod.java

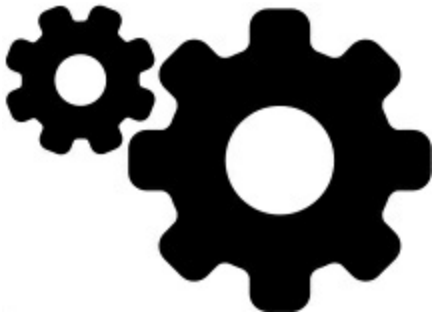
// Simple demonstration of Template Method

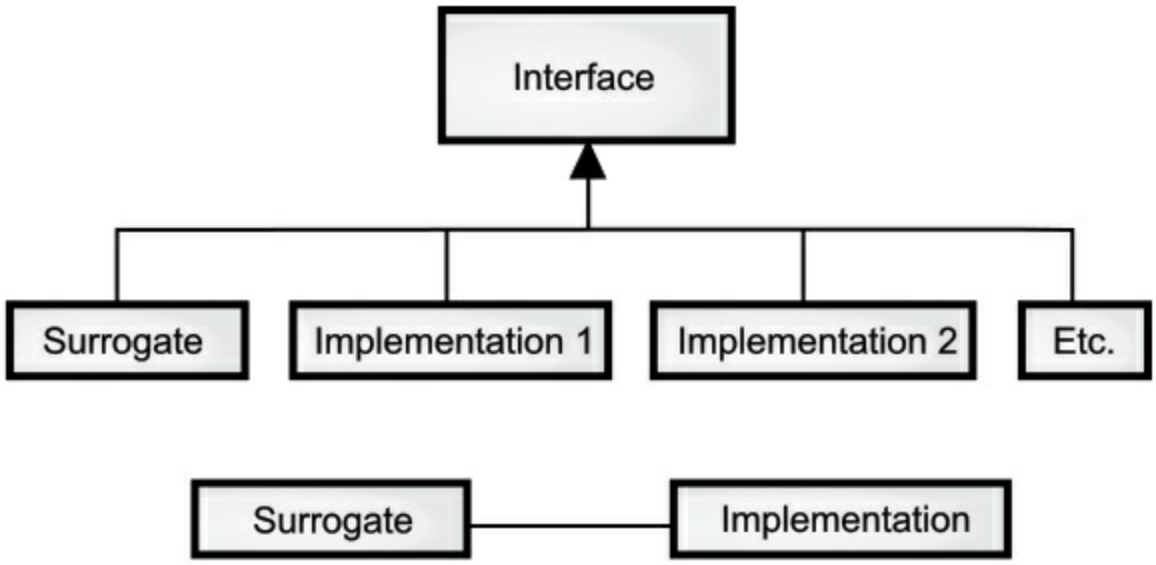
```
import java.util.stream.*;
abstract class ApplicationFramework {
ApplicationFramework() {
templateMethod();
}
abstract void customize1();
abstract void customize2();
// "private" means automatically "final":
private void templateMethod() {
IntStream.range(0, 5).forEach(
n -> { customize1(); customize2(); });
}
}
// Create a new "application":
class MyApp extends ApplicationFramework {
@Override
void customize1() {
System.out.print("Hello ");
}
@Override
```

```
void customize2() {
System.out.println("World!");
}
}
public class TemplateMethod {
public static void main(String[] args) {
new MyApp();
}
}
/* Output:
Hello World!
Hello World!
Hello World!
Hello World!
Hello World!
*/
```

The base-class constructor is responsible for performing the necessary initialization, then starting the “engine” (the template method) that runs the application (in a GUI application, this “engine” is the main event loop). The client programmer simply provides definitions for

customize1() and **customize2()** and the “application” is ready





to run.

Fronting for an

Implementation

Both *Proxy* and *Bridge* provide a surrogate class you use in your code; the real class that does the work is hidden behind this surrogate class. When you call a method in the surrogate, it simply turns around and calls the method in the implementing class. These two patterns are so

similar that the *Proxy* is simply a special case of *Bridge*. One is tempted to just lump the two together into a pattern called *Surrogate*, but the term “proxy” has a long-standing and specialized meaning, which probably explains the reason for the two different patterns.

The basic idea is simple: from a base class, the surrogate is derived along with the class or classes that provide the actual implementation: When a surrogate object is created, it is given an implementation to send all of its method calls.

Structurally, the difference between *Proxy* and *Bridge* is simple: a *Proxy* has only one implementation, while *Bridge* has more than one.

The application of the patterns is considered (in *Design Patterns*) to be distinct: *Proxy* is used to control access to its implementation, while *Bridge* allows you to change the implementation dynamically. However, if you expand your notion of “controlling access to implementation” then the two fit neatly together.

Proxy

If we implement *Proxy* by following the above diagram, it looks like

this:

```
// patterns/ProxyDemo.java
// Simple demonstration of the Proxy pattern
interface ProxyBase {
void f();
void g();
void h();
}
class Proxy implements ProxyBase {
private ProxyBase implementation;
Proxy() {
implementation = new Implementation();
}
// Pass method calls to the implementation:
@Override
public void f() { implementation.f(); }
@Override
public void g() { implementation.g(); }
@Override
public void h() { implementation.h(); }
```

```
}
class Implementation implements ProxyBase {
public void f() {
System.out.println("Implementation.f()");
}
public void g() {
```

```
System.out.println("Implementation.g()");
}
public void h() {
System.out.println("Implementation.h()");
}
}
public class ProxyDemo {
public static void main(String[] args) {
Proxy p = new Proxy();
p.f();
p.g();
```

```
p.h();
}
}
/* Output:
Implementation.f()
Implementation.g()
Implementation.h()
*/
```

It isn’t necessary that **Implementation** have the same interface as **Proxy**; as long as **Proxy** is somehow “speaking for” the class it refers method calls to, then the basic idea is satisfied. However, it is convenient to have a common interface so **Implementation** is forced to fulfill all the methods that **Proxy** must call.

State

The *State* pattern adds more implementations to *Proxy*, along with a way to switch from one implementation to another during the lifetime of the surrogate:

```
// patterns/StateDemo.java
// Simple demonstration of the State pattern
interface StateBase {
```

```
void f();
void g();
void h();
void changeImp(StateBase newImp);
}
class State implements StateBase {
private StateBase implementation;
State(StateBase imp) {
implementation = imp;
}
@Override
public void changeImp(StateBase newImp) {
implementation = newImp;
}
// Pass method calls to the implementation:
@Override
public void f() { implementation.f(); }
@Override
public void g() { implementation.g(); }
@Override
```

```
public void h() { implementation.h(); }
}
class Implementation1 implements StateBase {
@Override
public void f() {
System.out.println("Implementation1.f()");
}
@Override
public void g() {
System.out.println("Implementation1.g()");
}
@Override
public void h() {
System.out.println("Implementation1.h()");
}
@Override
public void changeImp(StateBase newImp) {}
}
class Implementation2 implements StateBase {
@Override
```

```
public void f() {
System.out.println("Implementation2.f()");
}
@Override
public void g() {
System.out.println("Implementation2.g()");
}
@Override
public void h() {
System.out.println("Implementation2.h()");
}
@Override
public void changeImp(StateBase newImp) {}
}
public class StateDemo {
static void test(StateBase b) {
b.f();
b.g();
b.h();
}
```

```
public static void main(String[] args) {
StateBase b =
new State(new Implementation1());
test(b);
b.changeImp(new Implementation2());
test(b);
}
}
/* Output:
Implementation1.f()
Implementation1.g()
Implementation1.h()
Implementation2.f()
Implementation2.g()
Implementation2.h()
*/
```

In **main()**, the first implementation is used for a bit, then the second implementation is swapped in.

The difference between *Proxy* and *State* is in the problems they solve.

The common uses for *Proxy* as described in *Design Patterns* are:

1. **Remote proxy**. This proxies for an object in a different address space. A remote proxy is created for you automatically by the *Remote Method Invocation* (RMI) compiler **rmic**.

2. **Virtual proxy**. This provides “lazy initialization” to create expensive objects on demand.

3. **Protection proxy**. Used when you don’t want the client programmer to have full access to the proxied object.

4. **Smart reference**. To add additional actions when the proxied object is accessed. For example, to keep track of the number of references held for a particular object, to implement the *copy-on-write* idiom and prevent object aliasing. A simpler example is keeping track of the number of calls to a particular method.

You can look at a Java reference as a kind of protection proxy, since it controls access to the actual object on the heap (and ensures, for example, that you don’t use a **null** reference).

In *Design Patterns*, *Proxy* and *Bridge* are not seen as related to each other because the two are given (what I consider arbitrarily) different

structures. *Bridge*, in particular, uses a separate implementation hierarchy but this seems unnecessary to me, unless you have decided that the implementation is not under your control (certainly a possibility, but if you own all the code there's no reason not to benefit from the elegance and helpfulness of the single base class). In addition, *Proxy* need not use the same base class for its implementation, as long as the proxy object is controlling access to the object for which it "fronts." Regardless of the specifics, in both *Proxy* and *Bridge* a surrogate is passing method calls through to an implementation object.

StateMachine

While *Bridge* allows the client programmer to change the implementation, *StateMachine* imposes a structure to automatically change the implementation from one object to the next. The current implementation represents the state that a system is in, and the system behaves differently from one state to the next (because it uses *Bridge*). Basically, this is a "state machine" using objects.

The code that moves the system from one state to the next is often a *Template Method*, as seen in this example:

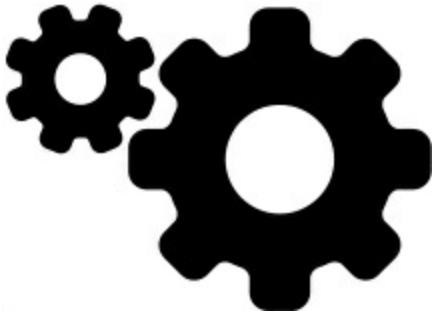
// patterns/state/StateMachineDemo.java

```
// The StateMachine pattern and Template method
// {java patterns.state.StateMachineDemo}
package patterns.state;
import onjava.Nap;
interface State {
void run();
}
abstract class StateMachine {
protected State currentState;
protected abstract boolean changeState();
// Template method:
protected final void runAll() {
while(changeState()) // Customizable
currentState.run();
}
}
// A different subclass for each state:
class Wash implements State {
@Override
public void run() {
```

```
System.out.println("Washing");
new Nap(0.5);
}
}
class Spin implements State {
@Override
public void run() {
System.out.println("Spinning");
new Nap(0.5);
}
}
class Rinse implements State {
@Override
public void run() {
System.out.println("Rinsing");
new Nap(0.5);
}
}
class Washer extends StateMachine {
private int i = 0;
```

```
// The state table:
private State[] states = {
new Wash(), new Spin(),
new Rinse(), new Spin(),
};
Washer() { runAll(); }
@Override
public boolean changeState() {
if(i < states.length) {
// Change the state by setting the
// surrogate reference to a new object:
currentState = states[i++];
return true;
} else
return false;
}
}
```

```
public class StateMachineDemo {
public static void main(String[] args) {
new Washer();
}
}
/* Output:
Washing
Spinning
Rinsing
```



```
Spinning
*/
```

Here, the class that controls the states (**StateMachine** in this case) is responsible for deciding the next state. However, the state objects themselves may also decide what state to move to next, typically based on some kind of input to the system. This is the more flexible solution.

Factories:

Encapsulating Object

Creation

When you discover you must add new types to a system, a sensible first step is to use polymorphism to create a common interface to those new types. This separates the rest of the code in your system from the knowledge of the specific types you are adding. New types may be added without disturbing existing code … or so it seems. At first it would appear that the only place you must change the code in such a design is the place where you inherit a new type, but this is not quite true. You must still create an object of your new type, and at the point of creation you must specify the exact constructor to use. Thus, if the code that creates objects is distributed throughout your application, you have the same problem when adding new types—you must still chase down all the points of your code where type matters. It happens to be the *creation* of the type that matters here rather than the *use* of the type (which is taken care of by polymorphism), but the effect is the same: adding a new type can cause problems.

The solution is to force the creation of objects to occur through a common *factory* rather than to allow the creational code to spread throughout your system. If all the code in your program must go

through this factory to create one of your objects, then when you add a new class, you modify the factory.

Since every object-oriented program creates objects, and since it's very likely you will extend your program by adding new types, factories are one of the most universally useful kinds of design patterns.

As an example, let's revisit the **Shape** system. First, we need a basic framework to use with all the examples. If a **Shape** cannot be created, we need an appropriate exception:

```
// patterns/shapes/BadShapeCreation.java
package patterns.shapes;
public class BadShapeCreation
extends RuntimeException {
public BadShapeCreation(String msg) {
super(msg);
}
}
```

Next, the basic **Shape** class:

```
// patterns/shapes/Shape.java
package patterns.shapes;
public class Shape {
```

```
private static int counter = 0;
private int id = counter++;
@Override
public String toString() {
return
getClass().getSimpleName() + "[" + id + "]";
}
public void draw() {
System.out.println(this + " draw");
}
public void erase() {
System.out.println(this + " erase");
}
}
```

This automatically creates a unique **id** for each **Shape**.

toString() uses runtime information to discover the name of the specific **Shape** subtype.

Now we can quickly create some **Shape** classes:

```
// patterns/shapes/Circle.java
package patterns.shapes;
```

public class Circle **extends** Shape {}

// patterns/shapes/Square.java

package patterns.shapes;

public class Square **extends** Shape {}

// patterns/shapes/Triangle.java

package patterns.shapes;

public class Triangle **extends** Shape {}

A *Factory* is a class that has a method to create objects. We have several example versions so we'll define an **interface**:

// patterns/shapes/FactoryMethod.java

package patterns.shapes;

public interface FactoryMethod {

Shape create(String type);

}

create() takes an argument that allows it to determine what type of **Shape** to create; it happens to be a **String** here but it could be any set of data. The initialization data (**String**s, in this case) for the objects will presumably come from somewhere outside the system. This will exercise the factory:

// patterns/shapes/FactoryTest.java

```
package patterns.shapes;
import java.util.stream.*;
public class FactoryTest {
public static void test(FactoryMethod factory) {
Stream.of("Circle", "Square", "Triangle",
"Square", "Circle", "Circle", "Triangle")
.map(factory::create)
.peek(Shape::draw)
.peek(Shape::erase)
.count(); // Terminal operation
}
}
```

In **main()**, remember that a **Stream** doesn't do anything until you put a terminal operation on the end. Here, the value of **count()** is thrown away.

One approach to creating a *Factory* is to explicitly create each type:

```
// patterns/ShapeFactory1.java
// A simple static factory method
import java.util.*;
import java.util.stream.*;
```

```
import patterns.shapes.*;
public class ShapeFactory1 implements FactoryMethod {
public Shape create(String type) {
switch(type) {
case "Circle": return new Circle();
case "Square": return new Square();
case "Triangle": return new Triangle();
default:
throw new BadShapeCreation(type);
}
}
public static void main(String[] args) {
FactoryTest.test(new ShapeFactory1());
```

```
}
}
/* Output:
Circle[0] draw
```

Circle[0] erase

Square[1] draw

Square[1] erase

Triangle[2] draw

Triangle[2] erase

Square[3] draw

Square[3] erase

Circle[4] draw

Circle[4] erase

Circle[5] draw

Circle[5] erase

Triangle[6] draw

Triangle[6] erase

**/*

create() is now the only other code in the system that needs changing when a new type of **Shape** is added.

A Dynamic Factory

The **static create()** method in the previous example forces all the creation operations to be focused in one spot, so that's the only place you must change the code when you add a new type of **Shape**.

This is certainly a reasonable solution, as it throws a box around the process of creating objects. However, it would be nice if you didn't have to modify anything when you add a new class. The following version uses reflection to dynamically load the **Constructor** for a **Shape** into the **factories** list the first time it is needed:

```
// patterns/ShapeFactory2.java
import java.util.*;
import java.lang.reflect.*;
import java.util.stream.*;
import patterns.shapes.*;
public class ShapeFactory2 implements FactoryMethod {
Map<String, Constructor> factories =
new HashMap<>();
static Constructor load(String id) {
System.out.println("loading " + id);
try {
return Class.forName("patterns.shapes." + id)
.getConstructor();
} catch(ClassNotFoundException |
NoSuchMethodException e) {
```

```
throw new BadShapeCreation(id);
}
}
public Shape create(String id) {
try {
return (Shape)factories
.computeIfAbsent(id, ShapeFactory2::load)
.newInstance();
} catch(InstantiationException |
IllegalAccessException |
InvocationTargetException e) {
throw new BadShapeCreation(id);
}
}
public static void main(String[] args) {
FactoryTest.test(new ShapeFactory2());
}
}
/* Output:
loading Circle
```

Circle[0] draw

Circle[0] erase

loading Square

Square[1] draw

Square[1] erase

loading Triangle

Triangle[2] draw

Triangle[2] erase

Square[3] draw

Square[3] erase

Circle[4] draw

Circle[4] erase

Circle[5] draw

Circle[5] erase

Triangle[6] draw

Triangle[6] erase

*/

As before, the **create()** method generates new **Shape**s based on the **String** argument you pass it, but here it does so by looking up the **String** as a key in a **HashMap**. The value returned is a **Constructor**, which is used to create the new **Shape** object by calling **newInstance()**.

However, when you begin running the program the **factories** map is empty. **create()** uses **Map**'s **computeIfAbsent()** method to either find the **Constructor** if it's already in the **Map**, or compute it using **load()** and insert it in the **Map** if it isn't. You can see from the output that each specific type of **Shape** is only loaded the first time it is requested, and from then on it is simply retrieved from the **Map**.

Polymorphic Factories

The *Design Patterns* book emphasizes that the reason for the *Factory Method* pattern is that different types of factories can be subclassed from the basic factory. Here is the example again, modified so the factory methods are in separate classes:

```
// patterns/ShapeFactory3.java
// Polymorphic factory methods
import java.util.*;
import java.util.function.*;
```

```
import java.util.stream.*;
import patterns.shapes.*;
interface PolymorphicFactory {
Shape create();
}
class RandomShapes implements Supplier<Shape> {
private final PolymorphicFactory[] factories;
private Random rand = new Random(42);
RandomShapes(PolymorphicFactory... factories) {
this.factories = factories;
}
public Shape get() {
return factories[
rand.nextInt(factories.length)].create();
}
}
public class ShapeFactory3 {
public static void main(String[] args) {
RandomShapes rs = new RandomShapes(
Circle::new, Square::new, Triangle::new
```

```
);
Stream.generate(rs)
.limit(6)
.peek(Shape::draw)
.peek(Shape::erase)
.count();
}
}
/* Output:
Triangle[0] draw
Triangle[0] erase
Circle[1] draw
Circle[1] erase
Circle[2] draw
Circle[2] erase
Triangle[3] draw
Triangle[3] erase
Circle[4] draw
Circle[4] erase
Square[5] draw
```

Square[5] erase

*/

RandomShapes is a **Supplier<Shape>** so it can be used to create a **Stream** with **Stream.generate()**. Its constructor takes a variable argument list of **PolymorphicFactory** objects. A variable argument list comes through as an array, so that is how the list is stored internally. The **get()** method randomly indexes into this array and calls **create()** on the result to produce a new **Shape**.

The **RandomShapes** constructor is the only place that requires changing when we add a new type of **Shape**. Notice that this constructor expects **Supplier<Shape>** s. We pass it **Shape** constructor method references, which fulfill the **Supplier<Shape>** contract because Java 8 supports *structural conformance*.

Whereas **ShapeFactory2.java** could potentially throw exceptions, there are none in this approach—it is deterministic at compile time.

Abstract Factories

The *Abstract Factory* pattern looks like the factory objects we've seen previously, with not one but several factory methods. Each of the factory methods creates a different kind of object. The idea is that at the point of creation of the factory object, you decide how all the objects created by that factory are used. The example given in *Design Patterns* implements portability across various *graphical user interfaces* (GUIs): you create a factory object appropriate to the GUI that you're working with, and from then on when you ask it for a menu, button, slider, etc., it will automatically create the appropriate version of that item for the GUI. Thus you're able to isolate, in one place, the effect of changing from one GUI to another.

As another example suppose you are creating a general-purpose gaming environment to support different types of games. Here's how it might look using an abstract factory:

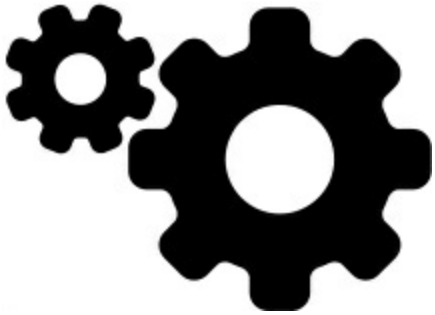
```
// patterns/abstractfactory/GameEnvironment.java
// An example of the Abstract Factory pattern
// {java patterns.abstractfactory.GameEnvironment}
package patterns.abstractfactory;
import java.util.function.*;
interface Obstacle {
```

```
void action();
}
interface Player {
void interactWith(Obstacle o);
}
class Kitty implements Player {
@Override
public void interactWith(Obstacle ob) {
System.out.print("Kitty has encountered a ");
ob.action();
}
}
class KungFuGuy implements Player {
@Override
public void interactWith(Obstacle ob) {
System.out.print("KungFuGuy now battles a ");
ob.action();
}
}
class Puzzle implements Obstacle {
```

```
@Override
public void action() {
System.out.println("Puzzle");
}
}
class NastyWeapon implements Obstacle {
@Override
public void action() {
System.out.println("NastyWeapon");
}
}
// The Abstract Factory:
class GameElementFactory {
Supplier<Player> player;
Supplier<Obstacle> obstacle;
}
// Concrete factories:
class KittiesAndPuzzles
extends GameElementFactory {
KittiesAndPuzzles() {
```

```
player = Kitty::new;
obstacle = Puzzle::new;
}
}
class KillAndDismember
extends GameElementFactory {
KillAndDismember() {
player = KungFuGuy::new;
obstacle = NastyWeapon::new;
}
}
public class GameEnvironment {
private Player p;
private Obstacle ob;
public
GameEnvironment(GameElementFactory factory) {
p = factory.player.get();
ob = factory.obstacle.get();
}
public void play() {
```

```
p.interactWith(ob);
}
public static void main(String[] args) {
GameElementFactory
kp = new KittiesAndPuzzles(),
kd = new KillAndDismember();
```



```
GameEnvironment
g1 = new GameEnvironment(kp),
g2 = new GameEnvironment(kd);
g1.play();
g2.play();
}
}
/* Output:
Kitty has encountered a Puzzle
KungFuGuy now battles a NastyWeapon
```

*/

In this environment, **Player** objects interact with **Obstacle** objects, but there are different types of players and obstacles depending on the kind of game you're playing. You determine the kind of game by choosing a particular **GameElementFactory**, then the **GameEnvironment** controls the setup and play of the game. In this example, the setup and play is very simple, but those activities (the *initial conditions* and the *state change*) can determine much of the game's outcome. Here, **GameEnvironment** is not designed for inheritance, although it could very possibly make sense to do that. This also contains examples of *Double Dispatching* and the *Factory Method*, both of which are explained later.

Function Objects

A *Function Object* encapsulates a function. The point is to decouple the choice of function to be called from the site where that function is called.

This term is mentioned but not used in *Design Patterns*. However, the theme of the *Function Object* is repeated in a number of patterns in that book.

Command

This is the *Function Object* in its purest sense: a method that's an object. You pass a *Function Object* to a method or an object as a parameter, to vary the operation.

Before Java 8, to produce the effect of a standalone functions you had to explicitly wrap a method into an object, which required a lot of ceremony. With Java 8 lambdas, the *Command* pattern becomes almost trivial:

```
// patterns/CommandPattern.java
import java.util.*;
public class CommandPattern {
public static void main(String[] args) {
List<Runnable> macro = Arrays.asList(
() -> System.out.print("Hello "),
() -> System.out.print("World! "),
() -> System.out.print("I'm the command pattern!")
);
```

```
macro.forEach(Runnable::run);
}
}
/* Output:
Hello World! I'm the command pattern!
*/
```

The primary point of *Command* is to allow you to hand a desired action to a method or object. In the above example, this object is **macro**, and *Command* provides a way to queue a set of actions to be performed collectively. Here, it allows you to dynamically create new behavior, something you can normally only do by writing new code but in the above example could be done by interpreting a script (see the *Interpreter* pattern if what you must do gets very complex).

Design Patterns says that “Commands are an object-oriented replacement for callbacks.” However, I think the word “back” is an

essential part of the concept of callbacks. That is, I think a callback actually reaches back to the creator of the callback. On the other hand,

with a *Command* object you typically just create it and hand it to some method or object, and are not otherwise connected over time to the *Command* object. That's my take on it, anyway. Later in this chapter, I combine a group of design patterns under the heading of "callbacks."

Strategy

Strategy appears to be a family of *Command* classes, all inherited from the same base. But if you look at *Command*, you'll see it has the same structure: a hierarchy of *Function Object* s. The difference is in the way this hierarchy is used. As seen in **io/DirList.java**, you use *Command* to solve a particular problem—in that case, selecting files from a list. The "thing that stays the same" is the body of the method that's called, and the part that varies is isolated in the *Function Object*. I suggest that *Command* provides flexibility while you're writing the program, whereas *Strategy*'s flexibility is at run-time. Nonetheless, it seems a rather fragile distinction.

Strategy also adds a "Context" which can be a surrogate class that controls the selection and use of the particular strategy object—just like *Bridge*! Here's what it looks like:

```
// patterns/strategy/StrategyPattern.java
// {java patterns.strategy.StrategyPattern}
```

```
package patterns.strategy;
import java.util.function.*;
import java.util.*;
// The common strategy base type:
class FindMinima {
Function<List<Double>, List<Double>> algorithm;
}
// The various strategies:
class LeastSquares extends FindMinima {
LeastSquares() {
// Line is a sequence of points (Dummy data):
algorithm = (line) -> Arrays.asList(1.1, 2.2);
}
}
class Perturbation extends FindMinima {
Perturbation() {
algorithm = (line) -> Arrays.asList(3.3, 4.4);
}
}
class Bisection extends FindMinima {
```

```
Bisection() {
algorithm = (line) -> Arrays.asList(5.5, 6.6);
}
}
// The "Context" controls the strategy:
class MinimaSolver {
private FindMinima strategy;
MinimaSolver(FindMinima strat) {
strategy = strat;
}
List<Double> minima(List<Double> line) {
return strategy.algorithm.apply(line);
}
void changeAlgorithm(FindMinima newAlgorithm) {
strategy = newAlgorithm;
}
}
public class StrategyPattern {
public static void main(String[] args) {
MinimaSolver solver =
```

```
new MinimaSolver(new LeastSquares());
List<Double> line = Arrays.asList(
1.0, 2.0, 1.0, 2.0, -1.0,
3.0, 4.0, 5.0, 4.0 );
System.out.println(solver.minima(line));
solver.changeAlgorithm(new Bisection());
System.out.println(solver.minima(line));
}
}
/* Output:
[1.1, 2.2]
[5.5, 6.6]
*/
```

The **changeAlgorithm()** method in **MinimaSolver** plugs a different strategy into the **private** field **strategy**, which makes a call to **minima()** use a different approach.

We can simplify the solution by incorporating the context into **FindMinima**:

```
// patterns/strategy/StrategyPattern2.java
// {java patterns.strategy.StrategyPattern2}
```

```
package patterns.strategy;
import java.util.function.*;
import java.util.*;
// "Context" is now incorporated:
class FindMinima2 {
Function<List<Double>, List<Double>> algorithm;
FindMinima2() { leastSquares(); } // default
// The various strategies:
void leastSquares() {
algorithm = (line) -> Arrays.asList(1.1, 2.2);
}
void perturbation() {
algorithm = (line) -> Arrays.asList(3.3, 4.4);
}
void bisection() {
algorithm = (line) -> Arrays.asList(5.5, 6.6);
}
List<Double> minima(List<Double> line) {
return algorithm.apply(line);
}
```

```
}

public class StrategyPattern2 {

public static void main(String[] args) {
```

```
FindMinima2 solver = new FindMinima2();

List<Double> line = Arrays.asList(

1.0, 2.0, 1.0, 2.0, -1.0,

3.0, 4.0, 5.0, 4.0 );

System.out.println(solver.minima(line));

solver.bisection();

System.out.println(solver.minima(line));

}

}

/* Output:

[1.1, 2.2]

[5.5, 6.6]

*/
```

FindMinima2 encapsulates the different algorithms, and now also

includes the “Context” so it controls the algorithm choice in a single class.

Chain of Responsibility

Chain of Responsibility might be thought of as a dynamic generalization of recursion using *Strategy* objects. You make a call, and each *Strategy* in a linked sequence tries to satisfy the call. The process ends when one of the strategies is successful or the chain ends. In recursion, one method calls itself over and over until a termination condition is reached; with *Chain of Responsibility*, a method calls the same base-class method (with different implementations) which calls another implementation of the base-class method, etc., until a termination condition is reached.

Instead of calling a single method to satisfy a request, multiple methods in the chain have a chance to satisfy the request, so it has the flavor of an expert system. Since the chain is effectively a linked list, it can be dynamically created, so you can also think of it as a more general, dynamically-built **switch** statement.

In **StrategyPattern.java**, above, what you probably want is to automatically find a solution. *Chain of Responsibility* provides a way to do this:

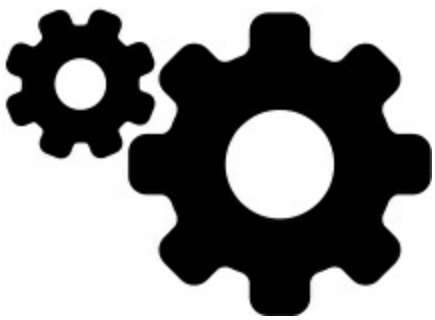
// patterns/chain/ChainOfResponsibility.java

```
// Using the Functional interface
// {java patterns.chain.ChainOfResponsibility}
package patterns.chain;
import java.util.*;
import java.util.function.*;
class Result {
boolean success;
List<Double> line;
Result(List<Double> data) {
success = true;
line = data;
}
Result() {
success = false;
line = Collections.<Double>emptyList();
}
}
class Fail extends Result {}
interface Algorithm {
Result algorithm(List<Double> line);
```

```
}
class FindMinima {
public static Result leastSquares(List<Double> line) {
System.out.println("LeastSquares.algorithm");
boolean weSucceed = false;
if(weSucceed) // Actual test/calculation here
return new Result(Arrays.asList(1.1, 2.2));
else // Try the next one in the chain:
return new Fail();
}
public static Result perturbation(List<Double> line) {
System.out.println("Perturbation.algorithm");
boolean weSucceed = false;
if(weSucceed) // Actual test/calculation here
return new Result(Arrays.asList(3.3, 4.4));
else
return new Fail();
}
public static Result bisection(List<Double> line) {
System.out.println("Bisection.algorithm");
```

```
boolean weSucceed = true;
if(weSucceed) // Actual test/calculation here
return new Result(Arrays.asList(5.5, 6.6));
else
return new Fail();
}
static List<Function<List<Double>, Result>>
algorithms = Arrays.asList(
FindMinima::leastSquares,
FindMinima::perturbation,
FindMinima::bisection
);
public static Result minima(List<Double> line) {
for(Function<List<Double>, Result> alg :
algorithms) {
Result result = alg.apply(line);
if(result.success)
return result;
}
return new Fail();
```

```
}
}
public class ChainOfResponsibility {
public static void main(String[] args) {
FindMinima solver = new FindMinima();
List<Double> line = Arrays.asList(
1.0, 2.0, 1.0, 2.0, -1.0,
3.0, 4.0, 5.0, 4.0);
Result result = solver.minima(line);
if(result.success)
System.out.println(result.line);
else
System.out.println("No algorithm found");
}
}
/* Output:
```



LeastSquares.algorithm

Perturbation.algorithm

Bisection.algorithm

[5.5, 6.6]

/

We start by defining the **Result** class which contains a **success** flag so the recipient can tell whether the algorithm succeeded, and **line** to carry the actual data. The **Fail** class provides a meaningful name when an algorithm fails. Note that returning a **Result** object is more appropriate here than throwing an exception upon failure, because you expect that sometimes you won't solve it.

Each **Algorithm** implementation has a different approach for the **algorithm()** method. In **FindMinima**, a **List** of the algorithms is created (this is the "chain"), and the **minima()** method simply goes through this list searching for one that succeeds.

Changing the

Interface

Sometimes the problem that you're solving is as simple as "I don't have the interface I need." Two of the patterns in *Design Patterns* solve this problem: *Adapter* takes one type and produces an interface to some other type. *Façade* creates an interface to a set of classes, simply to provide a more comfortable way to deal with a library or bundle of resources.

Adapter

When you've got *this*, and you need *that*, *Adapter* solves the problem.

The only requirement is to produce a *that*, and there are a number of ways you can accomplish this adaptation.

```
// patterns/adapt/Adapter.java
// Variations on the Adapter pattern
// {java patterns.adapt.Adapter}
package patterns.adapt;
class WhatIHave {
public void g() {}
public void h() {}
}
interface WhatIWant {
void f();
}
```

```
class ProxyAdapter implements WhatIWant {
WhatIHave whatIHave;
ProxyAdapter(WhatIHave wih) {
whatIHave = wih;
}
@Override
public void f() {
// Implement behavior using
// methods in WhatIHave:
whatIHave.g();
whatIHave.h();
}
}
class WhatIUse {
public void op(WhatIWant wiw) {
wiw.f();
}
}
// Approach 2: build adapter use into op():
class WhatIUse2 extends WhatIUse {
```

```
public void op(WhatIHave wih) {
new ProxyAdapter(wih).f();
}
}
// Approach 3: build adapter into WhatIHave:
class WhatIHave2 extends WhatIHave
implements WhatIWant {
@Override
public void f() {
g();
h();
}
}
// Approach 4: use an inner class:
class WhatIHave3 extends WhatIHave {
private class InnerAdapter implements WhatIWant{
@Override
public void f() {
g();
h();
```

```
}
}
public WhatIWant whatIWant() {
return new InnerAdapter();
}
}
public class Adapter {
public static void main(String[] args) {
WhatIUse whatIUse = new WhatIUse();
WhatIHave whatIHave = new WhatIHave();
WhatIWant adapt= new ProxyAdapter(whatIHave);
whatIUse.op(adapt);
// Approach 2:
WhatIUse2 whatIUse2 = new WhatIUse2();
whatIUse2.op(whatIHave);
// Approach 3:
WhatIHave2 whatIHave2 = new WhatIHave2();
whatIUse.op(whatIHave2);
// Approach 4:
WhatIHave3 whatIHave3 = new WhatIHave3();
```

```
whatIUse.op(whatIHave3.whatIWant());
}
}
```

I’m taking liberties with the term “proxy” here, because in the *Design Patterns* book, they assert that a proxy must have an identical interface to the object for which it is a surrogate. However, taking the two words together as “proxy adapter” is perhaps more reasonable.

Façade

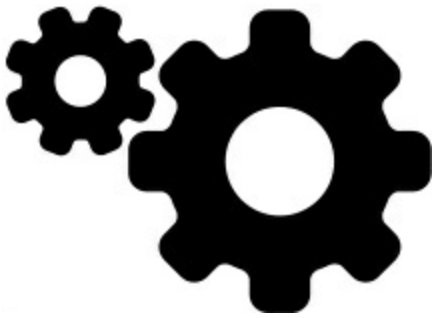
Here’s a general principle I apply when casting about trying to mold requirements into a first-cut object design:

If something is ugly, hide it inside an object.

This is basically what *Façade* accomplishes. If you have a rather confusing collection of classes and interactions that the client programmer doesn’t really need to see, you can create an interface that is useful for the client programmer and only presents what’s necessary.

Façade is often a implemented as singleton abstract factory. You can easily get this effect by creating a class containing **static** factory methods:

```
// patterns/Facade.java
class A { A(int x) {} }
class B { B(long x) {} }
class C { C(double x) {} }
// Other classes that aren't exposed by the
// facade go here ...
public class Facade {
static A makeA(int x) { return new A(x); }
static B makeB(long x) { return new B(x); }
static C makeC(double x) { return new C(x); }
public static void main(String[] args) {
```



```
// The client programmer gets the objects
// by calling the static methods:
```

```
A a = Facade.makeA(1);
B b = Facade.makeB(1);
C c = Facade.makeC(1.0);
}
}
```

The example given in *Design Patterns* isn't really a *Façade* but just a class that uses the other classes.

Package as a Variation of *Façade*

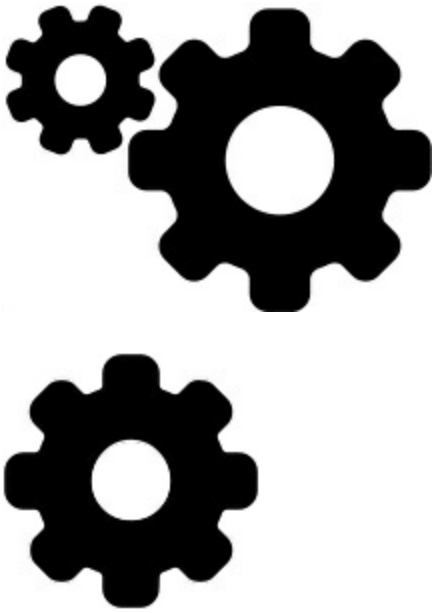
To me, the *Façade* has a rather "procedural" (non-object-oriented) feel to it: you are just calling some functions to give you objects. And how different is it, really, from *Abstract Factory*? The point of *Façade* is to hide part of a library of classes (and their interactions) from the client programmer, to make the interface to that group of classes more digestible and easier to understand.

However, this is precisely what the packaging features in Java accomplish: outside of the library, you can only create and use **public** classes; all the non-**public** classes are only accessible within the package. It's as if *Façade* is a built-in feature of Java.

To be fair, *Design Patterns* is written primarily for a C++ audience. Although C++ has namespaces to prevent clashes of globals and class

names, this does not provide the class hiding mechanism you get with non-**public** classes in Java. The majority of the time I think Java packages will solve the *Façade* problem.

***Interpreter*: Run-Time Flexibility**



If the application user needs greater run-time flexibility, for example to create scripts describing the desired behavior of the system, you can use the *Interpreter* design pattern. Here, you create and embed a language interpreter into your program.

Developing your own language and building an interpreter for it is a time-consuming distraction from the process of building your application. The best solution is to reuse code: that is, to embed an interpreter that’s already been built and debugged for you. The Python

language can be freely embedded in your for-profit application without any license agreement, royalties, or **String**s of any kind. In addition, there is a version of Python called Jython which is entirely Java byte codes, so incorporating it into your application is simple. Python is a scripting language that is very easy to learn, very logical to read and write, supports functions and objects, has a large set of available libraries, and runs on virtually every platform. You can download Python and learn more about it at www.Python.org.

Callbacks

Callbacks decouple code from behavior. These include *Observer*, and a category of callbacks called "multiple dispatching" (not in *Design Patterns*), including *Visitor* from *Design Patterns*.

Observer

Like the other forms of callback, this contains a hook point where you can change code. The difference is in the observer's completely dynamic nature. It is often used for the specific case of changes based on other objects' change of state, but is also the basis of event management. Observers allow you to decouple the source of the call from the called code in a completely dynamic way.

The observer pattern solves a fairly common problem: What if a group

of objects must update themselves when some object changes state? This can be seen in the “model-view” aspect of SmallTalk’s MVC (model-view-controller), or the almost-equivalent “Document-View Architecture.” Suppose you have some data (the “document”) and more than one view, say a plot and a textual view. When you change the data, the two views must know to update themselves, and that’s what the observer facilitates. It’s a common enough problem that its solution is part of the standard **java.util** library.

There are two types of objects used to implement the observer pattern in Java. The **Observable** class keeps track of everybody who wants to be informed when a change happens, whether the “state” has changed or not. When someone says “OK, everybody should check and potentially update themselves,” the **Observable** class performs this task by calling the **notifyObservers()** method for each one on the list. The **notifyObservers()** method is part of the base class **Observable**.

There are actually two “things that change” in the observer pattern: the quantity of observing objects and the way an update occurs. That is, the observer pattern allows you to modify both of these without affecting the surrounding code.

Observer is an “interface” class that only has one method, **update()**. This function is called by the object that’s observed, when that object decides its time to update all its observers. The arguments are optional; you can have an **update()** with no arguments and that would still fit the observer pattern; however this is more general—it allows the observed object to pass the object that caused the update (since an **Observer** may be registered with more than one observed object) and any extra information if that’s helpful, rather than forcing the **Observer** object to hunt around to see who is updating and to fetch any other information it needs.

The “observed object” that decides when and how to do the updating is called the **Observable**.

Observable has a flag to indicate whether it’s been changed. In a simpler design, there would be no flag; if something happened, everyone is notified. The flag allows you to wait, and only notify the **Observer**s when you decide the time is right. Notice, however, that the control of the flag’s state is **protected**, so only an inheritor can

decide what constitutes a change, and not the end user of the resulting derived **Observer** class.

Most of the work is done in **notifyObservers()**. If the **changed** flag has not been set, this does nothing. Otherwise, it first clears the **changed** flag so repeated calls to **notifyObservers()** won't waste time. This is done before notifying the observers in case the calls to **update()** do anything that causes a change back to this **Observable** object. Then it moves through the **set** and calls back to the **update()** method of each **Observer**.

At first it may appear you can use an ordinary **Observable** object to manage the updates. But this doesn't work; to get an effect, you *must* inherit from **Observable** and somewhere in your derived-class code call **setChanged()**. This is the method that sets the "changed" flag, which means when you call **notifyObservers()**, all observers will, in fact, get notified. *Where* you call **setChanged()** depends on the logic of your program.

Observing Flowers

Here is an example of the observer pattern:

// patterns/observer/ObservedFlower.java

// Demonstration of "Observer" pattern

```
// {java patterns.observer.ObservedFlower}
package patterns.observer;
import java.util.*;
class Flower {
private boolean isOpen;
private boolean alreadyOpen;
private boolean alreadyClosed;
Flower() { isOpen = false; }
OpenNotifier opening = new OpenNotifier();
CloseNotifier closing = new CloseNotifier();
public void open() { // Opens its petals
isOpen = true;
opening.notifyObservers();
alreadyClosed = false;
}
public void close() { // Closes its petals
isOpen = false;
closing.notifyObservers();
alreadyOpen = false;
}
```

```
class OpenNotifier extends Observable {
@Override
public void notifyObservers() {
if(isOpen && !alreadyOpen) {
setChanged();
super.notifyObservers();
alreadyOpen = true;
}
}
}
class CloseNotifier extends Observable{
@Override
public void notifyObservers() {
if(!isOpen && !alreadyClosed) {
setChanged();
super.notifyObservers();
alreadyClosed = true;
}
}
}
```

```
}
class Bee {
private String name;
Bee(String nm) { name = nm; }
// Observe openings:
public Observer openObserver() {
return (ob, a) -> System.out.println(
"Bee " + name + "'s breakfast time!");
}
// Observe closings:
public Observer closeObserver() {
return (ob, a) -> System.out.println(
"Bee " + name + "'s bed time!");
}
}
class Hummingbird {
private String name;
Hummingbird(String nm) { name = nm; }
public Observer openObserver() {
return (ob, a) -> System.out.println(
```

```
"Hummingbird " + name +
"'s breakfast time!");
}
public Observer closeObserver() {
return (ob, a) -> System.out.println(
"Hummingbird " + name + "'s bed time!");
}
}
public class ObservedFlower {
public static void main(String[] args) {
Flower f = new Flower();
Bee
ba = new Bee("A"),
bb = new Bee("B");
Hummingbird
ha = new Hummingbird("A"),
hb = new Hummingbird("B");
f.opening.addObserver(ha.openObserver());
f.opening.addObserver(hb.openObserver());
f.opening.addObserver(ba.openObserver());
```

```
f.opening.addObserver(bb.openObserver());
f.closing.addObserver(ha.closeObserver());
f.closing.addObserver(hb.closeObserver());
f.closing.addObserver(ba.closeObserver());
f.closing.addObserver(bb.closeObserver());
// Hummingbird B decides to sleep in:
f.opening.deleteObserver(hb.openObserver());
// A change that interests observers:
f.open();
f.open(); // It's already open, no change.
// Bee A doesn't want to go to bed:
f.closing.deleteObserver(ba.closeObserver());
f.close();
f.close(); // It's already closed; no change
f.opening.deleteObservers();
f.open();
f.close();
}
}
/* Output:
```

Bee B's breakfast time!

Bee A's breakfast time!

Hummingbird B's breakfast time!

Hummingbird A's breakfast time!

Bee B's bed time!

Bee A's bed time!

Hummingbird B's bed time!

Hummingbird A's bed time!

Bee B's bed time!

Bee A's bed time!

Hummingbird B's bed time!

Hummingbird A's bed time!

*/

The events of interest are that a **Flower** can open or close. Because of the use of the inner class idiom, both these events can be separately-observable phenomena. **OpenNotifier** and **CloseNotifier** both inherit **Observable**, so they have access to **setChanged()** and can be handed to anything that needs an **Observable**. Because **Observable** is a class, we don’t have an opportunity to use lambda

expressions.

Observer is a functional interface, so **openObserver()** and **closeObserver()** in **Bee** and **Hummingbird** can be defined using lambdas. Both of those classes may independently observe **Flower** openings and closings.

In **main()**, you see one of the prime benefits of the observer pattern: the ability to change behavior at runtime by dynamically registering and un-registering **Observer**s with **Observable**s.

Notice you can create other completely different observing objects; the only connection the **Observer**s have with **Flower**s is the **Observer** interface.

A Visual Example of Observers

The following example cheats by using the Swing library to create graphics, which are not introduced in this book (See *Thinking in Java, 4th edition*, available at www.OnJava8.com). Boxes are placed in a grid on the screen and each one is initialized to a random color. In

addition, each box **implements** the **Observer** interface and is registered with an **Observable** object. When you click on a box, all other boxes are notified of the change because the **Observable** object automatically calls each **Observer** object's **update()** method. Inside this method, the box checks to see if it's adjacent to the one that was clicked, and if so it changes its color to match the clicked box.

The **java.awt.event** library has a **MouseListener** class with multiple methods, but we are only interested in the **mouseClicked()** method. You can't write a lambda expression if you just want to implement **mouseClicked()** because **MouseListener** is not a functional interface due to its multiple methods. Java 8 allows us to simplify our code using the **default** keyword to create a helper interface and solve this problem:

```
// onjava/MouseClick.java
// Helper interface to allow lambda expressions
package onjava;
import java.awt.event.*;
// Default everything except mouseClicked():
public interface MouseClick extends MouseListener {
```

```
@Override
default void mouseEntered(MouseEvent e) {}
@Override
default void mouseExited(MouseEvent e) {}
@Override
default void mousePressed(MouseEvent e) {}
@Override
default void mouseReleased(MouseEvent e) {}
}
```

Now you can successfully cast a lambda expression to a **MouseClick** and pass it to **addMouseListener()**.

```
// patterns/BoxObserver.java
// Demonstration of Observer pattern using
// Java's built-in observer classes
// {ExcludeFromTravisCI}
import javax.swing.*;
import java.awt.*;
import java.awt.event.*;
import java.util.*;
import onjava.*;
```

```
import onjava.MouseClick;
// You must inherit a new type of Observable:
class BoxObservable extends Observable {
@Override
public void notifyObservers(Object b) {
// Otherwise it won't propagate changes:
setChanged();
super.notifyObservers(b);
}
}
public class BoxObserver extends JFrame {
Observable notifier = new BoxObservable();
public BoxObserver(int grid) {
setTitle("Demonstrates Observer pattern");
Container cp = getContentPane();
cp.setLayout(new GridLayout(grid, grid));
for(int x = 0; x < grid; x++)
for(int y = 0; y < grid; y++)
cp.add(new OCBox(x, y, notifier));
}
```

```
public static void main(String[] args) {
new TimedAbort(4);
int grid = 8;
if(args.length > 0)
grid = Integer.parseInt(args[0]);
JFrame f = new BoxObserver(grid);
f.setSize(500, 400);
f.setVisible(true);
f.setDefaultCloseOperation(DISPOSE_ON_CLOSE);
}
}
class OCBox extends JPanel implements Observer {
Observable notifier;
int x, y; // Locations in grid
Color cColor = newColor();
static final Color[] COLORS = {
Color.black, Color.blue, Color.cyan,
Color.darkGray, Color.gray, Color.green,
Color.lightGray, Color.magenta,
Color.orange, Color.pink, Color.red,
```

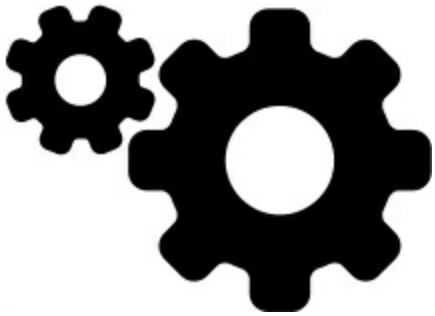
```
Color.white, Color.yellow
};
static Color newColor() {
return COLORS[
(int)(Math.random() * COLORS.length)
];
}
OCBox(int x, int y, Observable notifier) {
this.x = x;
this.y = y;
notifier.addObserver(this);
this.notifier = notifier;
addMouseListener((MouseClick)
e -> notifier.notifyObservers(OCBox.this));
}
@Override
public void paintComponent(Graphics g) {
super.paintComponent(g);
g.setColor(cColor);
Dimension s = getSize();
```

```
g.fillRect(0, 0, s.width, s.height);
}
@Override
public void update(Observable o, Object arg) {
OCBox clicked = (OCBox)arg;
if(nextTo(clicked)) {
cColor = clicked.cColor;
repaint();
}
}
private boolean nextTo(OCBox b) {
return Math.abs(x - b.x) <= 1 &&
Math.abs(y - b.y) <= 1;
}
}
```

Notice how **MouseClick** enables **addMouseListener()** to accept a lambda expression.

When you first look at the online documentation for **Observable**, it's a bit confusing because it appears you can use an ordinary **Observable** object to manage the updates. But this doesn't work.

Try it—inside **BoxObserver**, create an **Observable** object instead



of a **BoxObservable** object and see what happens: nothing. To get an effect, you *must* inherit from **Observable** and somewhere in your derived-class code call **setChanged()**. This is the method that sets the “changed” flag, which means when you call **notifyObservers()**, all observers will, in fact, get notified. In the example above **setChanged()** is simply called within **notifyObservers()**, but you can use any criterion to decide when to call **setChanged()**.

BoxObserver contains a single **Observable** object called **notifier**, and every time an **OCBox** object is created, it is tied to **notifier**. In **OCBox**, whenever you click the mouse the **notifyObservers()** method is called, passing the clicked object in as an argument so all the boxes receiving the message (in their **update()** method) know who was clicked and can decide whether to change themselves or not. Using a combination of code in

notifyObservers() and **update()** you can work out some fairly complex schemes.

It might appear that the way the observers are notified must be frozen at compile time in the **notifyObservers()** method. However, if you look more closely at the code above you'll see that the only place in **BoxObserver** or **OCBox** where you're aware you're working with a **BoxObservable** is at the point of creation of the **Observable** object—from then on everything uses the basic **Observable** interface. This means you can inherit other **Observable** classes and swap them at run-time to change notification behavior.

Multiple Dispatching

Programs can get especially messy when dealing with multiple interacting types. For example, consider a system that parses and executes mathematical expressions. You want to say **Number + Number**, **Number * Number**, etc., where **Number** is the base class for a family of numerical objects. But when you say **a + b**, and you don't know the exact type of either **a** or **b**, so how can you get them to interact properly?

The answer starts with something you probably don't think about: Java performs only single dispatching. That is, if you are performing

an operation on more than one object whose type is unknown, Java can invoke the dynamic binding mechanism on only one of those types. This doesn't solve the problem, so you end up detecting some types manually and effectively producing your own dynamic binding behavior.

The solution is called *multiple dispatching*. Because polymorphism only occurs via method calls, if you want double dispatching to occur, there must be two method calls: the first to determine the first unknown type, and the second to determine the second unknown type. With multiple dispatching, you must have a polymorphic method call to determine each of the types.

Generally, you'll set up a configuration such that a single method call produces more than one dynamic method call and thus determines more than one type in the process. The methods in the following example are called **compete()** and **eval()**, and are both members of the same type. (Here there are only two dispatches, which is called *double dispatching*). If you are working with two different interacting type hierarchies, you'll need a polymorphic method call in each hierarchy.

Here's an example of multiple dispatching:

```
// patterns/PaperScissorsRock.java
// Demonstration of multiple dispatching
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
import onjava.*;
import static onjava.Tuple.*;
enum Outcome { WIN, LOSE, DRAW }
interface Item {
Outcome compete(Item it);
Outcome eval(Paper p);
Outcome eval(Scissors s);
Outcome eval(Rock r);
}
class Paper implements Item {
@Override
public Outcome compete(Item it) {
return it.eval(this);
}
@Override
```

```
public Outcome eval(Paper p) {
return Outcome.DRAW;
}
@Override
public Outcome eval(Scissors s) {
return Outcome.WIN;
}
@Override
public Outcome eval(Rock r) {
return Outcome.LOSE;
}
@Override
public String toString() { return "Paper"; }
}
class Scissors implements Item {
@Override
public Outcome compete(Item it) {
return it.eval(this);
}
@Override
```

```
public Outcome eval(Paper p) {
return Outcome.LOSE;
}
@Override
public Outcome eval(Scissors s) {
return Outcome.DRAW;
}
@Override
public Outcome eval(Rock r) {
return Outcome.WIN;
}
@Override
public String toString() { return "Scissors"; }
}
class Rock implements Item {
@Override
public Outcome compete(Item it) {
return it.eval(this);
}
@Override
```

```
public Outcome eval(Paper p) {
return Outcome.WIN;
}
@Override
public Outcome eval(Scissors s) {
return Outcome.LOSE;
}
@Override
public Outcome eval(Rock r) {
return Outcome.DRAW;
}
@Override
public String toString() { return "Rock"; }
}
class ItemFactory {
static List<Supplier<Item>> items =
Arrays.asList(
Scissors::new, Paper::new, Rock::new);
static final int SZ = items.size();
private static SplittableRandom rand =
```

```
new SplittableRandom(47);
public static Item newItem() {
return items.get(rand.nextInt(SZ)).get();
}
public static Tuple2<Item,Item> newPair() {
return tuple(newItem(), newItem());
}
}
class Compete {
public static Outcome match(Tuple2<Item,Item> p) {
System.out.print(p.a1 + " -> " + p.a2 + " : ");
return p.a1.compete(p.a2);
}
}
public class PaperScissorsRock {
public static void main(String[] args) {
Stream.generate(ItemFactory::newPair)
.limit(20)
.map(Compete::match)
.forEach(System.out::println);
```

}

}

/ Output:*

Scissors -> Rock : LOSE

Scissors -> Paper : WIN

Rock -> Paper : LOSE

Rock -> Rock : DRAW

Rock -> Paper : LOSE

Paper -> Scissors : LOSE

Rock -> Paper : LOSE

Scissors -> Scissors : DRAW

Scissors -> Rock : LOSE

Scissors -> Paper : WIN

Scissors -> Rock : LOSE

Paper -> Scissors : LOSE

Rock -> Rock : DRAW

Scissors -> Scissors : DRAW

Paper -> Paper : DRAW

Scissors -> Paper : WIN

Scissors -> Rock : LOSE

Scissors -> Paper : WIN

Rock -> Paper : LOSE

Rock -> Scissors : WIN

*/

The **Item** interface contains the structure of the double dispatch: **compete()** performs the first dispatch, and the second dispatch occurs through the call to **eval()**.

Suppose you have two **item**s, **a** and **b**, and you don't know the type of either. Here's what happens as you call **a.compete(b)**: The **compete()** method is polymorphic, so through dynamic dispatching you wake up inside the particular **compete()** body for the type of **a**.

If we say **a** is type **Paper**, then we wake up in **Paper**s **compete()**, thus determining the type of the first unknown object via the first dispatch. But now **compete()** turns around and calls **eval()** on **b**, the second unknown type, while passing **a** as an argument, so the overloaded version of **eval()** is called for the type of **b**—and that's the second dispatch. At that point, you're inside an **eval()** that

knows the type of both objects.

Visitor, a Type of Multiple Dispatching

The assumption for *Visitor* is that you have a primary class hierarchy that is fixed; perhaps it's from another vendor and you can't make changes to that hierarchy. However, you'd like to add new polymorphic methods to that hierarchy, which means that normally you'd have to add something to the base class interface. So the dilemma is that you must add methods to the base class, but you can't touch the base class. How do you get around this?

Visitor (the final pattern in the *Design Patterns* book) solves this problem by building on the double dispatching scheme shown in the last section.

Visitor allows you to extend the interface of the primary type by creating a separate class hierarchy of type **Visitor** to virtualize the operations performed upon the primary type. The objects of the primary type simply "accept" the visitor, then call the visitor's dynamically-bound method.

// patterns/visitor/BeeAndFlowers.java

// Demonstration of "visitor" pattern

```
// {java patterns.visitor.BeeAndFlowers}
package patterns.visitor;
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
interface Visitor {
void visit(Gladiolus g);
void visit(Renuculus r);
void visit(Chrysanthemum c);
}
// The Flower hierarchy cannot be changed:
interface Flower {
void accept(Visitor v);
}
class Gladiolus implements Flower {
@Override
public void accept(Visitor v) { v.visit(this);}
}
class Renuculus implements Flower {
@Override
```

```
public void accept(Visitor v) { v.visit(this);}
}
class Chrysanthemum implements Flower {
@Override
public void accept(Visitor v) { v.visit(this);}
}
// Add the ability to produce a String:
class StringVal implements Visitor {
String s;
@Override
public String toString() { return s; }
@Override
public void visit(Gladiolus g) {
s = "Gladiolus";
}
@Override
public void visit(Renuculus r) {
s = "Renuculus";
}
@Override
```

```
public void visit(Chrysanthemum c) {
s = "Chrysanthemum";
}
}
// Add the ability to do "Bee" activities:
class Bee implements Visitor {
@Override
public void visit(Gladiolus g) {
System.out.println("Bee and Gladiolus");
}
@Override
public void visit(Renuculus r) {
System.out.println("Bee and Renuculus");
}
@Override
public void visit(Chrysanthemum c) {
System.out.println("Bee and Chrysanthemum");
}
}
class FlowerFactory {
```

```
static List<Supplier<Flower>> flowers =
Arrays.asList(Gladiolus::new,
Renuculus::new, Chrysanthemum::new);
static final int SZ = flowers.size();
private static SplittableRandom rand =
new SplittableRandom(47);
public static Flower newFlower() {
return flowers.get(rand.nextInt(SZ)).get();
}
}
public class BeeAndFlowers {
public static void main(String[] args) {
List<Flower> flowers =
Stream.generate(FlowerFactory::newFlower)
.limit(10)
.collect(Collectors.toList());
StringVal sval = new StringVal();
flowers.forEach(f -> {
f.accept(sval);
System.out.println(sval);
```

```
});
// Perform "Bee" operation on all Flowers:
Bee bee = new Bee();
flowers.forEach(f -> f.accept(bee));
}
}
/* Output:
Gladiolus
Chrysanthemum
Gladiolus
Renuculus
Chrysanthemum
Renuculus
Chrysanthemum
Chrysanthemum
Chrysanthemum
Renuculus
Bee and Gladiolus
Bee and Chrysanthemum
Bee and Gladiolus
```

Bee and Renuculus

Bee and Chrysanthemum

Bee and Renuculus

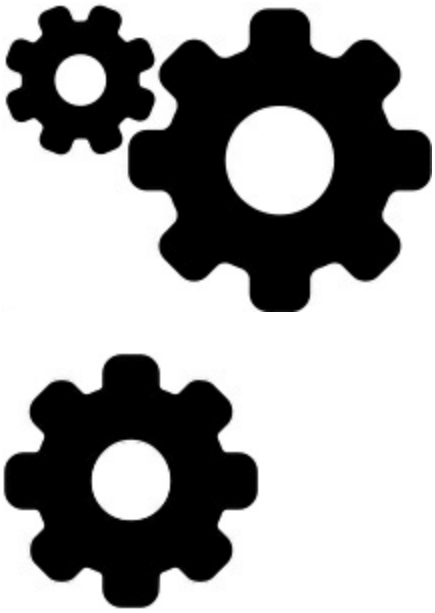
Bee and Chrysanthemum

Bee and Chrysanthemum

Bee and Chrysanthemum

Bee and Renuculus

*/



Note the similarity with the previous example: **Flower** accepts a **Visitor** for the first dispatch, then turns around and calls **visit()** (passing itself as an argument, to end up in the overloaded method according to the **Flower** type) as the second dispatch.

In **main()**, it's almost as if I added a method to produce a **Flower**

String representation, which is the point of **Visitor**: adding methods to a frozen hierarchy.

Pattern Refactoring

The remainder of the chapter will look at the process of solving a problem by applying design patterns in an evolutionary fashion. That is, a first cut design is used for the initial solution, then this solution is examined and various design patterns are applied to the problem (some of which work, and some of which won't). The key question in seeking improved solutions is always "what will change?"

This process is similar to what Martin Fowler talks about in his book *Refactoring: Improving the Design of Existing Code* (Addison-Wesley, 1999), although he tends to talk about pieces of code more than pattern-level designs. You start with a solution, and when you discover it doesn't continue to meet your needs, you fix it. This is a natural tendency, but in computer programming it's been extremely difficult to accomplish with procedural programs, and the acceptance of the idea that we *can* refactor code and designs adds to the idea that object-oriented programming seems to be beneficial.

Simulating a Trash Recycler

This is not a trivial design because it has an added constraint. It's more

like the messy problems you're likely to encounter in your work. The

extra constraint is that the trash arrives at the trash recycling plant all mixed together. The program models the sorting of that trash. In the

initial solution, RTTI (*Run Time Type Identification*, described in the

Type Information chapter) is used to take anonymous pieces of trash and figure out exactly what type they are.

```
// patterns/recyclea/RecycleA.java

// Recycling with RTTI

// {java patterns.recyclea.RecycleA}

package patterns.recyclea;

import java.util.*;

import java.util.function.*;

import java.util.stream.*;

abstract class Trash {

double weight;

Trash(double wt) { weight = wt; }

abstract double value();

// Sums the value of Trash in a bin:

private static double val;

static void sumValue(List<? extends Trash> bin) {

val = 0.0f;
```

```
bin.forEach( t -> {
// Polymorphism in action:
val += t.weight * t.value();
System.out.println(
"weight of " +
// Using RTTI to get type
// information about the class:
t.getClass().getSimpleName() +
" = " + t.weight);
});
System.out.println("Total value = " + val);
}
}
class Aluminum extends Trash {
static double val = 1.67f;
Aluminum(double wt) { super(wt); }
@Override
double value() { return val; }
static void value(double newval) {
val = newval;
```

```
}
}
class Paper extends Trash {
static double val = 0.10f;
Paper(double wt) { super(wt); }
@Override
double value() { return val; }
static void value(double newval) {
val = newval;
}
}
class Glass extends Trash {
static double val = 0.23f;
Glass(double wt) { super(wt); }
@Override
double value() { return val; }
static void value(double newval) {
val = newval;
}
}
```

```
class TrashFactory {
static List<Function<Double, Trash>> ttypes =
Arrays.asList(
Aluminum::new, Paper::new, Glass::new);
static final int SZ = ttypes.size();
private static SplittableRandom rand =
new SplittableRandom(47);
public static Trash newTrash() {
return ttypes
.get(rand.nextInt(SZ))
.apply(rand.nextDouble());
}
}
public class RecycleA {
public static void main(String[] args) {
List<Trash> bin =
Stream.generate(TrashFactory::newTrash)
.limit(25)
.collect(Collectors.toList());
List<Glass> glassBin = new ArrayList<>();
```

```
List<Paper> paperBin = new ArrayList<>();
List<Aluminum> alBin = new ArrayList<>();
// Sort the Trash:
bin.forEach( t -> {
// RTTI to discover Trash type:
if(t instanceof Aluminum)
alBin.add((Aluminum)t);
if(t instanceof Paper)
paperBin.add((Paper)t);
if(t instanceof Glass)
glassBin.add((Glass)t);
});
Trash.sumValue(alBin);
Trash.sumValue(paperBin);
Trash.sumValue(glassBin);
Trash.sumValue(bin);
}
}
/* Output: (First and Last 11 Lines)
weight of Aluminum = 0.2893030122276371
```

weight of Aluminum = 0.1970234961398979

weight of Aluminum = 0.36295525806274787

weight of Aluminum = 0.4825532324565849

weight of Aluminum = 0.8036398273294586

weight of Aluminum = 0.510430896154935

weight of Aluminum = 0.6703377164093444

weight of Aluminum = 0.41477933066243455

weight of Aluminum = 0.3603022312124007

weight of Aluminum = 0.43690089841661006

weight of Aluminum = 0.6708820087907101

..._____..._____..._____..._____...

weight of Aluminum = 0.41477933066243455

weight of Aluminum = 0.3603022312124007

weight of Aluminum = 0.43690089841661006

weight of Glass = 0.5999637765664924

weight of Glass = 0.7748836191212746

weight of Paper = 0.5735994548427199

weight of Glass = 0.5362827750851034

weight of Aluminum = 0.6708820087907101

weight of Paper = 0.8370669795210507

weight of Glass = 0.3397919679731668

Total value = 9.90671597531968

*/

This chapter rewrites this particular example a number of times and by putting each version in its own **package** the class names will not clash.

Several **ArrayList** objects are created to hold **Trash** references. It looks silly to upcast the types of **Trash** into a collection holding base type references, then turn around and downcast. Why not just put the trash into the appropriate receptacle in the first place? In this program it is easy to repair, but sometimes a system's structure and flexibility can benefit greatly from downcasting.

The program satisfies the design requirements: it works. This might be fine as long as it's a one-shot solution. However, a useful program tends to evolve over time, so you must ask, "What if the situation changes?" For example, cardboard is a valuable recyclable commodity, so how will that be integrated into the system (especially if the

program is large and complicated). Although the **TrashFactory** does encapsulate creation, in the rest of the program you see type-check coding scattered about, and you must go find all that code every time a new type is added. If you miss one the compiler won't give you any help by pointing out an error.

You know you're misusing RTTI when *every type is tested*. If you're looking for only a subset of types because that subset needs special treatment, that's probably fine. But if you're hunting for every type inside a switch statement, then you're probably missing an important point, and definitely making your code less maintainable. In the next section we'll evolve this program through multiple phases to make it much more flexible. This should prove a valuable example in program design.

"Make More Objects"

This brings up a general object-oriented design principle I first heard spoken by Grady Booch: "If the design is too complicated, make more objects." This is simultaneously counterintuitive and ludicrously

simple, and yet it's the most useful guideline I've found. (Observe that "making more objects" is often equivalent to "add another level of abstraction.") In general, if you find a place with messy code, consider what sort of class would clean that up. Often the side effect of cleaning up the code is a system that has better structure and is more flexible.

The original *TrashFactory* class is reasonably elegant, but what if the information required in the derived class requires more or different arguments? "Creating more objects" solves this problem. The **Trash** class gets a new method called **factory()**. To hide the creational data, there's a new class called **Info** that contains all necessary information for the **factory()** method to create the appropriate **Trash** object.

An **Info** object's only job is to hold information for the **factory()** method (it's a *Messenger* object). Now, if there's a situation where **factory()** needs more or different information to create a new type of **Trash** object, the **factory()** interface doesn't need changing.

The **Info** class can be changed by adding new data and new constructors, or in the more typical object-oriented fashion of subclassing.

You can also imagine a more complicated system where **factory()**

uses an elaborate algorithm. The point is that it's now hidden away in one place, and you know to come to this place when you add new types.

Generalizing the *Factory*

The design above still requires a central location where all the types of **Trash** must be known: inside the **factory()** method. If new types are regularly added to the system, the **factory()** method must be changed for each new type. When you discover something like this, it is useful to try to go one step further and move *all* information about the type—including its creation—into the class representing that type. This way, you only need to inherit a single class in order to add a new type to the system.

To move the information concerning type creation into each specific type of **Trash**, we start with an **Info** object containing all the information about the type of object to create. With reflection (introduced in the Type Information chapter) you can call a constructor if you have a reference to the **Class** object. We'll rewrite the **factory()** method to use reflection and the data in the **Info** object to create new **Trash** objects. This way, the **factory()** method doesn't need changing when a new type is added to the system.

We store a list of references to all the **Class** objects to create. If creation fails, the **factory()** method assumes it's because a particular **Class** object isn't in the list, and it will attempt to load it. By loading the **Class**es dynamically like this, the **Trash** class doesn't need to know what types it is working with, so it doesn't need any modifications when you add new types. This allows easy reuse throughout the rest of the chapter.

```
// patterns/trash/Trash.java
// Base class for Trash recycling examples
package patterns.trash;
import java.util.*;
import java.lang.reflect.*;
public abstract class Trash {
private double weight;
public Trash(double wt) { weight = wt; }
public Trash() {}
public abstract double value();
public double weight() { return weight; }
// Sums the value of Trash in a bin:
static double val;
```

```
public static <T extends Trash>
void sumValue(List<? extends T> bin) {
val = 0.0f;
bin.forEach( t -> {
val += t.weight() * t.value();
System.out.println("weight of " +
// RTTI gets type information
// about the class:
t.getClass().getName() +
" = " + t.weight());
});
System.out.println("Total value = " + val);
}
@Override
public String toString() {
// Print correct subclass name:
return getClass().getName() +
" w:" + weight() + " v:" +
String.format("%.2f", value());
}
```

```
// Remainder of class supports dynamic creation:
public static class CannotCreateTrashException
extends RuntimeException {
public CannotCreateTrashException(Exception why) {
super(why);
}
}
public static class TrashClassNotFoundException
extends RuntimeException {
public TrashClassNotFoundException(Exception why) {
super(why);
}
}
public static class Info {
public String id;
public double data;
public Info(String name, double data) {
id = name;
this.data = data;
}
```

```
}
private static List<Class> trashTypes =
new ArrayList<>();
@SuppressWarnings("unchecked")
public static <T extends Trash> T factory(Info info) {
for(Class trashType : trashTypes) {
// Determine the type and create one:
if(trashType.getName().contains(info.id)) {
try {
// Get the dynamic constructor method
// that takes a double argument:
Constructor ctor =
trashType.getConstructor(double.class);
// Call the constructor to create a
// new object:
return (T)ctor.newInstance(info.data);
} catch(Exception e) {
throw new CannotCreateTrashException(e);
}
}
```

```
}
// The necessary Class was not in the list. Try to
// load it, but it must be in your class path!
try {
System.out.println("Loading " + info.id);
trashTypes.add(Class.forName(info.id));
} catch(Exception e) {
throw new TrashClassNotFoundException(e);
}
// Loaded successfully. Recursive call
// should work this time:
return factory(info);
}
}
```

The basic **Trash** class and **sumValue()** remain as before. The rest of the class supports dynamic creation. You first see two inner classes (which are made **static**, so they are inner classes only for code organization purposes) describing exceptions that can occur.

The **trashTypes List** holds the **Class** references. In **Trash.factory()**, the **String id** inside the **Info** object

contains the type name of the **Trash** to be created; this **String** is compared to the **Class** names in the list. If there's a match, then that's the object to create. There are many ways to determine what object to make—this one is used so information read from a file can be turned into objects.

Once you've discovered the kind of **Trash** to create, the reflection methods come into play. The **getConstructor()** method takes an argument that's an array of **Class** references. This array represents the arguments, in their proper order, for the constructor you want. This code assumes that every **Trash** type has a constructor that takes a **double** (notice that **double.class** is distinct from **Double.class**). It's also possible, for a more flexible solution, to call **getConstructors()**, which returns an array of the possible constructors.

What comes back from **getConstructor()** is a reference to a **Constructor** object (part of **java.lang.reflect**). You call the constructor dynamically with the method **newInstance()**, which takes as a constructor argument **info.data**.

The process of creating a new object given only a **Class** reference is remarkably simple. Reflection also allows you to call methods in this

same dynamic fashion.

The appropriate **Class** reference might not be in the **trashTypes** list. Here, the **return** in the inner loop is never executed and you'll drop out at the end. Here, the program tries to rectify the situation by loading the **Class** object dynamically and adding it to the **trashTypes** list. If it still can't be found then something is really wrong, but if the load is successful then the **factory** method is called recursively to try again.

As you'll see, the beauty of this design is that the code doesn't change, regardless of the different situations where it's used (assuming that all **Trash** subclasses contain a constructor that takes a single **double** argument).

Notice that the **factory()** method doesn't use streams—it turns out that this piece of code is quite fragile and tricky, and I couldn't make streams work here. This could be a Java issue; it's not clear. Feel free to try rewriting it and send me the results if you're successful.

Trash Subclasses

Each new subclass of **Trash** must contain a constructor that takes a **double** argument. That's all. Java reflection handles everything else.

Here are the different types of **Trash**, each in their own file but part

of the **Trash** package (again, to facilitate reuse within the chapter):

```
// patterns/trash/Aluminum.java
package patterns.trash;
public class Aluminum extends Trash {
private static double val = 1.67f;
public Aluminum(double wt) { super(wt); }
@Override
public double value() { return val; }
public static void value(double newVal) {
val = newVal;
}
}
// patterns/trash/Paper.java
package patterns.trash;
public class Paper extends Trash {
private static double val = 0.10f;
public Paper(double wt) { super(wt); }
@Override
public double value() { return val; }
public static void value(double newVal) {
```

```
val = newVal;
}
}
// patterns/trash/Glass.java
package patterns.trash;
public class Glass extends Trash {
private static double val = 0.23f;
public Glass(double wt) { super(wt); }
@Override
public double value() { return val; }
public static void value(double newVal) {
val = newVal;
}
}
```

And here's a new type of **Trash**:

```
// patterns/trash/Cardboard.java
package patterns.trash;
public class Cardboard extends Trash {
private static double val = 0.23f;
public Cardboard(double wt) { super(wt); }
```

```
@Override
public double value() { return val; }
public static void value(double newVal) {
val = newVal;
}
}
```

Notice there’s nothing special about any of these classes.

Parsing Trash from a File

The information about **Trash** objects is read from a text file containing all necessary information about each piece of trash. Each piece of trash is described by a single line in the form **Trash:weight**:

```
// patterns/trash/Trash.dat
Glass:54
Paper:22
Paper:11
Glass:17
Aluminum:89
Paper:88
Aluminum:76
```

Cardboard:96

Aluminum:25

Aluminum:34

Glass:11

Glass:68

Glass:43

Aluminum:27

Cardboard:44

Aluminum:18

Paper:91

Glass:63

Glass:50

Glass:80

Aluminum:81

Cardboard:12

Glass:12

Glass:54

Aluminum:36

Aluminum:93

Glass:93

Paper:80

Glass:36

Glass:12

Glass:60

Paper:66

Aluminum:36

Cardboard:22

The **Trash** parser is placed in a separate file since it will also be reused throughout this chapter:

```
// patterns/trash/ParseTrash.java
// Open a file and parse its contents into
// Trash objects, placing each into a List
// {java patterns.trash.ParseTrash}
package patterns.trash;
import java.util.*;
import java.util.stream.*;
import java.io.*;
import java.nio.file.*;
import java.nio.file.Files;
public class ParseTrash {
```

```
public static <T extends Trash> void
fillBin(String pckg, Fillable<T> bin) {
try {
Files.lines(Paths.get("trash", "Trash.dat"))
// Remove empty lines and comment lines:
.filter(line -> line.trim().length() != 0)
.filter(line -> !line.startsWith("//"))
.forEach( line -> {
String type = "patterns." + pckg + "." +
line.substring(
0, line.indexOf(':')).trim();
double weight = Double.valueOf(
line.substring(line.indexOf(':') + 1)
.trim());
bin.addTrash(Trash.factory(
new Trash.Info(type, weight)));
});
} catch(IOException |
NumberFormatException |
Trash.TrashClassNotFoundException |
```

```
Trash.CannotCreateTrashException e) {
throw new RuntimeException(e);
}
}
// Special case to handle List:
public static <T extends Trash> void
fillBin(String pckg, List<T> bin) {
fillBin(pckg, new FillableList<>(bin));
}
// Basic test:
public static void main(String[] args) {
List<Trash> t = new ArrayList<>();
fillBin("trash", t);
t.forEach(System.out::println);
}
}
/* Output:
Loading patterns.trash.Glass
Loading patterns.trash.Paper
Loading patterns.trash.Aluminum
```

Loading patterns.trash.Cardboard

patterns.trash.Glass w:54.0 v:0.23

patterns.trash.Paper w:22.0 v:0.10

patterns.trash.Paper w:11.0 v:0.10

patterns.trash.Glass w:17.0 v:0.23

patterns.trash.Aluminum w:89.0 v:1.67

patterns.trash.Paper w:88.0 v:0.10

patterns.trash.Aluminum w:76.0 v:1.67

patterns.trash.Cardboard w:96.0 v:0.23

patterns.trash.Aluminum w:25.0 v:1.67

patterns.trash.Aluminum w:34.0 v:1.67

patterns.trash.Glass w:11.0 v:0.23

patterns.trash.Glass w:68.0 v:0.23

patterns.trash.Glass w:43.0 v:0.23

patterns.trash.Aluminum w:27.0 v:1.67

patterns.trash.Cardboard w:44.0 v:0.23

patterns.trash.Aluminum w:18.0 v:1.67

patterns.trash.Paper w:91.0 v:0.10

patterns.trash.Glass w:63.0 v:0.23

patterns.trash.Glass w:50.0 v:0.23

patterns.trash.Glass w:80.0 v:0.23

patterns.trash.Aluminum w:81.0 v:1.67

patterns.trash.Cardboard w:12.0 v:0.23

patterns.trash.Glass w:12.0 v:0.23

patterns.trash.Glass w:54.0 v:0.23

patterns.trash.Aluminum w:36.0 v:1.67

patterns.trash.Aluminum w:93.0 v:1.67

patterns.trash.Glass w:93.0 v:0.23

patterns.trash.Paper w:80.0 v:0.10

patterns.trash.Glass w:36.0 v:0.23

patterns.trash.Glass w:12.0 v:0.23

patterns.trash.Glass w:60.0 v:0.23

patterns.trash.Paper w:66.0 v:0.10

patterns.trash.Aluminum w:36.0 v:1.67

patterns.trash.Cardboard w:22.0 v:0.23

*/

The file path is read relative to the parent directory (**patterns**)

because related examples will also be packaged off of that directory.

Trash.dat is turned into a **Stream** of lines, and filtered for comments and empty lines. Then the **String** method **indexOf()**

produces the index of the **:**. This is first used with the **String**

method **substring()** to extract the name of the trash type, and next to get the weight that is turned into a **double** with the **static** **Double.valueOf()** method. The **trim()** method removes white space at both ends of a **String**. The specific **package** name is

included, with **trash** prepended, so that Java reflection is able to locate and load the class file.

In **RecycleA.java**, an **ArrayList** was used to hold the **Trash** objects. However, other types of collections can be used as well. To allow this, the first version of **fillBin()** takes a reference to a **Fillable**, which is simply an interface that supports a method called **addTrash()**:

```
// patterns/trash/Fillable.java
// Any object that can be filled with Trash
package patterns.trash;
public interface Fillable<T extends Trash> {
void addTrash(T t);
}
```

Anything that supports this interface can be used with **fillBin()**. However, **List** doesn't implement **Fillable**, so it won't work. Since **List** is used in most of the examples, it makes sense to add a second overloaded **fillBin()** method that takes an **List<Trash>** . The **List<Trash>** can be used as a **Fillable** object using an *Adapter* class:

```
// patterns/trash/FillableList.java
```

```
// Adapter that makes a List Fillable
package patterns.trash;
import java.util.*;
public class FillableList<T extends Trash>
implements Fillable<T> {
private List<T> v;
public FillableList(List<T> vv) {
v = vv;
}
@Override
public void addTrash(T t) { v.add(t); }
}
```

The only job of this class is to connect **Fillable**s **addTrash()** method to **List**s **add()**. With this class in hand, the overloaded **fillBin()** method can be used with an **List** in **ParseTrash.java**.

This approach works for any collection class that's used frequently. Alternatively, the collection class can provide its own adapter that implements **Fillable**. (You'll see this later, in **DynaTrash.java**.)

Recycling with Anonymous Trash Creation

Here's the revised version of **RecycleA.java** using the new technique:

```
// patterns/recycleb/RecycleB.java
// {java patterns.recycleb.RecycleB}
package patterns.recycleb;
import patterns.trash.*;
import java.util.*;
public class RecycleB {
public static void main(String[] args) {
List<Trash> bin = new ArrayList<>();
// Fill up the Trash bin:
ParseTrash.fillBin("trash", bin);
List<Glass> glassBin = new ArrayList<>();
List<Paper> paperBin = new ArrayList<>();
List<Aluminum> alBin = new ArrayList<>();
// Sort the Trash:
bin.forEach( t -> {
// RTTI to discover Trash type:
if(t instanceof Aluminum)
```

```
alBin.add((Aluminum)t);
if(t instanceof Paper)
paperBin.add((Paper)t);
if(t instanceof Glass)
glassBin.add((Glass)t);
});
Trash.sumValue(alBin);
Trash.sumValue(paperBin);
Trash.sumValue(glassBin);
Trash.sumValue(bin);
}
}
/* Output: (First and Last 10 Lines)
Loading patterns.trash.Glass
Loading patterns.trash.Paper
Loading patterns.trash.Aluminum
Loading patterns.trash.Cardboard
weight of patterns.trash.Aluminum = 89.0
weight of patterns.trash.Aluminum = 76.0
weight of patterns.trash.Aluminum = 25.0
```

weight of patterns.trash.Aluminum = 34.0

weight of patterns.trash.Aluminum = 27.0

weight of patterns.trash.Aluminum = 18.0

..._____..._____..._____..._____...

weight of patterns.trash.Aluminum = 93.0

weight of patterns.trash.Glass = 93.0

weight of patterns.trash.Paper = 80.0

weight of patterns.trash.Glass = 36.0

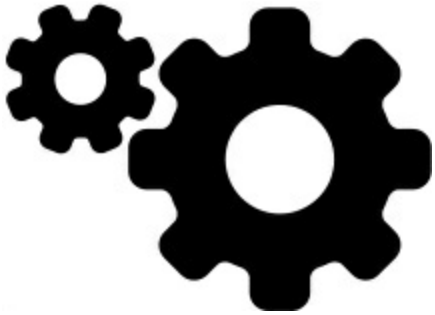
weight of patterns.trash.Glass = 12.0

weight of patterns.trash.Glass = 60.0

weight of patterns.trash.Paper = 66.0

weight of patterns.trash.Aluminum = 36.0

weight of patterns.trash.Cardboard = 22.0



Total value = 1086.0599818825722

**/*

The process of parsing **Trash.dat** is wrapped into the **static**

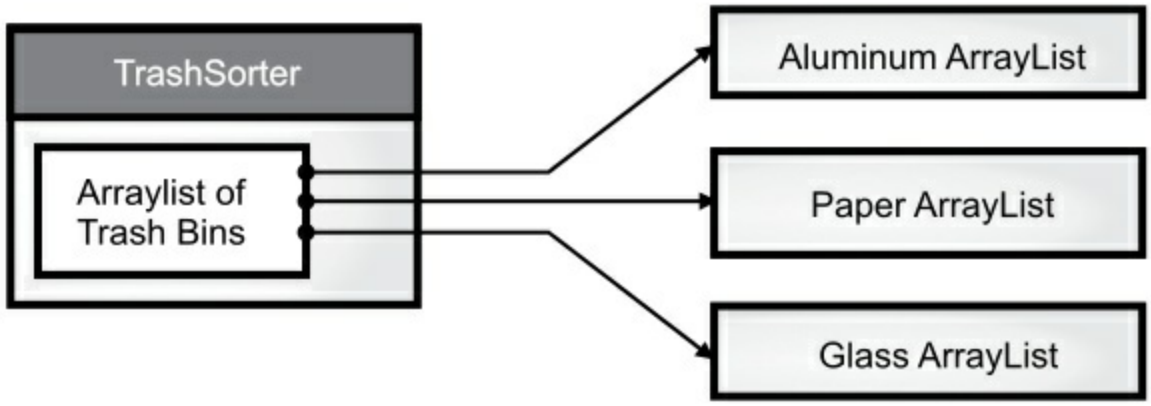
method **ParseTrash.fillBin()**, so now it's no longer a part of our design focus. Throughout the rest of the chapter, no matter what new classes are added, **ParseTrash.fillBin()** will continue to work without change, which indicates a good design.

In terms of object creation, this design does indeed severely localize the changes you must make to add a new type to the system. However, there's a significant problem in the use of RTTI that shows up clearly here. The program seems to run fine, and yet it never detects any cardboard, even though there is cardboard in the list! This happens *because* of the use of RTTI, which looks only for your desired types. The clue that RTTI is misused here is that *every type in the system* is tested, rather than a single type or subset of types. As you will see later, there are ways to use polymorphism instead when you're testing for every type. But if you use RTTI a lot in this fashion, and you add a new type to your system, you can easily forget to make the necessary changes in your program and produce a difficult-to-find bug. So it's worth trying to eliminate RTTI here, not just for aesthetic reasons—it produces more maintainable code.

Abstracting Usage

With creation out of the way, it's time to tackle the remainder of the

design: where the classes are used. Since it's the act of sorting into bins that's particularly ugly and exposed, let's apply the principle of "Hide ugliness inside methods or classes." It looks like this:



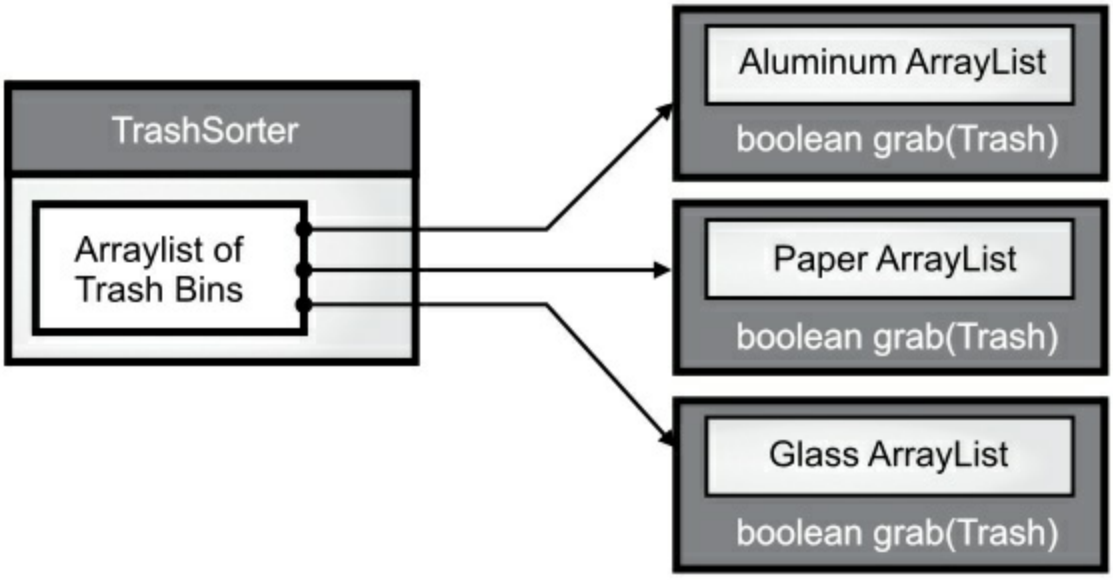
The **TrashSorter** object initialization must now be changed whenever a new type of **Trash** is added to the model. You can imagine that the **TrashSorter** class might look something like this:

```
class TrashSorter extends ArrayList<ArrayList<Trash>> {
void sort(Trash t) { /* ... */ }
}
```

That is, **TrashSorter** is a **List** of references to **List**s of **Trash** references, and with **add()** you can install another one.

Now, however, **sort()** becomes a problem. How does the statically-coded method deal with the fact that a new type was added? To solve this, the type information must be removed from **sort()** so all it

must do is call a general-purpose method that takes care of the details of type. This is another way to describe a dynamically-bound method. So **sort()** will simply move through the sequence and call a dynamically-bound method for each **ArrayList**. Since the job of this method is to grab the pieces of trash it is interested in, it's called **grab(Trash)**. The structure now looks like:



TrashSorter calls each **grab()** method and get a different result depending on what type of **Trash** the current **List** is holding. That is, each **List** must be aware of the type it holds. The classic approach to this problem is to create a base **Trash bin** class and inherit a new derived class for each different type to hold. Further observation can produce a better approach.

A basic OOP design principle is:

Use data members for variation in state,

use polymorphism for variation in

behavior.

Your first thought might be that the **grab()** method certainly

behaves differently for a **List** that holds **Paper** than for one that

holds **Glass**. But what it does is strictly dependent on the type, and

nothing else. This could be interpreted as a different state, and since

Java has a class to represent type (**Class**), this determines the type of

Trash a particular **Tbin** will hold.

The constructor for this **Tbin** requires that you hand it the **Class** of

your choice. This tells the **List** what type it is supposed to hold. Then the **grab()** method uses **Class BinType** and RTTI to see if the

Trash object you've handed it matches the type it's supposed to grab.

Here is the whole program. The commented tagged numbers (e.g. **//**

[1]) mark sections to be described following the code.

```
// patterns/recyclec/RecycleC.java
// Adding more objects to the recycling problem
// {java patterns.recyclec.RecycleC}
package patterns.recyclec;
import patterns.trash.*;
```

```
import java.util.*;
// A List that admits only the right type:
class Tbin<T extends Trash> extends ArrayList<T> {
Class<T> binType;
Tbin(Class<T> type) {
binType = type;
}
@SuppressWarnings("unchecked")
boolean grab(Trash t) {
// Comparing class types:
if(t.getClass().equals(binType)) {
add((T)t); // Downcast to this TBin's type
return true; // Object grabbed
}
return false; // Object not grabbed
}
}
class TbinList<T extends Trash>
extends ArrayList<Tbin<? extends T>> { // [1]
boolean sort(T t) {
```

```
for(Tbin<? extends T> ts : this)
if(ts.grab(t))
return true;
return false; // bin not found for t
}
void sortBin(Tbin<T> bin) { // [2]
for(T aBin : bin)
if(!sort(aBin))
System.err.println("Bin not found");
}
}
public class RecycleC {
static Tbin<Trash> bin = new Tbin<>(Trash.class);
public static void main(String[] args) {
// Fill up the Trash bin:
ParseTrash.fillBin("trash", bin);
TbinList<Trash> trashBins = new TbinList<>();
trashBins.add(new Tbin<>(Aluminum.class));
trashBins.add(new Tbin<>(Paper.class));
trashBins.add(new Tbin<>(Glass.class));
```

```
// add one line here: [*3*]
trashBins.add(new Tbin<>(Cardboard.class));
trashBins.sortBin(bin); // [4]
trashBins.forEach(Trash::sumValue);
Trash.sumValue(bin);
}
}
/* Output: (First and Last 10 Lines)
Loading patterns.trash.Glass
Loading patterns.trash.Paper
Loading patterns.trash.Aluminum
Loading patterns.trash.Cardboard
weight of patterns.trash.Aluminum = 89.0
weight of patterns.trash.Aluminum = 76.0
weight of patterns.trash.Aluminum = 25.0
weight of patterns.trash.Aluminum = 34.0
weight of patterns.trash.Aluminum = 27.0
weight of patterns.trash.Aluminum = 18.0
...________...________...________...________...
weight of patterns.trash.Aluminum = 93.0
```

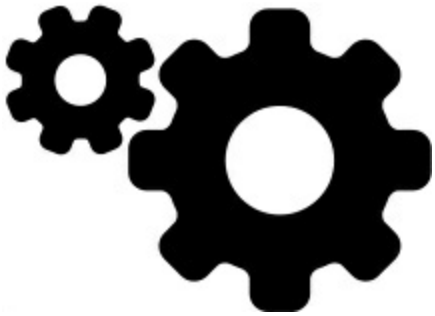
weight of patterns.trash.Glass = 93.0

weight of patterns.trash.Paper = 80.0

weight of patterns.trash.Glass = 36.0

weight of patterns.trash.Glass = 12.0

weight of patterns.trash.Glass = 60.0



weight of patterns.trash.Paper = 66.0

weight of patterns.trash.Aluminum = 36.0

weight of patterns.trash.Cardboard = 22.0

Total value = 1086.0599818825722

**/*

[1] TbinList holds a set of **Tbin** references, so **sort()** can iterate through the **Tbin**s when it's looking for a match for the **Trash** object you've handed it.

[2] sortBin() allows you to pass an entire **Tbin** in, and it moves through the **Tbin**, picks out each piece of **Trash**, and sorts it into the appropriate specific **Tbin**. Notice the genericity

of this code: it doesn’t change at all if new types are added. If the bulk of your code doesn’t need changing when a new type is added (or some other change occurs) then you have an easily-extensible system.

[3] Notice how easy it is to add a new type. Few lines must be changed to support the addition. If it’s really important, you can squeeze out even more by further manipulating the design.

[4] One method call causes the contents of **bin** to be sorted into the respective specifically-typed bins.

Multiple Dispatching

The above design is certainly satisfactory. Adding new types to the system consists of adding or modifying distinct classes without causing code changes to be propagated throughout the system. In addition, RTTI is not “misused” as it was in **RecycleA.java**. However, it’s possible to go one step further and take a purist viewpoint about RTTI and say it should be eliminated altogether from

the operation of sorting the trash into bins.

To accomplish this, you must first take the perspective that all type-dependent activities—such as detecting the type of a piece of trash and putting it into the appropriate bin—should be controlled through polymorphism and dynamic binding.

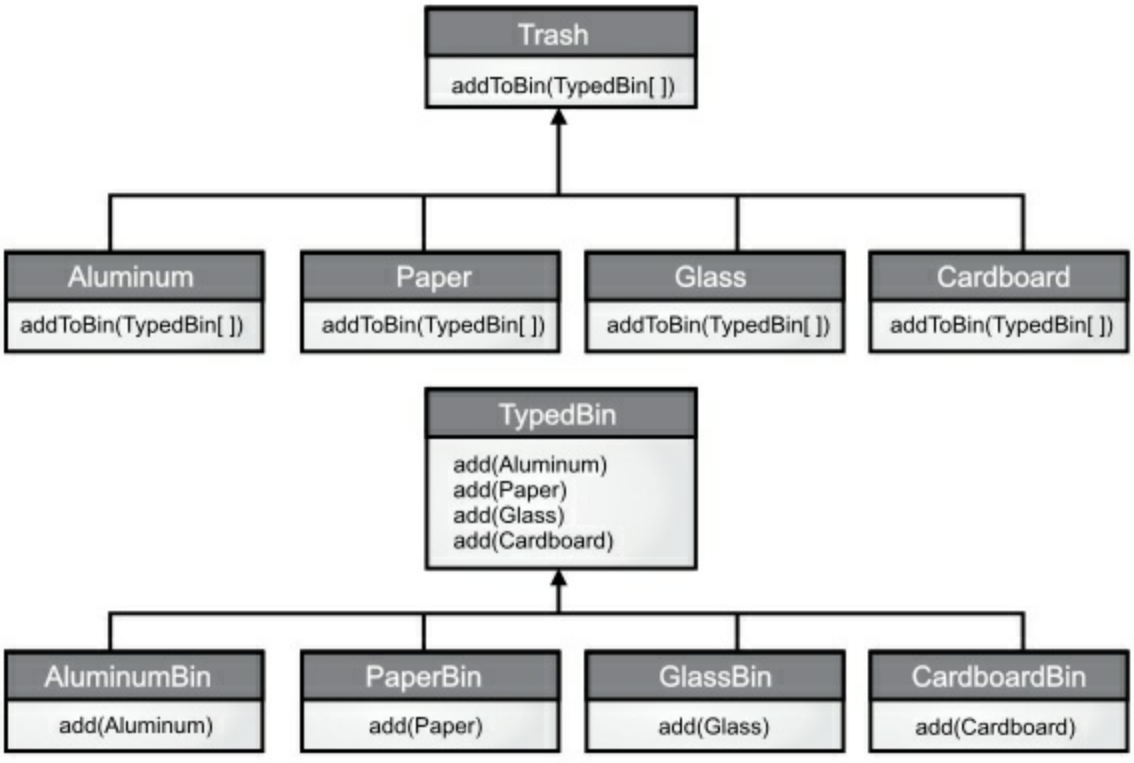
The previous examples first sorted by type, then acted on sequences of elements that were all of a particular type. But whenever you find yourself picking out particular types, stop and think. The whole idea of polymorphism (dynamically-bound method calls) is to handle type-specific information for you. So why are you hunting for types?

The answer is something you probably don’t think about: Java performs only single dispatching. That is, if you are performing an operation on more than one object whose type is unknown, Java will invoke the dynamic binding mechanism on only one of those types. This doesn’t solve the problem, so you end up detecting some types manually and effectively producing your own dynamic binding behavior.

The solution is *Multiple Dispatching*. We set up a configuration such that a single method call produces more than one dynamic method call and thus determines more than one type in the process. To get this effect, you must work with multiple type hierarchies: one type

hierarchy for each dispatch. The following example works with two hierarchies: the existing **Trash** family and a hierarchy of the types of trash bins that the trash is placed into. This second hierarchy isn't always obvious and here it was required to produce multiple dispatching (here there are only two dispatches, which is *Double Dispatching*).

Implementing the Double Dispatch



In the **Trash** hierarchy there is a new method called **addToBin()**, which takes an argument of an array of **TypedBin**. It uses this array

to step through and try to add itself to the appropriate bin, and this is where you'll see the double dispatch.

The new hierarchy is **TypedBin**, and it contains its own method called **add()** that is also used polymorphically. But here's an additional twist: **add()** is *overloaded* to take arguments of the different types of trash. So an essential part of the double dispatching scheme also involves overloading.

Redesigning the program produces a dilemma: it's now necessary for the base class **Trash** to contain an **addToBin()** method. One approach is to copy all the code and change the base class. Another approach, which you can take when you don't have control of the source code, is to put the **addToBin()** method into an interface, leave **Trash** alone, and inherit new specific types of **Aluminum**, **Paper**, **Glass**, and **Cardboard**. This is the approach we'll take.

Most of the classes in this design must be **public**, so they are placed in their own files. Here is the interface:

```
// patterns/doubledispatch/TypedBinMember.java
// An interface for adding the double dispatching
// method to the trash hierarchy without
// modifying the original hierarchy
package patterns.doubledispatch;
```

```
import java.util.*;
public interface TypedBinMember {
// The new method:
boolean addToBin(List<TypedBin> bins);
}
```

In each particular subtype of **Aluminum**, **Paper**, **Glass**, and **Cardboard**, the **addToBin()** method in the **interface TypedBinMember** is implemented, but it *looks* like the code is exactly the same in each case:

```
// patterns/doubledispatch/Aluminum.java
// Aluminum for double dispatching
package patterns.doubledispatch;
import patterns.trash.*;
import java.util.*;
public class Aluminum extends patterns.trash.Aluminum
implements TypedBinMember {
public Aluminum(double wt) { super(wt); }
@Override
public boolean addToBin(List<TypedBin> tbins) {
return tbins.stream()
```

```
.anyMatch(tb -> tb.add(this));
}
}
// patterns/doubledispatch/Paper.java
// Paper for double dispatching
package patterns.doubledispatch;
import patterns.trash.*;
import java.util.*;
public class Paper extends patterns.trash.Paper
implements TypedBinMember {
public Paper(double wt) { super(wt); }
@Override
public boolean addToBin(List<TypedBin> tbins) {
return tbins.stream()
.anyMatch(tb -> tb.add(this));
}
}
// patterns/doubledispatch/Glass.java
// Glass for double dispatching
package patterns.doubledispatch;
```

```
import patterns.trash.*;
import java.util.*;
public class Glass extends patterns.trash.Glass
implements TypedBinMember {
public Glass(double wt) { super(wt); }
@Override
public boolean addToBin(List<TypedBin> tbins) {
return tbins.stream()
.anyMatch(tb -> tb.add(this));
}
}
// patterns/doubledispatch/Cardboard.java
// Cardboard for double dispatching
package patterns.doubledispatch;
import patterns.trash.*;
import java.util.*;
public class Cardboard extends patterns.trash.Cardboard
implements TypedBinMember {
public Cardboard(double wt) { super(wt); }
@Override
```

```
public boolean addToBin(List<TypedBin> tbins) {
return tbins.stream()
.anyMatch(tb -> tb.add(this));
}
}
```

The code in each **addToBin()** calls **add()** for each **TypedBin** object in the array. But notice the argument: **this**. The type of **this** is different for each subclass of **Trash**, so the code is different. (With C++ templates, you can have a single definition of **addToBin()**, but because of erasure Java generics don't help here.) So this is the first part of the double dispatch, because once you're inside this method you know you're **Aluminum**, or **Paper**, etc. During the call to **add()**, this information is passed via the type of **this**. The compiler resolves the call to the proper overloaded version of **add()**. But since **tb** produces a reference to the base type **TypedBin**, this call will end up calling a different method depending on the type of **TypedBin** that's currently selected. That is the second dispatch.

Here's the base class for **TypedBin**:

```
// patterns/doubledispatch/TypedBin.java
// A List that can grab the right type
```

```
package patterns.doubledispatch;
import patterns.trash.*;
import java.util.*;
public class TypedBin {
List<Trash> v = new ArrayList<>();
protected boolean addIt(Trash t) {
v.add(t);
return true;
}
public boolean add(Aluminum a) {
return false;
}
public boolean add(Paper a) {
return false;
}
public boolean add(Glass a) {
return false;
}
public boolean add(Cardboard a) {
return false;
```

}

}

The overloaded **add()** methods all return **false**. If the method is not overloaded in a derived class, it will continue to return **false**, and the caller (**addToBin()**, in this case) will assume that the current **Trash** object has not been added successfully to a collection, and continue searching for the right collection.

In each of the subclasses of **TypedBin**, only one overloaded method is overridden, according to the type of bin that's created. For example, **CardboardBin** overrides **add(Cardboard)**. The overridden method adds the trash object to its collection and returns **true**, while all the rest of the **add()** methods in **CardboardBin** continue to return **false**, as they haven't been overridden.

Here's the rest of the program:

```
// patterns/doubledispatch/DoubleDispatch.java
// Using multiple dispatching to handle more
// than one unknown type during a method call
// {java patterns.doubledispatch.DoubleDispatch}
package patterns.doubledispatch;
import patterns.trash.*;
```

```
import java.util.*;
class AluminumBin extends TypedBin {
@Override
public boolean add(Aluminum a) {
return addIt(a);
}
}
class PaperBin extends TypedBin {
@Override
public boolean add(Paper a) {
return addIt(a);
}
}
class GlassBin extends TypedBin {
@Override
public boolean add(Glass a) {
return addIt(a);
}
}
class CardboardBin extends TypedBin {
```

```
@Override
public boolean add(Cardboard a) {
return addIt(a);
}
}
class TrashBinSet {
private List<TypedBin> binSet = Arrays.asList(
new AluminumBin(),
new PaperBin(),
new GlassBin(),
new CardboardBin()
);
@SuppressWarnings("unchecked")
public void sortIntoBins(List bin) {
bin.forEach( aBin -> {
TypedBinMember t = (TypedBinMember)aBin;
if(!t.addToBin(binSet))
System.err.println("Couldn't add " + t);
});
}
```

```
public List<TypedBin> binSet() { return binSet; }
}
public class DoubleDispatch {
public static void main(String[] args) {
List<Trash> bin = new ArrayList<>();
TrashBinSet bins = new TrashBinSet();
// ParseTrash still works, without changes:
ParseTrash.fillBin("doubledispatch", bin);
// Sort from the master bin into the
// individually-typed bins:
bins.sortIntoBins(bin);
// Perform sumValue for each bin...
bins.binSet()
.forEach(tb -> Trash.sumValue(tb.v));
// ... and for the master bin
Trash.sumValue(bin);
}
}
/* Output: (First and Last 10 Lines)
Loading patterns.doubledispatch.Glass
```

Loading patterns.doubledispatch.Paper

Loading patterns.doubledispatch.Aluminum

Loading patterns.doubledispatch.Cardboard

weight of patterns.doubledispatch.Aluminum = 89.0

weight of patterns.doubledispatch.Aluminum = 76.0

weight of patterns.doubledispatch.Aluminum = 25.0

weight of patterns.doubledispatch.Aluminum = 34.0

weight of patterns.doubledispatch.Aluminum = 27.0

weight of patterns.doubledispatch.Aluminum = 18.0

..._____..._____..._____..._____...

weight of patterns.doubledispatch.Aluminum = 93.0

weight of patterns.doubledispatch.Glass = 93.0

weight of patterns.doubledispatch.Paper = 80.0

weight of patterns.doubledispatch.Glass = 36.0

weight of patterns.doubledispatch.Glass = 12.0

weight of patterns.doubledispatch.Glass = 60.0

weight of patterns.doubledispatch.Paper = 66.0

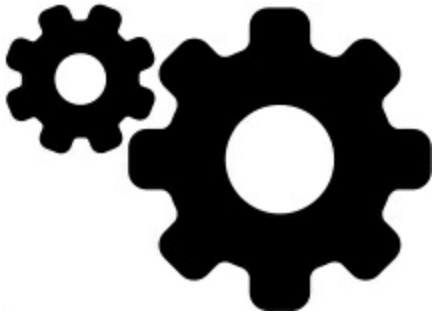
weight of patterns.doubledispatch.Aluminum = 36.0

weight of patterns.doubledispatch.Cardboard = 22.0

Total value = 1086.0599818825722

*/

TrashBinSet encapsulates all different types of **TypedBin**s, along



with the **sortIntoBins()** method, which is where all the double dispatching takes place. Once the structure is set up, sorting into the various **TypedBin**s is remarkably easy. In addition, the efficiency of two dynamic method calls is probably better than any other way you can sort.

Notice the ease of use of this system in **main()**, as well as the complete independence of any specific type information within **main()**. All other methods that talk only to the **Trash** base-class interface are equally invulnerable to changes in **Trash** types.

The changes necessary to add a new type are relatively isolated: you inherit the new type of **Trash** with its **addToBin()** method, then you inherit a new **TypedBin**, and finally you add a new type into the aggregate initialization for **TrashBinSet**.

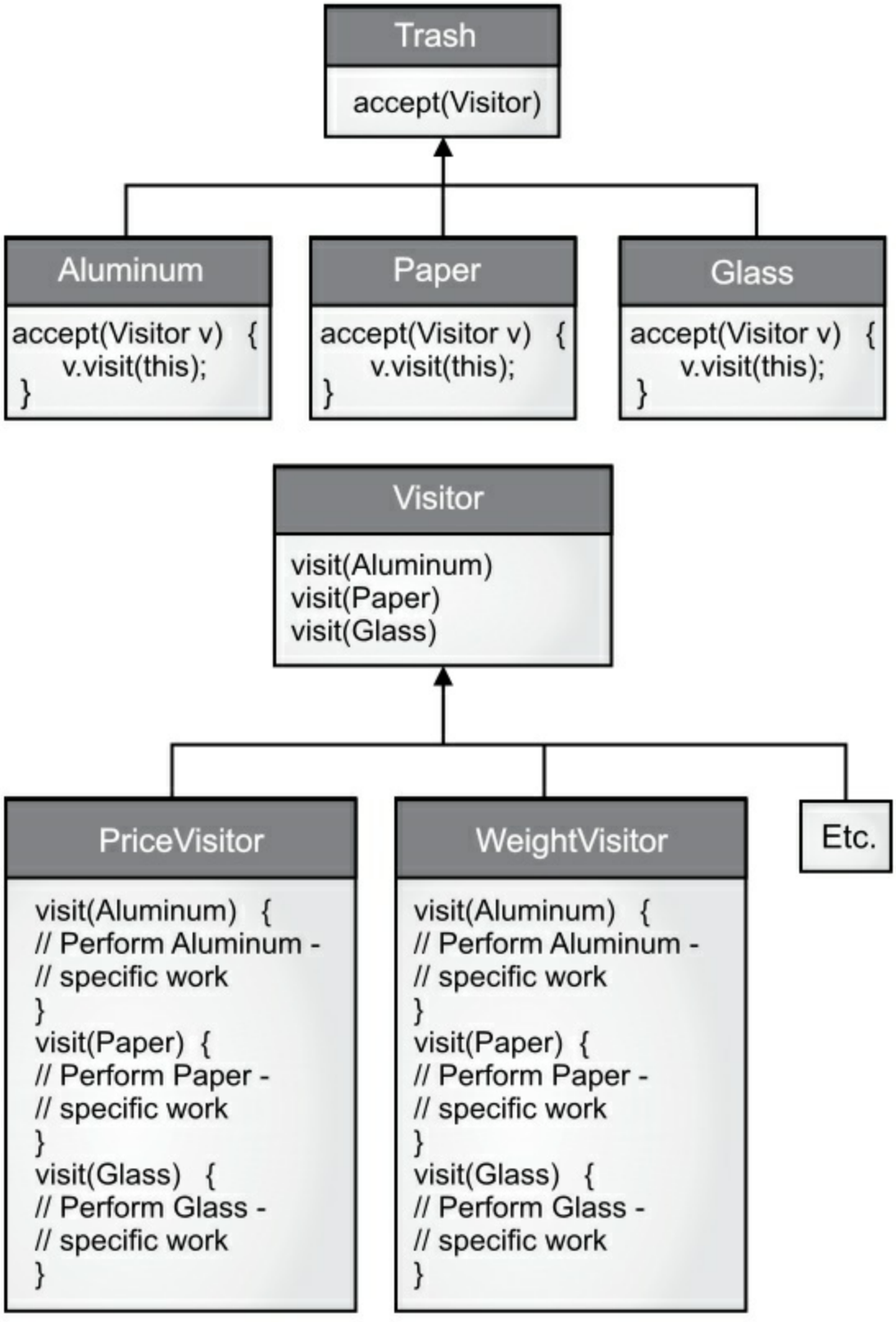
The *Visitor* Pattern

Now consider applying a design pattern with an entirely different goal to the trash-sorting problem.

For this pattern, we are no longer concerned with optimizing the addition of new types of **Trash** to the system. Indeed, *Visitor* makes adding a new type of **Trash** *more* complicated. The assumption is that you have a primary class hierarchy that is fixed; perhaps it's from another vendor and you can't make changes to that hierarchy. However, you'd like to add new polymorphic methods to that hierarchy, which means that normally you'd have to add something to the base class interface. So the dilemma is that you must add methods to the base class, but you can't touch the base class. How do you get around this?

The *Visitor* pattern solves this kind of problem, and it builds on the double dispatching scheme you've seen earlier.

Visitor allows you to extend the interface of the primary type by creating a separate class hierarchy of type **Visitor** to virtualize the operations performed upon the primary type. The objects of the primary type simply "accept" the visitor, then call the visitor's dynamically-bound method. It looks like this:



Now, if **v** is a **Visitable** reference to an **Aluminum** object, the

code:

PriceVisitor pv = **new** PriceVisitor();

v.accept(pv);

causes two polymorphic method calls: the first one to select **Aluminum**s version of **accept()**, and the second one within **accept()**, when the specific version of **visit()** is called dynamically using the base-class **Visitor** reference **v**.

This configuration means new functionality can be added to the system in the form of new subclasses of **Visitor**. The **Trash** hierarchy doesn't need modification. This is the prime benefit of the *Visitor* pattern: you can add new polymorphic functionality to a class hierarchy without touching that hierarchy (once the **accept()** methods are installed). Note that the benefit is helpful here but not exactly what we started out to accomplish, so at first blush you might decide this isn't the desired solution.

But look at one thing we've accomplished: the visitor solution avoids sorting from the master **Trash** sequence into individual typed sequences. Thus, you can leave everything in the single master sequence and simply pass through that sequence using the appropriate visitor to accomplish the goal. Although this behavior seems to be a

side effect of *Visitor*, it does give us what we want (avoiding RTTI). The double dispatching in the *Visitor* pattern determines both the type of **Trash** and the type of **Visitor**. In the following example, there are two implementations of **Visitor**: **PriceVisitor** to both determine and sum the price, and **WeightVisitor** to keep track of the weights.

You see all of this implemented in the new, improved version of the recycling program. As with **DoubleDispatch.java**, the **Trash** class is left alone and we create a new interface containing the **accept()** method:

```
// patterns/trashvisitor/Visitable.java
// An interface to add visitor functionality to the
// Trash hierarchy without modifying the base class
package patterns.trashvisitor;
public interface Visitable {
// The new method:
void accept(Visitor v);
}
```

The subtypes of **Aluminum**, **Paper**, **Glass**, and **Cardboard** implement the **accept()** method:

```
// patterns/trashvisitor/Aluminum.java
// Aluminum for the visitor pattern
package patterns.trashvisitor;
import patterns.trash.*;
public class Aluminum extends patterns.trash.Aluminum
implements Visitable {
public Aluminum(double wt) { super(wt); }
@Override
public void accept(Visitor v) {
v.visit(this);
}
}
// patterns/trashvisitor/Paper.java
// Paper for the visitor pattern
package patterns.trashvisitor;
import patterns.trash.*;
public class Paper extends patterns.trash.Paper
implements Visitable {
public Paper(double wt) { super(wt); }
@Override
```

```
public void accept(Visitor v) {
v.visit(this);
}
}
// patterns/trashvisitor/Glass.java
// Glass for the visitor pattern
package patterns.trashvisitor;
import patterns.trash.*;
public class Glass extends patterns.trash.Glass
implements Visitable {
public Glass(double wt) { super(wt); }
@Override
public void accept(Visitor v) {
v.visit(this);
}
}
// patterns/trashvisitor/Cardboard.java
// Cardboard for the visitor pattern
package patterns.trashvisitor;
import patterns.trash.*;
```

```
public class Cardboard extends patterns.trash.Cardboard
implements Visitable {
public Cardboard(double wt) { super(wt); }
@Override
public void accept(Visitor v) {
v.visit(this);
}
}
```

Since there's nothing concrete in the **Visitor** base class, it can be created as an interface:

```
// patterns/trashvisitor/Visitor.java
// The base interface for visitors
package patterns.trashvisitor;
public interface Visitor {
void visit(Aluminum a);
void visit(Paper p);
void visit(Glass g);
void visit(Cardboard c);
void total();
}
```

The rest of the program creates specific **Visitor** types and sends them through a single list of **Trash** objects:

```
// patterns/trashvisitor/TrashVisitor.java
// {java patterns.trashvisitor.TrashVisitor}
package patterns.trashvisitor;
import patterns.trash.*;
import java.util.*;
// Specific group of algorithms packaged
// in each implementation of Visitor:
class PriceVisitor implements Visitor {
private double alSum; // Aluminum
private double pSum; // Paper
private double gSum; // Glass
private double cSum; // Cardboard
public static void show(String s) {
System.out.println(s);
}
@Override
public void visit(Aluminum al) {
double v = al.weight() * al.value();
```

```
show("value of Aluminum= " + v);
alSum += v;
}
@Override
public void visit(Paper p) {
double v = p.weight() * p.value();
show("value of Paper= " + v);
pSum += v;
}
@Override
public void visit(Glass g) {
double v = g.weight() * g.value();
show("value of Glass= " + v);
gSum += v;
}
@Override
public void visit(Cardboard c) {
double v = c.weight() * c.value();
show("value of Cardboard = " + v);
cSum += v;
```

```
}
@Override
public void total() {
show(
"Total Aluminum: $" + alSum + "\n" +
"Total Paper: $" + pSum + "\n" +
"Total Glass: $" + gSum + "\n" +
"Total Cardboard: $" + cSum);
}
}
class WeightVisitor implements Visitor {
private double alSum; // Aluminum
private double pSum; // Paper
private double gSum; // Glass
private double cSum; // Cardboard
public static void show(String s) {
System.out.println(s);
}
@Override
public void visit(Aluminum al) {
```

```
alSum += al.weight();
show("Aluminum weight = " + al.weight());
}
@Override
public void visit(Paper p) {
pSum += p.weight();
show("Paper weight = " + p.weight());
}
@Override
public void visit(Glass g) {
gSum += g.weight();
show("Glass weight = " + g.weight());
}
@Override
public void visit(Cardboard c) {
cSum += c.weight();
show("Cardboard weight = " + c.weight());
}
@Override
public void total() {
```

```
show("Total weight Aluminum:" + alSum);
show("Total weight Paper:" + pSum);
show("Total weight Glass:" + gSum);
show("Total weight Cardboard:" + cSum);
}
}
public class TrashVisitor {
public static void main(String[] args) {
List<Trash> bin = new ArrayList<>();
// ParseTrash still works, without changes:
ParseTrash.fillBin("trashvisitor", bin);
List<Visitor> visitors = Arrays.asList(
new PriceVisitor(), new WeightVisitor());
bin.forEach( t -> {
Visitable v = (Visitable) t;
visitors.forEach(visitor -> v.accept(visitor));
});
visitors.forEach(Visitor::total);
}
}
```

/ Output: (First and Last 10 Lines)*

Loading patterns.trashvisitor.Glass

Loading patterns.trashvisitor.Paper

Loading patterns.trashvisitor.Aluminum

Loading patterns.trashvisitor.Cardboard

value of Glass= 12.420000225305557

Glass weight = 54.0

value of Paper= 2.2000000327825546

Paper weight = 22.0

value of Paper= 1.1000000163912773

Paper weight = 11.0

..._____..._____..._____..._____...

value of Cardboard = 5.060000091791153

Cardboard weight = 22.0

Total Aluminum: $860.0499778985977

Total Paper: $35.80000053346157

Total Glass: $150.1900027245283

Total Cardboard: $40.02000072598457

Total weight Aluminum:515.0

Total weight Paper:358.0

Total weight Glass:653.0

Total weight Cardboard:174.0

*/

Note that the shape of **main()** has changed again. Now there's only a single **Trash** bin. The two **Visitor** objects are accepted into every element in the sequence, and they perform their operations. The visitors keep their own internal data to tally the total weights and prices.

Finally, there's no run-time type identification.

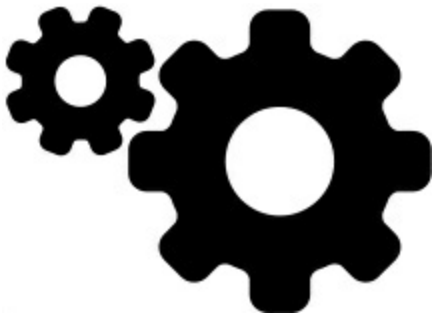
One way you can distinguish this solution from the double dispatching solution described previously is to note that, in the double dispatching solution, only one of the overloaded methods, **add()**, was overridden when each subclass was created, while here *each* one of the overloaded **visit()** methods is overridden in every subclass of **Visitor**.

More Coupling?

There's a lot more code here, and there's definite coupling between the

Trash hierarchy and the **Visitor** hierarchy. However, there's also high cohesion within the respective sets of classes: they each do only one thing (**Trash** describes Trash, while **Visitor** describes actions performed on **Trash**), which is an indicator of a good design. Here it works well only if you're adding new **Visitor**s, but it gets in the way when you add new types of **Trash**.

Low coupling between classes and high cohesion within a class is definitely an important design goal. Applied mindlessly, though, it can prevent you from achieving a more elegant design. It seems that some classes inevitably have a certain intimacy with each other. These often



occur in pairs that could perhaps be called *couplets*, for example, collections and iterators. The **Trash-Visitor** pair above appears to be another such couplet.

RTTI Considered Harmful?

Various designs in this chapter attempt to remove RTTI, which might

give you the impression it's "considered harmful" (the condemnation used for poor, ill-fated **goto**, which was thus never put into Java). This isn't true; it is the *misuse* of RTTI that is the problem. The reason our designs removed RTTI is because the misapplication of that feature prevented extensibility, while the stated goal was adding a new type to the system with low impact on surrounding code. Since RTTI is often misused by having it look for every single type in your system, it creates non-extensible code: when you add a new type, you have to go hunting for all the code where RTTI is used, and if you miss any you won't get help from the compiler.

However, RTTI doesn't automatically create non-extensible code. Let's revisit the trash recycler once more. This time, a new tool is introduced, which I call a **TypeMap**. It contains a **Map** that holds **List**s, but the interface is simple: you can **add()** a new object, and you can **get()** a **List** containing all the objects of a particular type. The keys for the contained **Map** are the types in the associated **List**. The beauty of this design is that the **TypeMap** dynamically adds a new pair whenever it encounters a new type, so whenever you add a new type to the system (even if you add the new type at run-time), it adapts.

Our example will again build on the structure of the **Trash** types in **package patterns.trash**:

```
// patterns/dynatrash/DynaTrash.java
// Using a Map of Lists and RTTI to automatically
// sort trash into Lists. This solution, despite
// the use of RTTI, is extensible.
// {java patterns.dynatrash.DynaTrash}
package patterns.dynatrash;
import patterns.trash.*;
import java.util.*;
import java.util.stream.*;
// Generic TypeMap works in any situation:
class TypeMap<T> {
private Map<Class,List<T>> t = new HashMap<>();
public void add(T o) {
Class type = o.getClass();
if(t.containsKey(type))
t.get(type).add(o);
else {
List<T> v = new ArrayList<>();
```

```
v.add(o);
t.put(type,v);
}
}
public Stream<List<T>> values() {
return t.values().stream();
}
}
// Adapter class for callbacks
// from ParseTrash.fillBin():
class TypeMapAdapter implements Fillable {
TypeMap<Trash> map;
TypeMapAdapter(TypeMap<Trash> tm) {
map = tm;
}
@Override
public void addTrash(Trash t) { map.add(t); }
}
public class DynaTrash {
@SuppressWarnings("unchecked")
```

```
public static void main(String[] args) {
TypeMap<Trash> bin = new TypeMap<>();
ParseTrash.fillBin(
"trash", new TypeMapAdapter(bin));
bin.values().forEach(Trash::sumValue);
}
}
/* Output: (First and Last 10 Lines)
Loading patterns.trash.Glass
Loading patterns.trash.Paper
Loading patterns.trash.Aluminum
Loading patterns.trash.Cardboard
weight of patterns.trash.Paper = 22.0
weight of patterns.trash.Paper = 11.0
weight of patterns.trash.Paper = 88.0
weight of patterns.trash.Paper = 91.0
weight of patterns.trash.Paper = 80.0
weight of patterns.trash.Paper = 66.0
...________...________...________...________...
weight of patterns.trash.Aluminum = 81.0
```

weight of patterns.trash.Aluminum = 36.0

weight of patterns.trash.Aluminum = 93.0

weight of patterns.trash.Aluminum = 36.0

Total value = 860.0499778985977

weight of patterns.trash.Cardboard = 96.0

weight of patterns.trash.Cardboard = 44.0

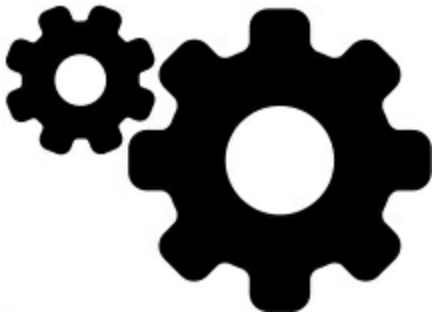
weight of patterns.trash.Cardboard = 12.0

weight of patterns.trash.Cardboard = 22.0

Total value = 40.02000072598457

**/*

Although powerful, the definition for **TypeMap** is simple. It contains a **Map**, and the **add()** method does most of the work. When you **add()** a new object, the **Class** object for that object's type is extracted. This is used as a key to determine whether a **List** holding objects of that type is already present in the **HashMap**. If so, that **List** is extracted and the object is added to the **List**. If not, the **Class** object and a new **ArrayList** are added as a key-value pair.



Even though this design wasn't created to handle the sorting, **fillBin()** is performing a sort every time it inserts a **Trash** object into **bin**.

Much of **class DynaTrash** should be familiar from the previous examples. This time, instead of placing the new **Trash** objects into a **bin** of type **List**, the **bin** is of type **TypeMap**, so when the trash is thrown into **bin** it's immediately sorted by **TypeMap**s internal sorting mechanism. Stepping through the **TypeMap** and operating on each individual **List** becomes a simple matter.

Adding a new type to the system won't affect this code at all, nor the code in **TypeMap**. This is certainly the smallest solution to the problem, and arguably the most elegant as well. It does rely heavily on RTTI, but notice that each key-value pair in the **Map** is looking for only one type. In addition, there's no way you can "forget" to add the proper code to this system when you add a new type, since there isn't any code you must add.

Summary

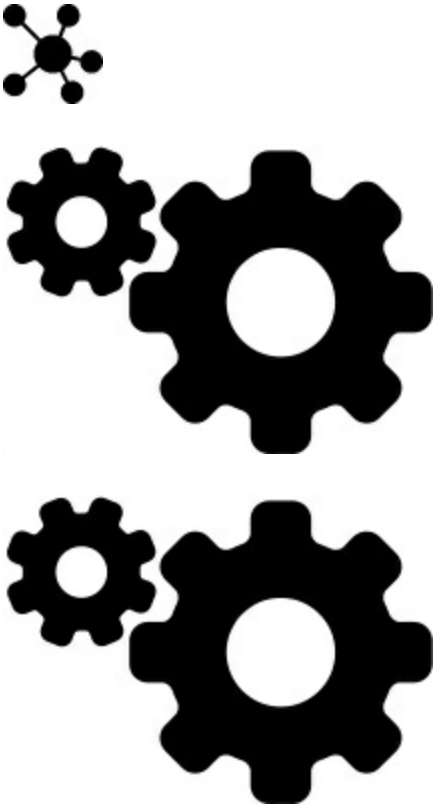
Discovering the vector of change is no trivial matter; it's not something that an analyst can usually detect before the program sees its initial design. The necessary insight will probably not appear until later phases in the project. Sometimes only at the design or implementation phases do you discover a deeper or more subtle need in your system. In the case of adding new types (which was the focus of most of the "recycle" examples) you might realize you need a particular inheritance hierarchy only when you are in the maintenance phase and you begin extending the system!

One of the most important things you'll learn by exploring design patterns seems to be an about-face from the impression people often get, that "OOP is all about polymorphism." This can produce the "two-year-old with a hammer" syndrome (everything looks like a nail). Put another way, it's hard to understand polymorphism, and once you do, you try to cast all your designs into that one particular mold.

What design patterns say is that OOP isn't just about polymorphism. It's about "separating the things that change from the things that stay the same." Polymorphism is an important way to do this, and it turns out to be helpful if the programming language directly supports

polymorphism (so you don’t have to wire it in yourself, which would tend to make it prohibitively expensive). But design patterns in general show *other* ways to accomplish the basic goal, and once your eyes open to this you begin to search for more creative designs.

1. But be warned: the examples are in C++. ↩



Appendix: Supplements

There are a number of supplements to this book, including the items and services available through the MindView Web site.

This appendix describes these supplements so you can decide if they

might be helpful to you.

Downloadable

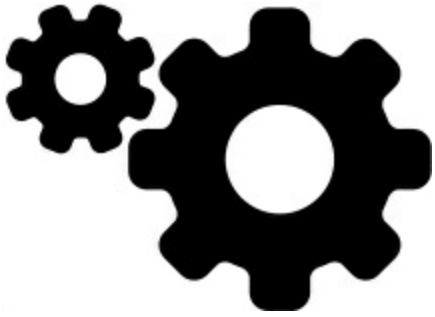
Supplements

The code for this book is freely available for download from

https://github.com/BruceEckel/OnJava8-examples. This includes the Gradle build files and other support files necessary to do a successful

build and execution of all the examples in the book.

Thinking in C:



Foundations for Java

At www.OnJava8.com, you will find the *Thinking in C* seminar as a free download. This presentation, created by Chuck Allison and

developed by MindView LLC, is an eSeminar which gives you an

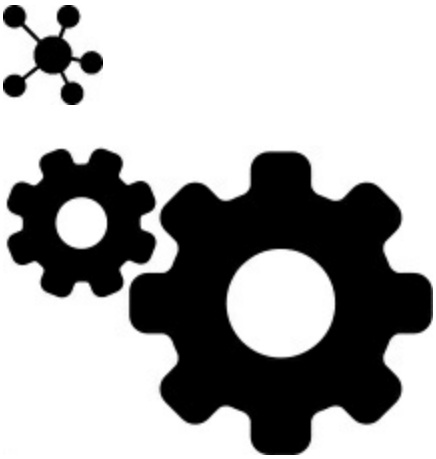
introduction to the C syntax, operators and functions that Java syntax

is based upon.

Hands-On Java

eSeminar

The *Hands-On Java eSeminar* is based on the 2nd edition of *Thinking in Java*. There is an audio lecture and slides corresponding to every chapter in that book. I created the seminar and I narrate the material on the eSeminar. The material is in HTML5, so it should run on most modern browsers. The *Hands-On Java eSeminar* is for sale at www.OnJava8.com, where you can find trial demos of the product.



Appendix:

Programming

Guidelines

This appendix contains suggestions to
help guide you in low-level program
design and writing code.

Naturally, these are guidelines and not rules. The idea is to use them as inspirations and to remember there are occasional situations where

they should be bent or broken.

Design

1. **Elegance always pays off**. In the short term it might seem like it takes much longer to come up with a truly graceful solution to a problem, but when it works the first time and easily adapts to new situations instead of requiring hours, days, or months of struggle, you'll see the rewards (even if no one can measure them). Not only does it give you a program that's easier to build and debug, but it's also easier to understand and maintain, and that's where the financial value lies. This point can take some experience to understand, because it can appear that you're not productive while you're making a piece of code elegant. Resist the urge to hurry; it will only slow you down.
2. **First make it work, then make it fast**. This is true even if you are certain a piece of code is really important and it is a principal bottleneck in your system. Don't do it. Get the system going first with as simple a design as possible. Then if it isn't going fast enough, profile it. You'll almost always discover that "your" bottleneck isn't the problem. Save your time for the really important stuff.

3. **Remember the "divide and conquer" principle**. If the problem you're looking at is too confusing, imagine the basic operation of the program, given the existence of a magic "piece" that handles the hard parts. That "piece" is an object—write the code that uses the object, then look at the object and encapsulate *its* hard parts into other objects, etc.

4. **Separate the class creator from the class user (*client programmer*)**. The class user is the "customer" and doesn't need or want to know what's going on behind the scenes of the class. The class creator must be the expert in class design and write the class so it can be used by the most novice programmer possible, yet still work robustly in the application. Think of the class as a *service provider* for other classes. Library use is easy only if it's transparent.

5. **When you create a class, attempt to make your names so clear that comments are unnecessary**. Your goal should be to make the client programmer's interface conceptually simple. To this end, use method overloading when appropriate to create an intuitive, easy-to-use interface.

6. **Your analysis and design must produce, at minimum,**

the classes in your system, their public interfaces, and their relationships to other classes, especially base classes. If your design method produces more than that, ask yourself if all the pieces produced by that method have value over the lifetime of the program. If they do not, maintaining them will cost you. Members of development teams tend not to maintain anything that does not contribute to their productivity; this is a fact of life that many design methods don't consider.

7. **Automate everything**. Write the test code first (before you write the class), and keep it with the class. Automate the running of your tests through a build tool—you'll probably use Gradle, the defacto standard Java build tool. This way, any changes are automatically verified by running the test code, and you'll immediately discover errors. Because you know you have the safety net of your test framework, you can be bolder about making sweeping changes when you discover the need. Remember that great improvements in languages come from the built-in testing provided by type checking, exception handling, etc., but those features take you only so far. You must go the rest of the way to create a robust system by filling in the tests that verify features

specific to your class or program.

8. **Write the test code first (before you write the class) to verify that your class design is complete**. If you can't write test code, you don't know what your class looks like. In addition, the act of writing the test code often flushes out additional features or constraints you need in the class—these features or constraints don't always appear during analysis and design. Tests also provide example code showing how your class can be used.

9. **All software design problems can be simplified by introducing an extra level of conceptual indirection**. This fundamental rule of software engineering1 is the basis of abstraction, the primary feature of object-oriented programming. In OOP, we could also say this as: "If your code is too complicated, make more objects."

10. **An indirection should have a meaning** (in concert with guideline 9). This meaning can be something as simple as "putting commonly used code in a single method." If you add levels of indirection (abstraction, encapsulation, etc.) that don't have meaning, it can be as bad as not having adequate indirection.

11. **Make classes as atomic as possible**. Give each class a single,

clear purpose—a cohesive service it provides to other classes. If your classes or your system design grows too complicated, break complex classes into simpler ones. The most obvious indicator of this is sheer size; if a class is big, chances are it's doing too much and should be broken up. Clues to suggest redesign of a class are:

A complicated switch statement: consider using polymorphism.

A large number of methods that cover broadly different types of operations: consider using several classes.

A large number of member variables that concern broadly different characteristics: consider using several classes.

Other suggestions are found in *Refactoring: Improving the Design of Existing Code* by Martin Fowler (Addison-Wesley 1999).

12. **Watch for long argument lists**. Method calls then become difficult to write, read, and maintain. Instead, try to move the method to a class where it is (more) appropriate, and/or pass objects in as arguments.

13. **Don't repeat yourself**. If a piece of code appears in many methods in derived classes, put that code into a single method in

the base class and call it from the derived-class methods. Not only do you save code space, but you enable easy propagation of changes. Sometimes the discovery of this common code will add valuable functionality to your interface. A simpler version of this guideline also occurs without inheritance: If a class has methods that repeat code, factor that code into a common method and call it from the other methods.

14. **Watch for *switch* statements or chained *if-else* clauses**. This can be an indicator of *type-check coding*, which means you are choosing what code to execute based on some kind of type information (the exact type may not be obvious at first). You can often replace this kind of code with inheritance and polymorphism; a polymorphic method call will perform the type checking for you and allow for more reliable and easier extensibility.

15. **From a design standpoint, look for and separate things that change from things that stay the same**. That is, search for the elements in a system you might want to change without forcing a redesign, then encapsulate those elements in classes.

16. **Don’t extend fundamental functionality by subclassing**. If

an interface element is essential to a class it should be in the base class, not added during derivation. If you're adding methods during inheritance, consider rethinking the design.

17. **Less is more**. Start with a minimal interface to a class, as small and simple as you need to solve the problem at hand, but don't try to anticipate all the ways your class *might* be used. As the class is used, you'll discover how you must expand the interface. However, once a class is in use, you cannot shrink the interface without breaking client code. If you must add more methods, that's fine; it won't break code. But even if new methods replace the functionality of old ones, leave the existing interface alone (you can combine the functionality in the underlying implementation if you want). If you must expand the interface of an existing method by adding more arguments, create an overloaded method with the new arguments; this way, you won't disturb any calls to the existing method.

18. **Read your classes aloud to make sure they're logical**. Refer to the relationship between a base class and derived class as "is-a" and member objects as "has-a."

19. **When deciding between inheritance and composition,**

ask if you must upcast to the base type. If not, prefer composition (member objects) to inheritance. This can eliminate the perceived need for multiple base types. If you inherit, users think they should upcast.

20. **Watch for overloading**. A method should not conditionally execute code based on the value of an argument. Here, create two or more overloaded methods instead.

21. **Use exception hierarchies**—preferably derived from specific appropriate classes in the standard Java exception hierarchy. The person catching the exceptions can then write handlers for the specific types of exceptions, followed by handlers for the base type. If you add new derived exceptions, existing client code will still catch the exception through the base type.

22. **Sometimes simple aggregation does the job**. A “passenger comfort system” on an airline consists of disconnected elements: seat, air conditioning, video, etc., and yet you must create many of these in a plane. Do you make private members and build a whole new interface? No—in this case, the components are also part of the public interface, so create public member objects. Those objects have their own private implementations, which are still

safe. Be aware that simple aggregation is not a solution to use often, but it does happen.

23. **Consider the perspective of the client programmer and the person maintaining the code**. Design your class to be as obvious as possible to use. Anticipate the kind of changes to be made, and design your class so those changes are easy.

24. **Watch out for "giant object syndrome."** This is often an affliction of procedural programmers who are new to OOP and who end up writing a procedural program and sticking it inside one or two giant objects. With the exception of application frameworks, objects represent concepts in your application, not the application itself.

25. **If you must do something ugly, at least localize the ugliness inside a class**.

26. **If you must do something nonportable, make an abstraction for that service and localize it within a class**. This extra level of indirection prevents the nonportability from being distributed throughout your program. (This idiom is embodied in the *Bridge* Pattern, among others).

27. **Objects should not simply hold some data**. They should

also have well-defined behaviors. (Occasionally, “data transfer objects” are appropriate, but only when used expressly to package and transport a group of items when a generalized collection is inappropriate.)

28. **Choose composition first when creating new classes from existing classes**. Only use inheritance if it is required by your design. If you use inheritance where composition will work, your designs become needlessly complicated.

29. **Use inheritance and method overriding to express differences in behavior, and fields to express variations in state**. If you find a class using state variables along with methods switching behavior based on those variables, redesign it to express the differences in behavior within subclasses and overridden methods. An extreme anti-example is inheriting different classes to represent colors instead of using a “color” field.

30. **Watch out for *variance***. Two semantically different objects may have identical actions or responsibilities. There is a natural temptation to try to make one a subclass of the other just to benefit from inheritance. This is called variance, but there’s no

real justification to force a superclass/subclass relationship where it doesn't exist. A better solution is to create a general base class that produces an interface for both as derived classes. You still benefit from inheritance and will probably make an important discovery about the design.

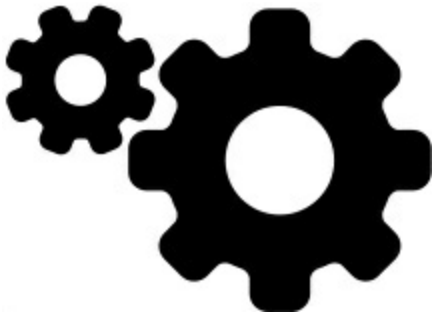
31. **Watch out for *limitation* during inheritance**. The clearest designs add new capabilities to inherited ones. A suspicious design removes old capabilities during inheritance without adding new ones. But rules are made to be broken, and if you are working from an old class library, it may be more efficient to restrict an existing class in its subclass than it would be to restructure the hierarchy so your new class fits in where it should, above the old class.

32. **Use design patterns to eliminate "naked functionality."** That is, if only one object of your class should be created, don't bolt ahead to the application and write a comment "Make only one of these." Wrap it in a singleton. If you have a lot of messy code in your main program that creates your objects, look for a creational pattern like a factory method where you can encapsulate that creation. Eliminating "naked functionality" will not only make your code much easier to understand and

maintain, but it will also make it more bulletproof against the well-intentioned maintainers that come after you.

33. **Watch out for "analysis paralysis."** Remember you must usually move forward in a project before you know everything, and that often the best and fastest way to learn about some of your unknown factors is to go to the next step rather than trying to figure it out in your head. You can't know the solution until you *have* the solution. Java has built-in firewalls; let them work for you. Your mistakes in a class or set of classes won't destroy the integrity of the whole system.

34. **When you think you've got a good analysis, design, or implementation, do a walkthrough**. Bring someone in from outside your group—this doesn't have to be a consultant, but can be someone from another group within your company. Reviewing your work with a fresh pair of eyes can reveal problems at a stage when it's much easier to fix them, and more than pays for the time and money "lost" to the walkthrough process.



Implementation

36. **Follow coding conventions**. There are plenty of different conventions, for example, Google uses these (the code in this book follows these conventions as much as I was able). If you doggedly stick to the coding style you've always used for some other language, you make it harder for your reader. Whatever coding conventions you decide on, ensure they are consistent throughout the project. Integrated development environments usually have reformatters and checkers built in.

37. **Whatever coding style you use, it really does make a difference if your team (and even better, your company) standardizes on it**. This means to the point that everyone considers it fair game to fix someone else's coding style if it doesn't conform. The value of standardization is it takes less brain cycles to parse the code, so you can focus more on what the code means.

38. **Follow standard capitalization rules**. Capitalize the first letter of class names. The first letter of fields, methods, and objects (references) should be lowercase. All identifiers should run their words together, and capitalize the first letter of all intermediate words. For example:

ThisIsAClassName

thisIsAMethodOrFieldName

Capitalize *all* the letters (and use underscore word separators) of **static final** primitive identifiers that have constant initializers in their definitions. This indicates they are compile-time constants.

Packages are a special case—they are all lowercase letters, even for intermediate words. The domain extension (com, org, net, edu, etc.) should also be lowercase. (This was a change between Java 1.1 and Java 2.)

39. **Don't create your own "decorated" private field names**. This is usually seen in the form of prepended underscores and characters. Hungarian notation is the worst example of this, where you attach extra characters that indicate data type, use, location, etc., as if you were writing assembly language and the

compiler provided no extra assistance at all. These notations are confusing, difficult to read, and unpleasant to enforce and maintain. Let classes and packages do the name scoping for you. If you feel you must decorate names to prevent confusion, your code is probably too confusing anyway and should be simplified.

40. **Follow a "canonical form"** when creating a class for general-purpose use. Include definitions for **equals()**, **hashCode()**, **toString()**, **clone()** (implement **Cloneable**, or choose some other object copying approach, like serialization), and implement **Comparable** and **Serializable**.

41. **Use the "get," "set," and "is" naming conventions** for methods that read and change **private** fields. Not only does it make it easy to use your class, but it's a standard way to name these kinds of methods, so it is more easily understood by the reader.

42. **For each class you create, include JUnit tests for that class** (see *junit.org*, and the example in Validating Your Code). You don't need to remove the test code to use the class in a project, and if you make changes, you can easily rerun the tests. The test code also becomes an example of how to use your class.

43. **Sometimes you need inheritance in order to access *protected* members of the base class**. This can lead to a perceived need for multiple base types. If you don't need to upcast, first derive a new class to perform the protected access. Then make that new class a member object inside any class that uses it, instead of inheriting.

44. **Avoid the use of *final* methods for efficiency purposes**. Use **final** for this purpose only when profiling shows a method invocation is the bottleneck.

45. **If two classes are associated with each other in some functional way (such as collections and iterators), try to make one an inner class of the other**. This not only emphasizes the association between the classes, but it allows class name reuse within a single package by nesting it within another class. The Java collections library does this by defining an inner **Iterator** class inside each collection class, thereby providing the collections with a common interface. The other reason to use an inner class is as part of the **private** implementation. Here, the inner class is beneficial for implementation hiding rather than the class association and prevention of namespace pollution noted

above.

46. **Anytime you notice that classes appear to have high coupling with each other, consider the coding and maintenance improvements you might get by using inner classes**. The use of inner classes will not uncouple the classes, but rather make the coupling explicit and more convenient.

47. **Don’t fall prey to premature optimization**. This way lies madness. In particular, don’t worry about writing (or avoiding) native methods, making some methods **final**, or tweaking code to be efficient when you are first constructing the system. Your primary goal should be to prove the design. Even if the design requires a certain efficiency, *first make it work, then make it fast*.

48. **Keep scopes as small as possible so the visibility and lifetime of your objects are as small as possible**. This reduces the chance of using an object in the wrong context and hiding a difficult-to-find bug. For example, suppose you have a collection and a piece of code that iterates through it. If you copy that code to use with a new collection, you may accidentally end up using the size of the old collection as the upper bound of the

new one. If, however, the old collection is out of scope, the error is caught at compile time.

49. **Use the collections in the standard Java library**. Become proficient with their use and you'll greatly increase your productivity. Prefer **ArrayList** for sequences, **HashSet** for sets, **HashMap** for associative arrays, and **LinkedList** for stacks (rather than **Stack**, although you may create an adapter to give a stack interface) and queues (which may also warrant an adapter, as shown in this book). When you use the first three, upcast to **List**, **Set**, and **Map**, respectively, so you can easily change to a different implementation if necessary.

50. **For a program to be robust, each component must be robust**. Use all the tools provided by Java—access control, exceptions, type checking, synchronization, and so on—in each class you create. That way you can safely move to the next level of abstraction when building your system.

51. **Prefer compile-time errors to run-time errors**. Try to handle an error as close to the point of its occurrence as possible. Catch any exceptions in the nearest handler that has enough information to deal with them. Do what you can with the

exception at the current level; if that doesn't solve the problem, rethrow the exception.

52. **Watch for long method definitions**. Methods should be brief, functional units that describe and implement a discrete part of a class interface. A long and complicated method is difficult and expensive to maintain, and is probably trying to do too much all by itself. If you see such a method, it indicates that, at the least, it should be broken up into multiple methods. It may also suggest the creation of a new class. Small methods will also foster reuse within your class. (Sometimes methods must be large, but they should still do just one thing.)

53. **Keep things as "*private* as possible"** . Once you publicize an aspect of your library (a method, a class, a field), you can never take it out. If you do, you'll wreck somebody's existing code, forcing them to rewrite and redesign. If you publicize only what you must, you can change everything else with impunity, and since designs tend to evolve, this is an important freedom. In this way, implementation changes have minimal impact on derived classes. Privacy is especially important when dealing with multithreading—only **private** fields can be protected against

un-**synchronized** use. Classes with package access should still have **private** fields, but it usually makes sense to give the methods of package access rather than making them **public**.

54. **Use comments liberally, and use the *Javadoc* comment-documentation syntax to produce your program documentation**. However, the comments should add genuine meaning to the code; comments that only reiterate what the code is clearly expressing are annoying. Note that the typical verbose detail of Java class and method names reduce the need for some comments.

55. **Avoid using "magic numbers"** . These are numbers hard-wired into code. These are a nightmare if you must change them, since you never know if "100" means "the array size" or "something else entirely." Instead, create a constant with a descriptive name and use the constant identifier throughout your program. This makes the program easier to understand and much easier to maintain.

56. **When creating constructors, consider exceptions**. In the best case, the constructor won't do anything that throws an exception. In the next-best scenario, the class is composed and

inherited from robust classes only, so it needs no cleanup if an exception is thrown. Otherwise, you must clean up composed classes inside a **finally** clause. If a constructor must fail, the appropriate action is to throw an exception, so the caller doesn't continue blindly, thinking that the object was created correctly.

57. **Inside constructors, do only what is necessary to set the object into the proper state**. Actively avoid calling other methods (except for **final** methods), because those methods can be overridden by someone else to produce unexpected results during construction. (See the Housekeeping chapter for details.) Smaller, simpler constructors are less likely to throw exceptions or cause problems.

58. **If your class requires any cleanup when the client programmer is finished with the object, place the cleanup code in a single, well-defined method**, with a name like **dispose()** that clearly suggests its purpose. In addition, place a **boolean** flag in the class to indicate whether **dispose()** was called so **finalize()** can check for "the termination condition" (see the Housekeeping chapter).

59. **The responsibility of *finalize()* can only be to verify "the termination condition" of an object for debugging**. (See

the Housekeeping chapter.) In special cases, it might be needed to release memory that would not otherwise be released by the

garbage collector. Since the garbage collector might not get called

for your object, you cannot use **finalize()** to perform

necessary cleanup. For that you must create your own

dispose() method. In the **finalize()** method for the class,

check to make sure that the object was cleaned up and throw a

class derived from **RuntimeException** if it hasn't, to indicate

a programming error. Before relying on such a scheme, ensure

that **finalize()** works on your system. (You might need to call

System.gc() to ensure this behavior.)

60. **If an object must be cleaned up (other than by garbage**

collection) within a particular scope, use the following

idiom: initialize the object and, if successful, immediately enter a

try block with a **finally** clause that performs the cleanup.

61. **When overriding *finalize()* during inheritance,**

remember to call *super.finalize()*. (This is not necessary if

Object is your immediate superclass.) Call

super.finalize() as the *final* act of your overridden

finalize() rather than the first, to ensure that base-class

components are still valid if you need them.

62. **When creating a fixed-size collection of objects, transfer them to an array**, especially if you're returning this collection from a method. This way you get the benefit of the array's compile-time type checking, and the recipient of the array might not need to cast the objects in the array to use them. Note that the base-class of the collections library, **java.util.Collection**, has two **toArray()** methods to accomplish this.

63. **Choose *interfaces* over *abstract* classes**. If you know something is a base class, your first choice should be to make it an interface, and only if you need method definitions or member variables should you change it to an **abstract** class. An interface talks about what the client wants to do, while a class tends to focus on (or allow) implementation details.

64. **To avoid a highly frustrating experience, make sure there is only one unpackaged class of each name anywhere in your classpath**. Otherwise, the compiler can find the identically-named other class first, and report error messages that make no sense. If you suspect you are having a classpath problem, try looking for **.class** files with the same names at each of the starting points in your classpath. Ideally, put all your classes within packages.

65. **Watch for accidental overloading**. If you attempt to override a base-class method and you don't get the spelling right, you'll end up adding a new method rather than overriding an existing method. However, this is perfectly legal, so you won't get any error message from the compiler or run-time system; your code simply won't work correctly. Always use the **@Override** annotation to prevent this.

66. **Watch for premature optimization**. First make it work, then make it fast—but only if you must, and only if you've proved there is a performance bottleneck in a particular section of your code. Unless you use a profiler to discover a bottleneck, you waste your time. The hidden extra cost of performance tweaks is that your code becomes less understandable and maintainable.

67. **Remember that code is read much more than it is written**. Clean designs make for easy-to-understand programs, but comments, detailed explanations, tests, and examples are invaluable. They help both you and everyone who comes after you. If nothing else, the frustration of trying to ferret out useful information from the JDK documentation should convince you.

1. Explained to me by Andrew Koenig. ↩

Appendix: Javadoc

Possibly the biggest problem with documenting code is maintaining that documentation. If the documentation and the code are separate, it becomes tedious to change the documentation every time you change the code. The solution seems simple: Link the code to the documentation. The easiest way to do this is to put everything in the same file. To complete the picture, however, you need a special comment syntax to mark the documentation and a tool to extract those comments into a useful form. This is what Java has done.

The tool to extract the comments is called *Javadoc*, and it comes as part of the JDK installation. It uses some of the technology from the Java compiler to look for special comment tags. It not only extracts the information marked by these tags, but it also pulls out the class name or method name that adjoins the comment. This way you can get away with the minimal amount of work to generate decent program documentation.

The output of Javadoc is an HTML file you can view with your Web browser. With Javadoc, you have a straightforward standard for

creating documentation, so you can expect documentation for all Java libraries.

In addition, you can write your own Javadoc handlers, called *doclets*, to perform special operations on the information processed by

Javadoc (to produce output in a different format, for example).

What follows is only an introduction and overview of the basics of Javadoc. A thorough description is found in the JDK documentation.

Syntax

All Javadoc directives occur within comments that begin with **/**** (but still end with ***/**). There are two primary ways to use Javadoc: Embed HTML or use "doc tags." *Standalone doc tags* are directives that start with an **@** and are placed at the beginning of a comment line. (A leading ***,** however, is ignored.) *Inline doc tags* can appear anywhere within a Javadoc comment and also start with an **@** but are surrounded by curly braces.

There are three types of comment documentation, which correspond to the element the comment precedes: class, field, or method. That is,

a class comment appears right before the definition of a class, a field comment appears right before the definition of a field, and a method comment appears right before the definition of a method. As a simple example:

```
// javadoc/Documentation1.java
/** A class comment */
public class Documentation1 {
/** A field comment */
public int i;
/** A method comment */
public void f() {}
}
```

Javadoc processes comment documentation only for **public** and **protected** members. Comments for **private** and package-access members (see the Implementation Hiding chapter) are ignored by default, and you'll see no output. This makes sense, since only

public and **protected** members are available outside the file,

which is the client programmer's perspective. You can use the **-private** flag to include **private** members.

To process the preceding code through Javadoc, the command is:

javadoc Documentation1.java

This produces a set of HTML files; if you open **index.html** in your browser you'll see that the result has the same standard format as all the rest of the Java documentation, so users are comfortable with the format and can easily navigate your classes.

Embedded HTML

Javadoc passes HTML code untouched to the generated HTML document. This allows you full use of HTML; however, the primary motive is to let you format code, such as:

```
// javadoc/Documentation2.java
/** <pre>
* System.out.println(new Date());
* </pre>
*/
public class Documentation2 {}
```

You can also use HTML just as you would in any other Web document to format the regular text in your descriptions:

// javadoc/Documentation3.java

/ You can even insert a list:**

*** **

*** Item one**

*** Item two**

*** Item three**

*** **

***/**

public class Documentation3 {}

Note that within the documentation comment, asterisks at the beginning of a line are thrown away by Javadoc, along with leading spaces. Javadoc reformats everything so it conforms to the standard documentation appearance. Don’t use headings such as **<h1>** or **<hr>** as embedded HTML, because Javadoc inserts its own headings and yours will interfere with them.

All types of comment documentation—class, field, and method—can support embedded HTML.

Some Example Tags

Here are some of the Javadoc tags available for code documentation. Before trying to do anything serious using Javadoc, consult the Javadoc reference in the JDK documentation to learn all the different ways you can use Javadoc.

@see

This tag refers to documentation in other classes. Javadoc will generate HTML with the **@see** tags hyperlinked to the other documentation. The forms are:

@see classname

@see fully-qualified-classname

@see fully-qualified-classname#method-name

Each adds a hyperlinked “See Also” entry to the generated documentation. Javadoc does not check the validity of the hyperlinks.

{@link *package.class#member label*}

Very similar to **@see**, except it can be used inline and uses **label** as the hyperlink text rather than “See Also.”

{@docRoot}

Produces the relative path to the documentation root directory. Useful for explicit hyperlinking to pages in the documentation tree.

{@inheritDoc}

Inherits the documentation from the nearest base class of this class into the current doc comment.

@version

This is of the form:

@version version-information

where **version-information** is any significant information you see fit to include. When the **-version** flag is placed on the Javadoc command line, the version information is called out specially in the generated HTML documentation.

@author

This is of the form:

@author author-information

where **author-information** is presumably your name, but can also include your email address or any other appropriate information. When the **-author** flag is placed on the Javadoc command line, the author information is called out specially in the generated HTML documentation.

You can use multiple author tags for a list of authors, but they must be placed consecutively. All author information is lumped together into a

single paragraph in the generated HTML.

@since

This tag indicates the version of this code that began using a particular feature. It appears, for example, in the HTML Java documentation to indicate the version of the JDK where a feature first appeared.

@param

This produces documentation for method arguments:

@param parameter-name description

where **parameter-name** is the identifier in the method parameter list, and **description** is text that can continue on subsequent lines. The description is considered finished when a new documentation tag is encountered. You can have any number of these, presumably one for each parameter.

@return

This documents the return value:

@return description

where **description** gives you the meaning of the return value. It

can continue on subsequent lines.

@throws

A method can produce any number of different types of exceptions, all of which need descriptions. The form for the exception tag is:

@throws fully-qualified-**class**-name description

where *fully-qualified-class-name* gives an unambiguous name of an exception class, and *description* (which can continue on subsequent lines) tells you why this particular type of exception can emerge from the method call.

@deprecated

This indicates features that are superseded by an improved feature. The deprecated tag suggests that you no longer use this particular feature, because sometime in the future it is likely to be removed. A method marked **@deprecated** causes the compiler to issue a warning if it is used. In Java 5, the **@deprecated** Javadoc tag was superseded by the **@Deprecated** *annotation* (described in the Annotations chapter).

Documentation Example

Here is **objects/HelloDate.java** with documentation comments:

```
// javadoc/HelloDateDoc.java
import java.util.*;
/** The first On Java 8 example program.
* Displays a String and today's date.
* @author Bruce Eckel
* @author www.MindviewInc.com
* @version 5.0
*/
public class HelloDateDoc {
/** Entry point to class & application.
* @param args array of String arguments
* @throws exceptions No exceptions thrown
*/
public static void main(String[] args) {
System.out.println("Hello, it's: ");
System.out.println(new Date());
}
}
/* Output:
Hello, it's:
```

Tue May 09 06:07:27 MDT 2017

*/

You can find many examples of Javadoc comment documentation in the source code for the Java standard libraries.

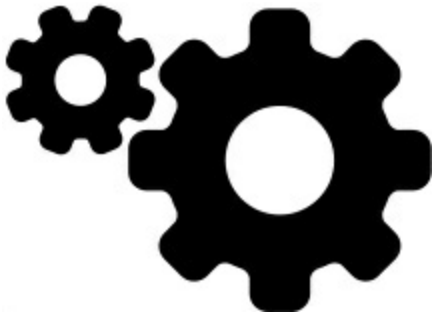
Appendix: Passing and Returning Objects

By now you are reasonably comfortable with the idea that when you're "passing" an object, you're actually passing a reference.

In many programming languages you can use that language's "regular" way to pass objects around, and most of the time everything works fine. But there usually comes a point at which you must do something irregular, and suddenly things get a bit more complicated. Java is no exception, and it's important you understand exactly what's happening as you pass objects and manipulate them. This appendix provides that insight.

Another way to pose the question of this appendix, if you're coming

from a programming language so equipped, is “Does Java have pointers?” Every object identifier in Java (except for primitives) is one of these pointers, but their use is restricted and guarded not only by the compiler but by the run-time system. Or to put it another way, Java has pointers, but no pointer arithmetic. These are what I’ve been calling “references,” and you can think of them as “safety pointers,” not unlike the safety scissors of elementary school—they aren’t sharp,



so you cannot hurt yourself without great effort, but they can sometimes be tedious.

Passing References

When you pass a reference into a method, you’re still pointing to the same object. A simple experiment demonstrates this:

```
// references/PassReferences.java
public class PassReferences {
public static void f(PassReferences h) {
System.out.println("h inside f(): " + h);
```

```
}
public static void main(String[] args) {
PassReferences p = new PassReferences();
System.out.println("p inside main(): " + p);
f(p);
}
}
/* Output:
p inside main(): PassReferences@15db9742
h inside f(): PassReferences@15db9742
*/
```

The method **toString()** is automatically invoked in the print statements, and **PassReferences** inherits directly from **Object** with no redefinition of **toString()**. Thus, **Object**s version of **toString()** is used, which prints out the class of the object followed by the address where that object is located (not the reference, but the actual object storage).

The output shows that that both **p** and **h** refer to the same object. This is far more efficient than duplicating a new **PassReferences** object just so you can send an argument to a method. But it brings up an

important issue.

Aliasing

Aliasing means that more than one reference is tied to the same object, as in the preceding example. The problem with aliasing occurs when someone *writes* to that object. If the owners of the other references aren't expecting that object to change, they'll be surprised. This can be demonstrated:

```
// references/Alias1.java
// Aliasing two references to one object
public class Alias1 {
private int i;
public Alias1(int ii) { i = ii; }
public static void main(String[] args) {
Alias1 x = new Alias1(7);
Alias1 y = x; // Assign the reference (1)
System.out.println("x: " + x.i);
System.out.println("y: " + y.i);
```

```
System.out.println("Incrementing x");
x.i++; // [2]
System.out.println("x: " + x.i);
System.out.println("y: " + y.i);
}
}
/* Output:
x: 7
y: 7
Incrementing x
x: 8
y: 8
*/
```

[1] Here, a new **Alias1** reference is created, but instead of being assigned to a fresh object created with **new**, it's assigned to an existing reference. So the contents of reference **x**, which is the address of the object **x** is pointing to, is assigned to **y**, and thus both **x** and **y** are attached to the same object.

[2] When **x**s **i** is incremented, **y**s **i** is affected as well, as shown in the output.

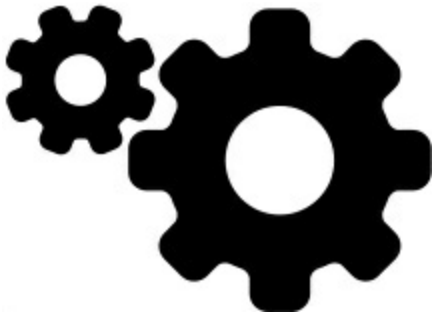
The best solution is simply not to do it; don't consciously alias more than one reference to an object at the same scope. Your code is then

much easier to understand and debug. However, when you're passing a reference in as an argument—which is the way Java is supposed to work—you automatically alias, because the local reference that's created can modify the "outside object" (the object that was created outside the scope of the method):

```
// references/Alias2.java
// Method calls implicitly alias their arguments
public class Alias2 {
private int i;
public Alias2(int i) { this.i = i; }
public static void f(Alias2 reference) {
reference.i++;
}
public static void main(String[] args) {
Alias2 x = new Alias2(7);
System.out.println("x: " + x.i);
System.out.println("Calling f(x)");
f(x);
System.out.println("x: " + x.i);
}
```

```
}
/* Output:
x: 7
Calling f(x)
x: 8
*/
```

The method is changing its argument, the outside object. When this kind of situation arises, you must decide whether it makes sense,



whether the user expects it, and whether it's going to cause problems. The answers are usually no, no, and yes, which is why pure functional languages disallow this behavior.

In general, you call a method to produce a return value and/or change the state of the object *the method is called for*. It's much less common to call a method to manipulate its arguments; this is one form of "calling a method for its *side effects*." Thus, when you create a method that modifies its arguments, the user must be clearly instructed and

warned about the use of that method and its potential surprises.

Because of the confusion and pitfalls, it’s much better to avoid changing the argument.

If you must modify an argument during a method call and you don’t intend to modify the outside argument, then protect that argument by making a copy inside your method. That’s the subject of much of this appendix.

Making Local Copies

All argument passing in Java is performed by passing references. That is, when you pass “an object,” you’re really passing only a reference to an object that lives outside the method, so if you perform any modifications through that reference, you modify the outside object.

In addition:

Aliasing happens automatically during argument passing.

There are no local objects, only local references.

References have scopes, objects do not.

Object lifetime is never an issue in Java.

There is no language support (e.g., “const”) to prevent objects from being modified and to stop the negative effects of aliasing. You can’t

simply use the **final** keyword in the argument list; that only prevents you from rebinding the reference to a different object.

If you're strictly reading information from an object and not modifying that object, passing a reference is the most efficient form of argument passing. This is nice; the default way of doing things is also the most efficient. However, sometimes it's necessary to treat the object as if it were "local" so changes you make affect only a local copy and do not modify the outside object. Many programming languages support the ability to automatically make a local copy of the outside object, inside the method. [1] Java does not, but it allows you to produce this effect.

Pass By Value

This brings up the terminology issue, which always seems good for an argument. The term is "pass by value," and the meaning depends on how you perceive the operation of the program. The concept is that you get a local copy of whatever you're passing, but the real question is how you think about what you're passing. When it comes to the meaning of "pass by value," there are two fairly distinct camps:

1. Java passes everything by value. When you pass primitives into a method, you get a distinct copy of the primitive. When you pass a reference into a method, you get a copy of the reference. Ergo, everything is pass by value. The assumption is that you're always thinking (and caring) that references are passed, but it seems like the Java design has gone a long way toward allowing you to ignore (most of the time) that you're working with a reference. That is, it seems to allow you to think of the reference as "the object," since it implicitly dereferences it whenever you make a method call.
2. Java passes primitives by value, but objects are passed by reference. This is the world view that the reference is an alias for the object, so you *don't* think about passing references, but instead say "I'm passing the object." Since you don't get a local

copy of the object when you pass it into a method, objects are clearly not passed by value. There appeared to be some support for this view within Sun, since at one time one of the "reserved but not implemented" keywords was **byvalue** (which will never be

implemented).

Having given both camps a good airing, and after saying “It depends on how you think of a reference,” I attempt to sidestep the issue. In the end, it isn’t *that* important—what is important is you understand that passing a reference allows the caller’s object to be changed unexpectedly.

Cloning Objects

Before you wade too far into cloning, check out the alternatives at the end of the summary.

The most likely reason for making a local copy of an object is if you modify that object but you don’t want to modify the caller’s object. One approach for making a local copy is to use the **clone()** method. **clone()** is defined as **protected** in the base class **Object**. You must override **clone()** as **public** in any derived classes you want to clone. For example, the standard library class **ArrayList** overrides **clone()**, so we can call **clone()** for **ArrayList**:

```
// references/CloneArrayList.java
// The clone() operation works for only a few
// items in the standard Java library
import java.util.*;
```

```
import java.util.stream.*;
class Int {
private int i;
Int(int ii) { i = ii; }
public void increment() { i++; }
@Override
public String toString() {
return Integer.toString(i);
}
}
public class CloneArrayList {
public static void main(String[] args) {
ArrayList<Int> v = IntStream.range(0, 10)
.mapToObj(Int::new)
.collect(Collectors
.toCollection(ArrayList::new));
System.out.println("v: " + v);
@SuppressWarnings("unchecked")
ArrayList<Int> v2 = (ArrayList<Int>)v.clone();
// Increment all v2's elements:
```

```
v2.forEach(Int::increment);
// See if it changed v's elements:
System.out.println("v: " + v);
}
}
/* Output:
v: [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
v: [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
*/
```

The **clone()** method produces an **Object**, which must then be recast to the proper type. This example shows how **ArrayList**s **clone()** method *does not* automatically try to clone each of the objects that the **ArrayList** contains—the old **ArrayList** and the cloned **ArrayList** are aliased to the same objects. This is a *shallow copy*, since it's copying only the "surface" portion of an object. The actual object consists of this "surface," plus all the objects that the references are pointing to, plus all the objects *those* objects are pointing to, etc. This is often called the "web of objects." Making a full copy of the entire mess is called a *deep copy*.

You see the effect of the shallow copy in the output, where the actions

performed on **v2** affect **v**. Not **clone()**ing the objects contained in

the **ArrayList** is probably a fair assumption, because there's no guarantee that those objects *are* cloneable.2

Adding Cloneability to a Class

Even though **clone()** is defined in the base-of-all-classes **Object**, cloning is *not* automatically available in every class. This would seem counterintuitive to the idea that base-class methods are always available in derived classes. Cloning in Java does indeed go against this idea; if you want it to exist for a class, you must specifically add code to make cloning work.

Using a Trick with Protected

To prevent default cloneability in every class you create, the **clone()** method is **protected** in the base class **Object**. This means it's not available by default to the client programmer who is simply using the class (not subclassing it). It also means you cannot call **clone()** via a reference to the base class. It is, in effect, a way to give you, at compile time, the information that your object is not cloneable—and oddly

enough, most classes in the standard Java library are not cloneable.

Thus, if you say:

Integer x = 1;

x = x.clone();

You get, at compile time, an error message that says **clone()** is not accessible (since **Integer** doesn't override it and it defaults to the **protected** version).

If, however, you're in a method of a class *derived* from **Object** (as all classes are), then you have permission to call **Object.clone()** because it's **protected** and you're an inheritor. The base class **clone()** has useful functionality; it performs the actual bitwise duplication *of the derived-class object*, thus acting as the common cloning operation. However, you must then make *your* clone operation **public** for it to be accessible. So, two key issues when you clone are:

Call **super.clone()**

Make your clone **public**

You'll probably override **clone()** in any further derived classes; otherwise, your (now **public**) **clone()** is used, and that might not do the right thing (although, since **Object.clone()** makes a copy of the actual object, it might). The **protected** trick works only once:

the first time you inherit from a class that has no cloneability and you want to make a class that's cloneable. In any classes inherited from your class, the **clone()** method is available since it's not possible in Java to reduce the access of a method during derivation. That is, once a class is cloneable, everything derived from it is cloneable unless you use provided mechanisms (described later) to "turn off" cloning.

Implementing the Cloneable Interface

There's one more action to complete the cloneability of an object: implement the **Cloneable** interface. This is an empty (tagging) interface.

There are two reasons for the existence of the **Cloneable** interface. First, you might have an upcast reference to a base type and not know whether it's possible to clone that object. Here, you can use the

instanceof keyword (described in the Type Information chapter) to find out whether the reference is connected to an object that can be cloned:

```
if(myReference instanceof Cloneable) // ...
```

The second reason is that mixed into this design for cloneability is the thought that maybe you don’t want all types of objects to be cloneable. So **Object.clone()** verifies that a class implements the **Cloneable** interface. If not, it throws a **CloneNotSupportedException** exception. So in general, you’re forced to **implement Cloneable** as part of support for cloning.

Successful Cloning

Once you understand the details of implementing the **clone()** method, you’re able to create classes that can be easily duplicated to provide a local copy:

```
// references/LocalCopy.java
// Creating local copies with clone()
class Duplo implements Cloneable {
private int n;
Duplo(int n) { this.n = n; }
@Override
public Duplo clone() { // [1]
try {
return (Duplo)super.clone();
} catch(CloneNotSupportedException e) {
```

```
throw new RuntimeException(e);
}
}
public int getValue() { return n; }
public void setValue(int n) { this.n = n; }
public void increment() { n++; }
@Override
public String toString() {
return Integer.toString(n);
}
}
public class LocalCopy {
public static Duplo g(Duplo v) {
// Passing a reference, modifies outside object:
v.increment();
return v;
}
public static Duplo f(Duplo v) {
v = v.clone(); // [2] Local copy
v.increment();
```

```
return v;
}
public static void main(String[] args) {
Duplo a = new Duplo(11);
Duplo b = g(a);
// Reference equivalence, not object equivalence:
System.out.println("a == b: " + (a == b) +
"\na = " + a + "\nb = " + b);
Duplo c = new Duplo(47);
Duplo d = f(c);
System.out.println("c == d: " + (c == d) +
"\nc = " + c + "\nd = " + d);
}
}
/* Output:
a == b: true
a = 12
b = 12
c == d: false
c = 47
```

d = 48

**/*

First of all, for **clone()** to be accessible, you must make it **public**. Second, for the initial part of your **clone()** operation, call the base-class version of **clone()**. The **clone()** that's called here is the one that's predefined inside **Object**, and you can call it because it's **protected** and thereby accessible in derived classes.

Object.clone() figures out how big the object is, creates enough memory for a new one, and copies all the bits from the old to the new. This is called a *bitwise copy*, and is typically what you'd expect a **clone()** method to do. But before **Object.clone()** performs its operations, it first checks to see if a class is **Cloneable**—that is, whether it implements the **Cloneable** interface. If it doesn't, **Object.clone()** throws a **CloneNotSupportedException** to indicate you can't clone it. Thus, you've got to surround your call to **super.clone()** with a **try** block to catch an exception that should never happen (because you've implemented the **Cloneable** interface).

[1] Notice the use of covariant return types here. The base class **Object**'s **clone()** can only return **Object**, but the derived

class **clone()** can return a more specific type. Before covariant return types, you had to cast the return type down to the proper type, but now it can be validated at compile time.

[2] Here, you see a call to **clone()** which returns a **Duplo**, with no cast required.

In **LocalCopy**, the methods **g()** and **f()** demonstrate the

difference between the two approaches for argument passing. The **g()** method shows passing by reference; it modifies the outside object and returns a reference to that outside object, whereas **f()** clones the argument, thereby decoupling it and leaving the original object alone. It can then proceed to do whatever it wants—even return a reference to this new object without any ill effects to the original.

In **main()**, the difference between the effects of the two different argument-passing approaches is tested. It's important to notice that the equivalence tests in Java do not look inside the objects being compared to see if their values are the same. The **==** and **!=** operators are simply comparing the *references*. If the addresses inside the references are the same, the references are pointing to the same object and are therefore "equal." So what the operators are really testing is whether the references are aliased to the same object!

The Effect of Object.clone()

What actually happens when **Object.clone()** is called that makes

it so essential to call **super.clone()** when you override **clone()** in your class? The **clone()** method in the root class is responsible for creating the correct amount of storage and making the bitwise copy of the bits from the original object into the new object's storage. That is, it doesn't just make storage and copy an **Object**; it actually figures out the size of the *real* object (not just the base-class object, but the derived object) that's copied, and duplicates that. Since all this is happening from the code in the **clone()** method defined in the root class (that has no idea what's been inherited), you can guess that the process involves RTTI to determine the actual object that's cloned. This way, the **clone()** method can create the proper amount of storage and do the correct bitwise copy for that type.

The first part of the cloning process should usually be a call to **super.clone()**. This establishes the groundwork for the cloning operation by making an exact duplicate. At this point you can perform other operations necessary to complete the cloning.

To know for sure what those other operations are, you must understand exactly what **Object.clone()** buys you. In particular, does it automatically clone the destination of all the references? We can test this:

```
// references/Snake.java
// Tests cloning to see if reference
// destinations are also cloned
public class Snake implements Cloneable {
private Snake next;
private char c;
// Value of i == number of segments
public Snake(int i, char x) {
c = x;
if(--i > 0)
next = new Snake(i, (char)(x + 1));
}
public void increment() {
c++;
if(next != null)
next.increment();
}
@Override
public String toString() {
String s = ":" + c;
```

```
if(next != null)
s += next.toString();
return s;
}
@Override
public Snake clone() {
try {
return (Snake)super.clone();
} catch(CloneNotSupportedException e) {
throw new RuntimeException(e);
}
}
public static void main(String[] args) {
Snake s = new Snake(5, 'a');
System.out.println("s = " + s);
Snake s2 = s.clone();
System.out.println("s2 = " + s2);
s.increment();
System.out.println(
"after s.increment, s2 = " + s2);
```

```
}
}
/* Output:
s = :a:b:c:d:e
s2 = :a:b:c:d:e
after s.increment, s2 = :a:c:d:e:f
*/
```

A **Snake** is made up of a bunch of segments, each of type **Snake**. Thus, it's a singly linked list. The segments are created recursively, decrementing the first constructor argument for each segment until zero is reached. To give each segment a unique tag, the second argument, a **char**, is incremented for each recursive constructor call. The **increment()** method recursively increments each tag to show the change, and the **toString()** recursively prints each tag. The output shows that only the first segment is duplicated by **Object.clone()**, therefore it does a shallow copy. If you want the whole snake duplicated—a deep copy—you must perform the additional operations inside your overridden **clone()**.

You'll typically call **super.clone()** in any class derived from a cloneable class to make sure that all base-class operations (including

Object.clone()) take place. This is followed by an explicit call to **clone()** for every reference in your object; otherwise those references are aliased to those of the original object. It's analogous to the way constructors are called: base-class constructor first, then the next-derived constructor, and so on, to the most-derived constructor. The difference is that **clone()** is not a constructor, so there's nothing to make it happen automatically. You must make sure to do it yourself.

Cloning a Composed Object

There's a problem you'll encounter when trying to deep copy a composed object. You must assume that the **clone()** method in the member objects will in turn perform a deep copy on *their* references, and so on. This is a commitment. It effectively means that for a deep copy to work, you must either control all code in all classes, or at least have enough knowledge about all classes involved in the deep copy to know they are performing their own deep copy correctly.

Here's what you must do to accomplish a deep copy when dealing with

a composed object:

```
// references/DepthReading.java
// Cloning a composed object
package references;
public class DepthReading implements Cloneable {
private double depth;
public DepthReading(double depth) {
this.depth = depth;
}
@Override
public DepthReading clone() {
try {
return (DepthReading)super.clone();
} catch(CloneNotSupportedException e) {
throw new RuntimeException(e);
}
}
public double getDepth() { return depth; }
public void setDepth(double depth) {
this.depth = depth;
```

```
}
@Override
public String toString() {
return String.valueOf(depth);
}
}
// references/TemperatureReading.java
// Cloning a composed object
package references;
public class TemperatureReading implements Cloneable {
private long time;
private double temperature;
public TemperatureReading(double temperature) {
time = System.currentTimeMillis();
this.temperature = temperature;
}
@Override
public TemperatureReading clone() {
try {
return (TemperatureReading)super.clone();
```

```
} catch(CloneNotSupportedException e) {
throw new RuntimeException(e);
}
}
public double getTemperature() {
return temperature;
}
public void setTemperature(double temp) {
this.temperature = temp;
}
@Override
public String toString() {
return String.valueOf(temperature);
}
}
// references/OceanReading.java
// Cloning a composed object
package references;
public class OceanReading implements Cloneable {
private DepthReading depth;
```

```
private TemperatureReading temperature;
public
OceanReading(double tdata, double ddata) {
temperature = new TemperatureReading(tdata);
depth = new DepthReading(ddata);
}
@Override
public OceanReading clone() {
OceanReading or = null;
try {
or = (OceanReading)super.clone();
} catch(CloneNotSupportedException e) {
throw new RuntimeException(e);
}
// Must clone references:
or.depth = (DepthReading)or.depth.clone();
or.temperature =
(TemperatureReading)or.temperature.clone();
return or;
}
```

```
public TemperatureReading getTemperatureReading() {
return temperature;
}
public void
setTemperatureReading(TemperatureReading tr) {
temperature = tr;
}
public DepthReading getDepthReading() {
return depth;
}
public void setDepthReading(DepthReading dr) {
this.depth = dr;
}
@Override
public String toString() {
return "temperature: " + temperature +
", depth: " + depth;
}
}
```

Now we can test it using JUnit:

```
// references/tests/DeepCopyTest.java
package references;
import org.junit.jupiter.api.*;
import static org.junit.jupiter.api.Assertions.*;
public class DeepCopyTest {
@Test
public void testClone() {
OceanReading reading =
new OceanReading(33.9, 100.5);
// Now clone it:
OceanReading clone = reading.clone();
TemperatureReading tr =
clone.getTemperatureReading();
tr.setTemperature(tr.getTemperature() + 1);
clone.setTemperatureReading(tr);
DepthReading dr = clone.getDepthReading();
dr.setDepth(dr.getDepth() + 1);
clone.setDepthReading(dr);
assertEquals(reading.toString(),
"temperature: 33.9, depth: 100.5");
```

```
assertEquals(clone.toString(),
"temperature: 34.9, depth: 101.5");
}
}
```

DepthReading and **TemperatureReading** are similar; they both contain only primitives. Therefore, the **clone()** method can be simple: it calls **super.clone()** and returns the result. Note that the **clone()** code for both classes is identical.

OceanReading is composed of **DepthReading** and **TemperatureReading** objects and so, to produce a deep copy, its **clone()** must clone the references inside **OceanReading**. To accomplish this, the result of **super.clone()** must be cast to an **OceanReading** object (so you can access the **depth** and **temperature** references).

A Deep Copy with ArrayList

Let’s revisit **CloneArrayList.java** from earlier in this appendix. This time the **Int2** class is cloneable, so the **ArrayList** can be deep

copied:

```
// references/AddingClone.java
// You must go through a few gyrations
// to add cloning to your own class
import java.util.*;
import java.util.stream.*;
class Int2 implements Cloneable {
private int i;
Int2(int ii) { i = ii; }
public void increment() { i++; }
@Override
public String toString() {
return Integer.toString(i);
}
@Override
public Int2 clone() {
try {
return (Int2)super.clone();
} catch(CloneNotSupportedException e) {
throw new RuntimeException(e);
```

```
}
}
}
// Inheritance doesn't remove cloneability:
class Int3 extends Int2 {
private int j; // Automatically duplicated
Int3(int i) { super(i); }
}
public class AddingClone {
@SuppressWarnings("unchecked")
public static void main(String[] args) {
Int2 x = new Int2(10);
Int2 x2 = x.clone();
x2.increment();
System.out.println(
"x = " + x + ", x2 = " + x2);
// Anything inherited is also cloneable:
Int3 x3 = new Int3(7);
x3 = (Int3)x3.clone();
ArrayList<Int2> v = IntStream.range(0, 10)
```

```
.mapToObj(Int2::new)
.collect(Collectors
.toCollection(ArrayList::new));
System.out.println("v: " + v);
ArrayList<Int2> v2 =
(ArrayList<Int2>)v.clone();
// Now clone each element:
IntStream.range(0, v.size())
.forEach(i -> v2.set(i, v.get(i).clone()));
// Increment all v2's elements:
v2.forEach(Int2::increment);
System.out.println("v2: " + v2);
// See if it changed v's elements:
System.out.println("v: " + v);
}
}
/* Output:
x = 10, x2 = 11
v: [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
v2: [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
```

v: [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]

/

Int3 inherits **Int2**, and a new primitive member, **int j**, is added.

You might think you'd need to override **clone()** again to make sure

j is copied, but that's not the case. When **Int2**s **clone()** is called as **Int3**s **clone()**, it calls **Object.clone()**, which determines it's

working with an **Int3** and duplicates all the bits in the **Int3**. As long

as you don't add references that need cloning, the one call to

Object.clone() performs all necessary duplication regardless of

how far down in the hierarchy **clone()** is defined.

Here's what's necessary to do a deep copy of an **ArrayList**: After

the **ArrayList** is cloned, you have to step through and clone each

one of the objects pointed to by the **ArrayList**. You'd also have to

do something similar to this to do a deep copy of, for example, a

HashMap.

The remainder of the example demonstrates that cloning actually

happened by showing that, once an object is cloned, you can change it,

and the original object is left untouched.

Deep Copy Via Serialization

When you consider Java's object serialization (introduced in the

Appendix: Object Serialization), you might observe that an object that's first serialized and then deserialized is, in effect, cloned.

So why not use serialization to perform deep copying? Here's an

example that compares the two approaches by timing them:

```
// references/Compete.java

import java.io.*;

import onjava.Timer;

class Thing1 implements Serializable {}

class Thing2 implements Serializable {

Thing1 t1 = new Thing1();

}

class Thing3 implements Cloneable {

@Override

public Thing3 clone() {

try {

return (Thing3)super.clone();

} catch(CloneNotSupportedException e) {

throw new RuntimeException(e);
```

```
}
}
}
class Thing4 implements Cloneable {
private Thing3 t3 = new Thing3();
@Override
public Thing4 clone() {
Thing4 t4 = null;
try {
t4 = (Thing4)super.clone();
} catch(CloneNotSupportedException e) {
throw new RuntimeException(e);
}
// Clone the field, too:
t4.t3 = t3.clone();
return t4;
}
}
public class Compete {
public static final int SIZE = 100000;
```

```
public static void
main(String[] args) throws Exception {
Thing2[] a = new Thing2[SIZE];
for(int i = 0; i < SIZE; i++)
a[i] = new Thing2();
Thing4[] b = new Thing4[SIZE];
for(int i = 0; i < SIZE; i++)
b[i] = new Thing4();
Timer timer = new Timer();
try(
ByteArrayOutputStream buf =
new ByteArrayOutputStream();
ObjectOutputStream oos =
new ObjectOutputStream(buf)
) {
for(Thing2 a1 : a) {
oos.writeObject(a1);
}
// Now get copies:
try(
```

```
ObjectInputStream in =
new ObjectInputStream(
new ByteArrayInputStream(
```

```
buf.toByteArray()))
) {
Thing2[] c = new Thing2[SIZE];
for(int i = 0; i < SIZE; i++)
c[i] = (Thing2)in.readObject();
}
}
System.out.println(
"Duplication via serialization: " +
timer.duration() + " Milliseconds");
// Now try cloning:
timer = new Timer();
Thing4[] d = new Thing4[SIZE];
for(int i = 0; i < SIZE; i++)
```

```
d[i] = b[i].clone();
System.out.println(
"Duplication via cloning: " +
timer.duration() + " Milliseconds");
}
}
/* Output:
Duplication via serialization: 516 Milliseconds
Duplication via cloning: 71 Milliseconds
*/
```

Thing2 and **Thing4** contain member objects so there's some deep copying going on. **Serializable** classes are easy to set up, but there's much more work going on to duplicate them. On the other hand, cloning involves more work to set up the class, but the actual duplication of objects is relatively simple.

Notice that serialization is at least an order of magnitude slower than cloning.

Adding Cloneability Further

Down a Hierarchy

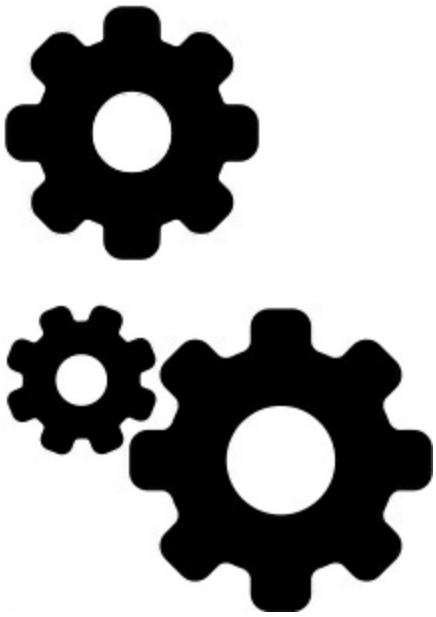
If you create a new class, its base class defaults to **Object**, which defaults to noncloneability. As long as you don't explicitly add

cloneability, you won't get it. But you can add it in at any layer and it will then be cloneable from that layer downward, like this:

```
// references/HorrorFlick.java
// Insert Cloneability at any level of inheritance
class Person {}
class Hero extends Person {}
class Scientist extends Person implements Cloneable {
@Override
public Scientist clone() {
try {
return (Scientist)super.clone();
} catch(CloneNotSupportedException e) {
throw new RuntimeException(e);
}
}
}
class MadScientist extends Scientist {}
public class HorrorFlick {
public static void main(String[] args) {
Person p = new Person();
```

```
Hero h = new Hero();
Scientist s = new Scientist();
MadScientist m = new MadScientist();
//- p = (Person)p.clone(); // Compile error
//- h = (Hero)h.clone(); // Compile error
s = s.clone();
m = (MadScientist)m.clone();
}
}
```

Before cloneability was added in the hierarchy, the compiler stopped you from trying to clone things. When cloneability is added in **Scientist**, then **Scientist** and all its descendants are cloneable.



Notice that **Scientist**'s **clone()** returns a **Scientist**, whereas

cloning **MadScientist**, which inherits **Scientist**'s **clone()** rather than creating its own specific version, requires a cast.

Why This Strange Design?

If all this seems a strange scheme, that's because it is. You might wonder why it worked out this way. What is the meaning behind this design?

Originally, Java was designed as a language to control hardware boxes, and definitely not with the Internet in mind. In a general-purpose language like this, it makes sense for the programmer to clone any object. Thus, **clone()** was placed in the root class **Object**, *but* it was a **public** method so you can always clone any object. This seemed the most flexible approach, and after all, what could it hurt? When Java was seen as an Internet programming language, things changed. Suddenly, there are security issues, and these issues are dealt with using objects, and you don't necessarily want anyone to clone your security objects. So what you're seeing is many patches applied on the original simple and straightforward scheme: **clone()** is now **protected** in **Object**. You must override it *and* **implement Cloneable** *and* deal with the exceptions.

It's worth noting you must implement the **Cloneable** interface *only*

if you're going to call **Objects clone()** method, since that method checks at run time to make sure that your class implements **Cloneable**.

Controlling Cloneability

You might suggest that, to remove cloneability, the **clone()** method should simply be made **private**, but this won't work, because you cannot take a base-class method and make it less accessible in a derived class. And yet, it's necessary to control whether an object can be cloned. There are a number of attitudes you can take for your classes:

1. Indifference. You don't do anything about cloning, which means your class can't be cloned, but a class that inherits from you can add cloning if it wants. This works only if the default **Object.clone()** will do something reasonable with all the fields in your class.
2. Support **clone()**. Implement **Cloneable** and override **clone()**. In the overridden **clone()**, call **super.clone()** and catch all exceptions (so your overridden **clone()** doesn't throw any exceptions).

3. Support cloning conditionally. If your class holds references to other objects that might or might not be cloneable (a container class, for example), your **clone()** can try to clone all objects for which you have references, and if they throw exceptions, just pass those exceptions out to the programmer. For example, consider a special sort of **ArrayList** that tries to clone all the objects it holds. When you write such an **ArrayList**, you don't know what sort of objects the client programmer might put into your **ArrayList**, so you don't know whether they can be cloned.

4. Don't implement **Cloneable** but override **clone()** as **protected**, producing the correct copying behavior for any fields. This way, anyone inheriting from this class can override **clone()** and call **super.clone()** to produce the correct copying behavior. Note that your implementation can and should invoke **super.clone()** even though that method expects a **Cloneable** object (it will throw an exception otherwise), because no one will directly invoke it on an object of your type. It will get invoked only through a derived class, which, if it is to work successfully, implements **Cloneable**.

5. Try to prevent cloning by not implementing **Cloneable** and

overriding **clone()** to throw an exception. This is successful only if any class derived from this calls **super.clone()** in its redefinition of **clone()**. Otherwise, a programmer might circumvent it.

6. Prevent cloning by making your class **final**. If **clone()** has not been overridden by any of your ancestor classes, then it can't be. If it has been overridden, then override it again and throw **CloneNotSupportedException**. Making the class **final** is the only way to guarantee that cloning is prevented. In addition, when dealing with security objects or other situations where you control the number of objects created, make all constructors **private** and provide one or more special methods for creating objects. That way, these methods can restrict the number of objects created and the conditions in which they're created.

Here's an example that shows the various ways cloning can be implemented and then, later in the hierarchy, "turned off":

```
// references/CheckCloneable.java
// Check to see if a reference can be cloned
// Can't clone this -- doesn't override clone():
class Ordinary {}
```

```
// Overrides clone, doesn't implement Cloneable:
class WrongClone extends Ordinary {
@Override public Object clone()
throws CloneNotSupportedException {
return super.clone(); // Throws exception
}
}
// Does all the right things for cloning:
class IsCloneable extends Ordinary
implements Cloneable {
@Override public Object clone()
throws CloneNotSupportedException {
return super.clone();
}
}
// Turn off cloning by throwing the exception:
class NoMore extends IsCloneable {
@Override public Object clone()
throws CloneNotSupportedException {
throw new CloneNotSupportedException();
```

```
}
}
class TryMore extends NoMore {
@Override public Object clone()
throws CloneNotSupportedException {
// Calls NoMore.clone(), throws exception:
return super.clone();
}
}
class BackOn extends NoMore {
private BackOn duplicate(BackOn b) {
// Somehow make a copy of b and return that
// copy. A dummy copy, just to make a point:
return new BackOn();
}
@Override
public Object clone() {
// Doesn't call NoMore.clone():
return duplicate(this);
}
```

```
}
// You can't inherit from this, so you can't
// override clone() as you can in BackOn:
final class ReallyNoMore extends NoMore {}
public class CheckCloneable {
public static
Ordinary tryToClone(Ordinary ord) {
String id = ord.getClass().getName();
System.out.println("Attempting " + id);
Ordinary x = null;
if(ord instanceof Cloneable) {
try {
x = (Ordinary)((IsCloneable)ord).clone();
System.out.println("Cloned " + id);
} catch(CloneNotSupportedException e) {
System.out.println(
"Could not clone " + id);
}
} else {
System.out.println("Doesn't implement Cloneable");
```

```
}
return x;
}
public static void main(String[] args) {
// Upcasting:
Ordinary[] ord = {
new IsCloneable(),
new WrongClone(),
new NoMore(),
new TryMore(),
new BackOn(),
new ReallyNoMore(),
};
Ordinary x = new Ordinary();
// This won't compile because
// clone() is protected in Object:
//- x = (Ordinary)x.clone();
// Checks first to see if the class
// implements Cloneable:
for(Ordinary ord1 : ord) {
```

```
tryToClone(ord1);
}
}
}
/* Output:
Attempting IsCloneable
Cloned IsCloneable
Attempting WrongClone
Doesn't implement Cloneable
Attempting NoMore
Could not clone NoMore
Attempting TryMore
Could not clone TryMore
Attempting BackOn
Cloned BackOn
Attempting ReallyNoMore
Could not clone ReallyNoMore
*/
```

The first class, **Ordinary**, represents the kinds of classes we've seen throughout this book: no support for cloning, but as it turns out, no

prevention of cloning either. But if you have a reference to an **Ordinary** object that might be upcast from a more derived class, you can't tell if it can be cloned or not.

The class **WrongClone** shows an incorrect way to implement cloning. It does override **Object.clone()** and makes that method **public**, but it doesn't implement **Cloneable**, so when **super.clone()** is called (which results in a call to **Object.clone()**), **CloneNotSupportedException** is thrown, so the cloning doesn't work.

IsCloneable performs all the right actions for cloning; **clone()** is overridden and **Cloneable** is implemented. However, this **clone()** method and several others that follow in this example *do not* catch **CloneNotSupportedException**, but instead pass it through to the caller, who must then put a try-catch block around it. In your own **clone()** methods you typically catch **CloneNotSupportedException** *inside* **clone()** rather than passing it through. As you'll see, in this example it's more informative to pass the exceptions through.

Class **NoMore** attempts to "turn off" cloning in the way that the Java designers intended: in the derived class **clone()**, you throw

CloneNotSupportedException. The **clone()** method in class **TryMore** properly calls **super.clone()**, and this resolves to **NoMore.clone()**, which throws an exception and prevents cloning. But what if the programmer doesn't follow the "proper" path of calling **super.clone()** inside the overridden **clone()** method? In **BackOn**, you see how this can happen. This class uses a separate method **duplicate()** to make a copy of the current object and calls this method inside **clone()** *instead* of calling **super.clone()**. The exception is never thrown and the new class is cloneable. You can't rely on throwing an exception to prevent making a cloneable class. The only sure-fire solution is shown in **ReallyNoMore**, which is **final** and thus cannot be inherited. That means if **clone()** throws an exception in the **final** class, it cannot be modified with inheritance, and the prevention of cloning is assured. (You cannot explicitly call **Object.clone()** from a class that has an arbitrary level of inheritance; you are limited to calling **super.clone()**, which has access to only the direct base class.) Thus, if you make any objects that involve security issues, make those classes **final**.

The first method you see in class **CheckCloneable** is **tryToClone()**, which takes any **Ordinary** object and checks to

see whether it's cloneable with **instanceof**. If so, it casts the object

to an **IsCloneable**, calls **clone()**, and casts the result back to **Ordinary**, catching any exceptions. Notice the use of run-time type identification (see the Type Information chapter) to display the class name and show what's happening.

In **main()**, different types of **Ordinary** objects are created and upcast to **Ordinary** in the array definition. The subsequent two lines of code create a plain **Ordinary** object and try to clone it. However, this code will not compile because **clone()** is a **protected** method in **Object**. The remainder of the code steps through the array and tries to clone each object, reporting the success or failure of each.

So to summarize, if you want a cloneable class:

1. Implement the **Cloneable** interface.
2. Override **clone()**.
3. Call **super.clone()** inside your **clone()**.
4. Capture exceptions inside your **clone()**.

This will produce the most convenient effects.

The Copy Constructor

Cloning can be a complicated process to set up. Is there an alternative? One (slow) approach is to use serialization, as shown earlier. You can also make a special constructor whose job it is to duplicate an object. In C++, this is called the *copy constructor*. A first attempt seems like it should work, but it doesn't:

```
// references/CopyConstructor.java
// A constructor to copy an object of the same
// type, as an attempt to create a local copy
import java.lang.reflect.*;
class FruitQualities {
private int weight;
private int color;
private int firmness;
private int ripeness;
private int smell;
// etc.
// No-arg constructor:
FruitQualities() {
```

```
// Do something meaningful...
}
// Other constructors:
// ...
// Copy constructor:
FruitQualities(FruitQualities f) {
weight = f.weight;
color = f.color;
firmness = f.firmness;
ripeness = f.ripeness;
smell = f.smell;
// etc.
}
}
class Seed {
// Members...
Seed() { /* No-arg constructor */ }
Seed(Seed s) { /* Copy constructor */ }
}
class Fruit {
```

```
private FruitQualities fq;
private int seeds;
private Seed[] s;
Fruit(FruitQualities q, int seedCount) {
fq = q;
seeds = seedCount;
s = new Seed[seeds];
for(int i = 0; i < seeds; i++)
s[i] = new Seed();
}
// Other constructors:
// ...
// Copy constructor:
Fruit(Fruit f) {
fq = new FruitQualities(f.fq);
seeds = f.seeds;
s = new Seed[seeds];
// Call all Seed copy-constructors:
for(int i = 0; i < seeds; i++)
s[i] = new Seed(f.s[i]);
```

```
// Other copy-construction activities...
}
// This allows derived constructors (or other
// methods) to put in different qualities:
protected void addQualities(FruitQualities q) {
fq = q;
}
protected FruitQualities getQualities() {
return fq;
}
}
class Tomato extends Fruit {
Tomato() {
super(new FruitQualities(), 100);
}
Tomato(Tomato t) { // Copy-constructor
super(t); // Upcast to base copy-constructor
// Other copy-construction activities...
}
}
```

```
class ZebraQualities extends FruitQualities {
private int stripedness;
// No-arg constructor:
ZebraQualities() {
super();
// do something meaningful...
}
ZebraQualities(ZebraQualities z) {
super(z);
stripedness = z.stripedness;
}
}
class GreenZebra extends Tomato {
GreenZebra() {
addQualities(new ZebraQualities());
}
GreenZebra(GreenZebra g) {
super(g); // Calls Tomato(Tomato)
// Restore the right qualities:
addQualities(new ZebraQualities());
```

```
}
public void evaluate() {
ZebraQualities zq =
(ZebraQualities)getQualities();
// Do something with the qualities
// ...
}
}
public class CopyConstructor {
public static void ripen(Tomato t) {
// Use the "copy constructor":
t = new Tomato(t); // [1]
System.out.println("In ripen, t is a " +
t.getClass().getName());
}
public static void slice(Fruit f) {
f = new Fruit(f); // [2] Hmmm... will this work?
System.out.println("In slice, f is a " +
f.getClass().getName());
}
```

```
@SuppressWarnings("unchecked")
public static void ripen2(Tomato t) {
try {
Class c = t.getClass();
// Use the "copy constructor":
Constructor ct =
c.getConstructor(new Class[] { c });
Object obj =
ct.newInstance(new Object[] { t });
System.out.println("In ripen2, t is a " +
obj.getClass().getName());
} catch(NoSuchMethodException |
SecurityException |
InstantiationException |
IllegalAccessException |
IllegalArgumentException |
InvocationTargetException e) {
System.out.println(e);
}
}
```

```
@SuppressWarnings("unchecked")
public static void slice2(Fruit f) {
try {
Class c = f.getClass();
Constructor ct =
c.getConstructor(new Class[] { c });
Object obj =
ct.newInstance(new Object[] { f });
System.out.println("In slice2, f is a " +
obj.getClass().getName());
} catch(NoSuchMethodException |
SecurityException |
InstantiationException |
IllegalAccessException |
IllegalArgumentException |
InvocationTargetException e) {
System.out.println(e);
}
}
public static void main(String[] args) {
```

```
Tomato tomato = new Tomato();
ripen(tomato); // OK
slice(tomato); // OOPS!
ripen2(tomato); // OK
slice2(tomato); // OK
GreenZebra g = new GreenZebra();
ripen(g); // OOPS!
slice(g); // OOPS!
ripen2(g); // OK
slice2(g); // OK
g.evaluate();
}
}
/* Output:
In ripen, t is a Tomato
In slice, f is a Fruit
java.lang.NoSuchMethodException: Tomato.<init>(Tomato)
java.lang.NoSuchMethodException: Tomato.<init>(Tomato)
In ripen, t is a Tomato
In slice, f is a Fruit
```

java.lang.NoSuchMethodException:

GreenZebra.<init>(GreenZebra)

java.lang.NoSuchMethodException:

GreenZebra.<init>(GreenZebra)

/

This seems a bit strange at first. Sure, fruit has qualities, but why not just put fields representing those qualities directly into the **Fruit** class? There are two potential reasons.

1. To easily insert or change the qualities. Note that **Fruit** has a **protected addQualities()** method to allow derived classes to do this. (You might think the logical thing to do is include a **protected** constructor in **Fruit** that takes a **FruitQualities** argument, but constructors don't inherit, so it wouldn't be available in second or greater level classes.) By making the fruit qualities into a separate class and using composition, you have greater flexibility, including the ability to change the qualities midway through the lifetime of a particular **Fruit** object.

2. Making **FruitQualities** a separate object allows you to add new qualities or to change the behavior via inheritance and

polymorphism. Note that for **GreenZebra** (which *really is* a type of tomato), the constructor calls **addQualities()** and passes it a **ZebraQualities** object, which is derived from **FruitQualities**, so it can be attached to the **FruitQualities** reference in the base class. When **GreenZebra** uses the **FruitQualities**, it must downcast it to the correct type (as seen in **evaluate()**), but it always knows that type is **ZebraQualities**.

You'll also see there's a **Seed** class, and that **Fruit** (which by definition carries its own seeds) contains an array of **Seed**s.

Finally, notice that each class has a copy constructor, and that each copy constructor must take care to call the copy constructors for the base class and member objects to produce a deep copy. The copy constructor is tested inside the class **CopyConstructor**.

[1] ripen() takes a **Tomato** argument and performs copy-construction on it to duplicate the object.

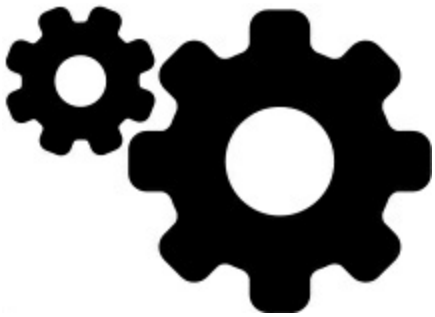
[2] slice() takes a more generic **Fruit** object and also duplicates it.

These are tested with different kinds of **Fruit** in **main()**. The output shows the problem. After the copy-construction that happens

to the **Tomato** inside **slice()**, the result is no longer a **Tomato** object, but just a **Fruit**. It has lost all of its tomato-ness. Furthermore, when you take a **GreenZebra**, both **ripen()** and **slice()** turn it into a **Tomato** and a **Fruit**, respectively. Thus, unfortunately, the copy constructor scheme is no good to us in Java when attempting to make a local copy of an object.

Why Does It Work in C++ and Not Java?

The copy constructor is a fundamental part of C++, since it automatically makes a local copy of an object. Yet the preceding



example proves it does not work for Java. Why? In Java, everything that we manipulate is a reference, but in C++, you can have reference-like entities and you can *also* pass objects around directly. That's what the C++ copy constructor is for: to take an object and pass it in by value, thus duplicating the object. So it works fine in C++, but keep in mind this scheme fails in Java, so don't use it.

Immutable Classes

Although the local copy produced by **clone()** gives the desired results in the appropriate cases, it is an example of forcing the programmer (the author of the method) to be responsible for preventing the ill effects of aliasing. What if you're making a library that's so general purpose and commonly used you cannot make the assumption it will always be cloned in the proper places? Or more likely, how do you allow aliasing for efficiency—to prevent the needless duplication of objects—without the negative side effects of aliasing? One solution (used by pure functional programming languages) is to create *immutable objects* that belong to read-only classes. You can define a class such that no methods in the class change the internal state of the object. In such a class, aliasing has no impact since you can only read the internal state, so if many pieces of code are reading the same object, there's no problem.

As a simple example of immutable objects, Java's standard library contains "wrapper" classes for all the primitive types. You might have already discovered that, to store an **int** inside a container such as an **ArrayList** (which takes only **Object** references), you must wrap your **int** inside the standard library **Integer** class. Here, the wrapping occurs automatically, with autoboxing:

```
// references/ImmutableInteger.java
// The Integer class cannot be changed
import java.util.*;
import java.util.stream.*;
public class ImmutableInteger {
public static void main(String[] args) {
List<Integer> v = IntStream.range(0, 10)
.mapToObj(Integer::new)
.collect(Collectors.toList());
System.out.println(v);
// But how do you change the int
// inside the Integer?
}
}
/* Output:
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
*/
```

The **Integer** class (as well as all the primitive “wrapper” classes) implements immutability in a simple fashion: It has no methods that allow you to change the object.

If you do need an object to hold a primitive type that can be modified, you must create it yourself. Fortunately, this is trivial:

```
// references/MutableInteger.java
// A changeable wrapper class
import java.util.*;
import java.util.stream.*;
class IntValue {
private int n;
IntValue(int x) { n = x; }
public int getValue() { return n; }
public void setValue(int n) { this.n = n; }
public void increment() { n++; }
@Override
public String toString() {
return Integer.toString(n);
}
}
public class MutableInteger {
public static void main(String[] args) {
List<IntValue> v = IntStream.range(0, 10)
```

```
.mapToObj(IntValue::new)
.collect(Collectors.toList());
System.out.println(v);
v.forEach(IntValue::increment);
System.out.println(v);
}
}
/* Output:
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
[1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
*/
```

IntValue can be even simpler if privacy is not an issue:

```
// references/SimplerMutableInteger.java
// A trivial wrapper class
import java.util.*;
import java.util.stream.*;
class IntValue2 {
public int n;
IntValue2(int n) { this.n = n; }
}
```

```
public class SimplerMutableInteger {
public static void main(String[] args) {
List<IntValue2> v = IntStream.range(0, 10)
.mapToObj(IntValue2::new)
.collect(Collectors.toList());
v.forEach(iv2 ->
System.out.print(iv2.n + " "));
System.out.println();
v.forEach(iv2 -> iv2.n += 1);
v.forEach(iv2 ->
System.out.print(iv2.n + " "));
}
}
/* Output:
0 1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9 10
```

```
*/
```

Directly selecting the **n** member is a bit awkward, however.

Creating Immutable Classes

Here’s one way to create your own immutable class:

```
// references/Immutable1.java
// Immutable objects are immune to aliasing
public class Immutable1 {
private int data;
public Immutable1(int initVal) {
data = initVal;
}
public int read() { return data; }
public boolean nonzero() { return data != 0; }
public Immutable1 multiply(int multiplier) {
return new Immutable1(data * multiplier);
}
public static void f(Immutable1 i1) {
Immutable1 quad = i1.multiply(4);
System.out.println("i1 = " + i1.read());
System.out.println("quad = " + quad.read());
}
```

```
public static void main(String[] args) {
Immutable1 x = new Immutable1(47);
System.out.println("x = " + x.read());
f(x);
System.out.println("x = " + x.read());
}
}
/* Output:
x = 47
i1 = 47
quad = 188
x = 47
*/
```

All data is **private**, and you'll see that none of the **public** methods modify that data. Indeed, the method that does appear to modify an object is **multiply()**, but this creates a new **Immutable1** object and leaves the original untouched.

The method **f()** takes an **Immutable1** object and performs various operations on it, and the output of **main()** demonstrates there is no change to **x**. Thus, **x**s object could be aliased many times without harm, because the **Immutable1** class is designed to guarantee that objects cannot be changed.

The Drawback to

Immutability

Creating an immutable class seems at first to provide an elegant solution. However, whenever you do need a modified object of that new type, you must suffer the overhead of a new object creation, as well as potentially causing more frequent garbage collections. For some classes this is not a problem (and functional programming languages rely on it), but for others (such as the **String** class) it can be expensive—but remember always the dictum against premature optimization. (Note that languages that only provide immutability do quite well, despite the perceived overhead).

The solution is to create a companion class that *can* be modified. Then, when you're doing many modifications, you can switch to using the modifiable companion class and switch back to the immutable class when you're done.

We can change **Immutable1.java** to show this:

```
// references/Immutable2.java
// A companion class to modify immutable objects
class Mutable {
private int data;
Mutable(int initVal) {
data = initVal;
}
public Mutable add(int x) {
data += x;
return this;
}
public Mutable multiply(int x) {
data *= x;
return this;
}
public Immutable2 makeImmutable2() {
return new Immutable2(data);
}
}
```

```
public class Immutable2 {
private int data;
public Immutable2(int initVal) {
data = initVal;
}
public int read() { return data; }
public boolean nonzero() {
return data != 0;
}
public Immutable2 add(int x) {
return new Immutable2(data + x);
}
public Immutable2 multiply(int x) {
return new Immutable2(data * x);
}
public Mutable makeMutable() {
return new Mutable(data);
}
public static
Immutable2 modify1(Immutable2 y) {
```

```
Immutable2 val = y.add(12);
val = val.multiply(3);
val = val.add(11);
val = val.multiply(2);
return val;
}
// This produces the same result:
public static
Immutable2 modify2(Immutable2 y) {
Mutable m = y.makeMutable();
m.add(12).multiply(3).add(11).multiply(2);
return m.makeImmutable2();
}
public static void main(String[] args) {
Immutable2 i2 = new Immutable2(47);
Immutable2 r1 = modify1(i2);
Immutable2 r2 = modify2(i2);
System.out.println("i2 = " + i2.read());
System.out.println("r1 = " + r1.read());
System.out.println("r2 = " + r2.read());
```

```
}
}
/* Output:
i2 = 47
r1 = 376
r2 = 376
*/
```

Immutable2 contains methods that, as before, preserve the immutability of the objects by producing new objects whenever a modification is desired. These are the **add()** and **multiply()** methods. The companion class is called **Mutable**, and it also has **add()** and **multiply()** methods, but these modify the **Mutable** object rather than making a new one. In addition, **Mutable** has a method to use its data to produce an **Immutable2** object and vice versa.

The two static methods **modify1()** and **modify2()** show two different approaches to producing the same result. In **modify1()**, everything is done within the **Immutable2** class and you see that four new **Immutable2** objects are created in the process. (And each

time **val** is reassigned, the previous object becomes garbage.)

The first action in **modify2()** is to take the **Immutable2 y** and produce a **Mutable** from it. (This is just like calling **clone()** as you saw earlier, but this time a different type of object is created.) Then the **Mutable** object is used to perform many change operations *without* requiring the creation of many new objects. Finally, it's turned back into an **Immutable2**. Here, two new objects are created (the **Mutable** and the result **Immutable2**) instead of four.

This approach makes sense, then, when:

1. You need immutable objects and
2. You often need to make many modifications or
3. It's expensive to create new immutable objects.

Immutable Strings

Consider the following code:

```
// references/Stringer.java
public class Stringer {
public static String upcase(String s) {
```

```
return s.toUpperCase();
}
public static void main(String[] args) {
String q = new String("howdy");
System.out.println(q); // howdy
String qq = upcase(q);
System.out.println(qq); // HOWDY
System.out.println(q); // howdy
}
}
/* Output:
howdy
HOWDY
howdy
*/
```

When **q** is passed in to **upcase()** it's actually a copy of the reference to **q**. The object this reference is connected to stays in a single physical location. The references are copied as they are passed around.

In the definition for **upcase()**, the reference that's passed in has the name **s**, and it exists for only as long as the body of **upcase()** is

executed. When **upcase()** completes, the local reference **s** vanishes. **upcase()** returns the result, which is the original **String** with all the characters set to uppercase. Of course, it actually returns a reference to the result. But the reference is for a new object, and the original **q** is left alone. How does this happen?

Implicit Constants

If you say:

String s = "asdf";

String x = Stringer.upcase(s);

do you really want the **upcase()** method to *change* the argument? In general, you don't, because an argument usually looks to the reader of the code as a piece of information provided to the method, not something to be modified. This is an important guarantee, since it makes code easier to write and understand.

Overloading + and StringBuilder

Objects of the **String** class are designed to be immutable, using the companion-class technique shown previously. If you examine the JDK documentation for the **String** class (which is summarized a little later in this appendix), you'll see that every method in the class that appears to modify a **String** really creates and returns a brand new **String** object containing the modification. The original **String** is

left untouched. Thus, there's no feature in Java like C++'s **const** to make the compiler support the immutability of your objects. If you want it, you have to wire it in yourself, like **String** does.

Since **String** objects are immutable, you can alias to a particular **String** as many times as you want. Immutability means there's no chance one reference will change something that affects other references. So an immutable object solves the aliasing problem nicely.

It also seems possible to handle all the cases where you need a modified object by creating a brand new version of the object with the modifications, as **String** does. However, for some operations this isn't efficient. A case in point is the operator **+** that is overloaded for **String** objects. Overloading means it has extra meaning when used with a particular class. (The **+** and **+=** for **String** are the only overloaded operators in Java, and Java does not allow the programmer to overload any others). 3

When used with **String** objects, the **+** concatenates **String**s together:

```
String s = "abc" + foo + "def" + Integer.toString(47);
```

You can imagine how this *might* work. The **String** "abc" could have a method **append()** that creates a new **String** object containing

“abc” concatenated with the contents of **foo**. The new **String** object would then create another new **String** that added “def,” and so on. This would certainly work, but it requires the creation of many **String** objects just to put together this new **String**, then you have a bunch of intermediate **String** objects that need garbage-collecting. I suspect that the Java designers tried this approach first (which is a lesson in software design—you don’t really know anything about a system until you try it out in code and get something working). I also suspect they discovered it delivered unacceptable performance.

The solution is a mutable companion class similar to the one shown previously. For **String**, this companion class is called **StringBuilder**, and the compiler automatically creates a **StringBuilder** to evaluate certain expressions, in particular when the overloaded operators **+** and **+=** are used with **String** objects. Here’s what it looks like:

```
// references/ImmutableStrings.java
// Demonstrating StringBuilder
public class ImmutableStrings {
public static void main(String[] args) {
String foo = "foo";
```

```
String s = "abc" + foo + "def"
+ Integer.toString(47);
System.out.println(s);
// The "equivalent" using StringBuilder:
StringBuilder sb =
new StringBuilder("abc"); // Creates String
sb.append(foo);
sb.append("def"); // Creates String
sb.append(Integer.toString(47));
System.out.println(sb);
}
}
/* Output:
abcfoodef47
abcfoodef47
```

```
*/
```

In the creation of **String s**, the compiler is doing the rough

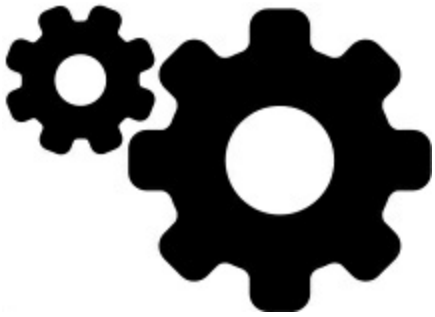
equivalent of the subsequent code that uses **sb**: a **StringBuilder** is created, and **append()** is used to add new characters directly into the **StringBuilder** object (rather than making new copies each time). While this is more efficient, it's worth noting that each time you create a quoted character string such as **"abc"** and **"def"** , the compiler turns those into **String** objects. This can create more objects than you expect, despite the efficiency afforded through **StringBuilder**.

You can find more details of **StringBuilder** in the Strings chapter.

Strings are Special

If you review the Strings chapter, you'll see that every **String** method carefully returns a new **String** object when the contents change. If the contents don't need changing, the method just returns a reference to the original **String**. This saves storage and overhead.

The **String** class is not just another class in Java. There are many special cases in **String**, not the least of which is that it's a built-in class and fundamental to Java. Then there's the fact that a quoted character string is converted to a **String** by the compiler and the special overloaded operators + and +=. In this appendix you've seen the remaining special case: the carefully-built immutability using the companion **StringBuilder** and some extra magic in the compiler.



Summary

Because all object identifiers are references in Java, and because every object is created on the heap and garbage collected only when it is no longer used, the flavor of object manipulation changes, especially when passing and returning objects. To initialize some piece of storage in a method in C or C++, you might request that the user pass the address of that piece of storage into the method. Otherwise, you have to worry about who is responsible for destroying that storage. Thus, the interface and understanding of such methods is more complicated. But in Java, you don’t worry about responsibility or whether an object will still exist when it is needed, since that is always taken care of for you. You create an object when it is needed (and no sooner) and never worry about mechanics of passing around responsibility for that object; you simply pass the reference. Sometimes the simplification this provides is unnoticed. Other times it is staggering.

The downside to all this underlying magic is twofold:

1. You always take the efficiency hit for the extra memory management (although this is usually a non-issue), and there's always a slight amount of uncertainty about the time something can take to run (since the garbage collector can be forced into action whenever you get low on memory). For most applications, the benefits outweigh the drawbacks, and the hotspot technologies in particular have sped things up to the point where it's not much of an issue.

2. Aliasing: Sometimes you end up with two references to the same object, which is a problem only if both references are assumed to point to a *distinct* object. This is where you must pay a little closer attention and, when necessary, **clone()** or otherwise duplicate an object to prevent the other reference from being surprised by an unexpected change. Alternatively, you can support aliasing for efficiency by creating immutable objects whose operations can return a new object of the same type or some different type, but never change the original object so anyone aliased to that object sees no change.

Some people say that cloning in Java is a botched design that shouldn't be used, so they implement their own version of cloning.

Doug Lea, who was helpful in resolving this issue, suggested this to me, saying that he simply creates a function called **duplicate()** for each class. This way, you never call **Object.clone()**, eliminating the need to implement **Cloneable** and catch the **CloneNotSupportedException**. This is certainly a reasonable approach, and since **clone()** is supported so rarely within the standard Java library, it is apparently a safe one as well.

Rather than writing your own clone support, consider either the *Apache Commons Serialization Utility Classes* or the deep cloning library.

1. In C, which generally handles small bits of data, the default is pass by value. C++ had to follow this form, but with objects, pass by value isn't usually the most efficient approach. In addition, coding classes to support pass by value in C++ is a big headache.↩

2. This is not the dictionary spelling of the word, but it's what is used in the Java library, so I've used it here, too, in some hopes of reducing confusion. ↩

3. C++ allows the programmer to overload operators at will. Because this can often be a complicated process (see Chapter 10 of *Thinking in C++, 2nd edition*, Prentice Hall, 2000), the Java

designers deemed it a “bad” feature that shouldn’t be included in Java. It wasn’t so bad they didn’t end up doing it themselves, and ironically enough, operator overloading would be much easier to use in Java than in C++. This can be seen in Python (see www.Python.org) which has garbage collection and straightforward operator overloading.↩

Appendix: I/O Streams

Java 7 introduced a simple and clear approach for reading and writing files and using directory paths. Most of the time, the libraries and techniques shown in the Files chapter are all you need. If, however, you must deal with specific needs, lower-level operations or with legacy code, you must understand the information in this appendix.

Creating a good input/output (I/O) system is one of the more difficult tasks for a language designer. This is evidenced by the number of

different approaches. The challenge seems to be in covering all possibilities. Not only are there different sources and sinks of I/O (files, the console, network connections, etc.), but you must talk to them in a wide variety of ways (sequential, random-access, buffered, binary, character, by lines, by words, etc.).

The Java library designers attacked this problem by creating lots of classes. In fact, there are so many classes in Java I/O streams it can be intimidating at first. There was also a significant change in the I/O library after Java 1.0, when the original byte-oriented library was supplemented with **char**-oriented, Unicode-based I/O classes. The **nio** classes (for "new I/O," a name used years after they were introduced in Java 1.4) were added for improved performance and functionality; these are covered in the Appendix: New I/O.

As a result, there are a fair number of classes to learn before you understand enough of Java I/O streams library to use it properly. It's also helpful to understand the evolution of the I/O library. The problem is that, without the historical perspective, you rapidly become confused with some of the classes and when you should and shouldn't use them.

Programming language I/O libraries often use the abstraction of a

stream, which represents any data source or sink as an object capable of producing or receiving pieces of data.

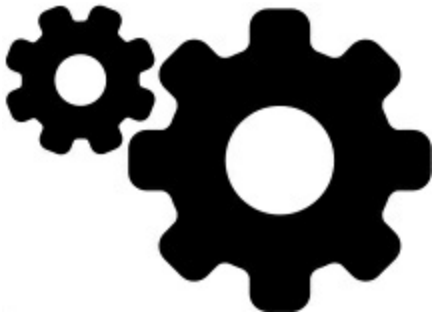
It's important to understand there is *no* connection between the Java 8 functional-style **Stream** classes and I/O Streams. This is another example where, if the designers could do it over again, they'd use different terminology.

An I/O stream hides details of what happens to the data inside the actual I/O device:

1. Byte Streams are for raw binary data.

2. Character Streams are for character data. These automatically handle translation to and from the local character set.

3. Buffered Streams improve performance. They optimize input and output by reducing the number of calls to the native API.



The Java library classes for I/O streams are divided by input and

output, as shown in the class hierarchy in the JDK documentation. In Java 1.0, the library designers decided that all classes that had anything to do with input are inherited from **InputStream**, and all classes associated with output are inherited from **OutputStream**. Everything derived from the **InputStream** or **Reader** classes has basic methods called **read()** for reading a single **byte** or an array of **byte**s. Likewise, everything derived from **OutputStream** or **Writer** classes has basic methods called **write()** for writing a single **byte** or an array of **byte**s. However, you won't generally use these methods; they exist so other classes can use them—these other classes provide a more useful interface.

You'll rarely create your stream object by using a single class, but instead will layer multiple objects together to provide your desired functionality (this is the *Decorator* design pattern). The fact you create more than one object to produce a single stream is the primary reason that Java's I/O library is confusing.

I attempt to provide an overview of the classes here, but assume you will use the JDK documentation to determine all the details, such as the exhaustive list of methods for a particular class.

Types of InputStream

InputStream represents classes that produce input from different sources. These sources can be:

1. An array of bytes.
2. A **String** object.
3. A file.
4. A “pipe,” which works like a physical pipe: You put things in at one end and they come out the other.
5. A sequence of other streams, so you can collect them together into a single stream.
6. Other sources, such as an Internet connection.

Each of these sources has an associated subclass of **InputStream**.

In addition, the **FilterInputStream** is also a type of **InputStream**, to provide a base class for “decorator” classes that attach attributes or useful interfaces to input streams. This is discussed later.

Table I/O-1: Types of InputStream

Constructor

Class

Function

arguments

Allows a buffer in

The buffer from which to

ByteArrayInputStream

memory to act as an

extract the bytes.

InputStream.

A **String**

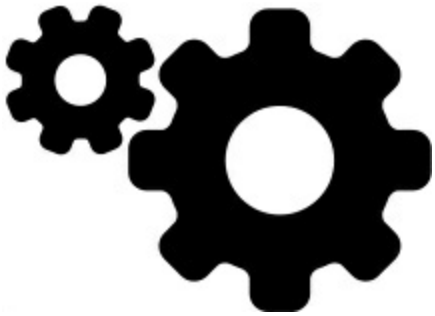
Converts a **String** into

underlying

StringBufferInputStream an **InputStream**.

implementation actually

uses a



For reading information

A **String**

FileInputStream

from a file.

the file name, or a

or **FileDescriptor**

object.

Produces the data that’s

written to the associated

PipedInputStream

PipedOutputStream.

PipedOutputStream

Implements the “piping”

concept.

Converts two or more

Two

objects or an

InputStream objects

SequenceInputStream

Enumeration

into a single

container

InputStream.

InputStream

Abstract class that is an

interface for decorators

that provide useful

FilterInputStream

functionality to the other

See **Table I/O-3**

InputStream classes.

See **Table I/O-3**.

Types of OutputStream

This category includes the classes that decide where your output will

go: an array of bytes (but not a **String**—presumably, you can create one using the array of bytes), a file, or a “pipe.”

In addition, the **FilterOutputStream** provides a base class for

“decorator” classes that attach attributes or useful interfaces to output

streams. This is discussed later.

Table I/O-2: Types of OutputStream

Constructor

Class

Function

arguments

Creates a buffer in

memory. All the data

Optional initial size of

ByteArrayOutputStream you send to the stream

the buffer.

is placed in this buffer.

A **String**

representing the file

For sending

FileOutputStream

name, or a

information to a file.

FileDescriptor

object.

Any information you

write to this

automatically ends up

as input for the

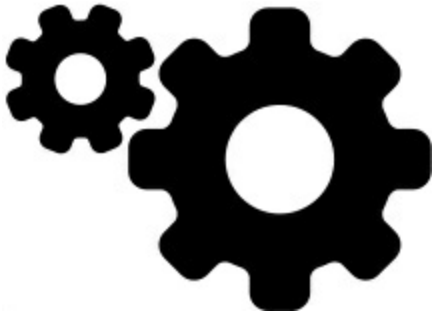
PipedOutputStream

associated

PipedInputStream

PipedInputStream.

Implements the



“piping” concept.

Abstract class that is an

interface for decorators

that provide useful

FilterOutputStream

functionality to the

See **Table I/O-4**

other **OutputStream**

classes. See **Table I/O-**

4.

Adding Attributes and

Useful Interfaces

Decorators were introduced in the Generics chapter. The Java I/O

library requires many different combinations of features, and this is

the justification for using the Decorator design pattern.1 The reason for the existence of the “filter” classes in the Java I/O library is that the abstract “filter” class is the base class for all the decorators. A decorator must have the same interface as the object it decorates, but the decorator can also extend the interface, which occurs in several of the “filter” classes.

There is a drawback to the Decorator pattern. Decorators provide more flexibility when writing a program (since you can easily mix and match attributes), but they add complexity to your code. The reason that the Java I/O library is awkward to use is that you must create many classes—the “core” I/O type plus all the decorators—to get the single I/O object you want.

The classes that provide the decorator interface to control a particular **InputStream** or **OutputStream** are **FilterInputStream**

and **FilterOutputStream**, which don’t have very intuitive names. **FilterInputStream** and **FilterOutputStream** are derived from the base classes of the I/O library, **InputStream** and

OutputStream, which is a key requirement of the decorator (so it provides the common interface to all decorated objects).

Reading from an InputStream

with FilterInputStream

The **FilterInputStream** classes accomplish two significantly different things. **DataInputStream** reads different types of primitive data as well as **String** objects. (All the methods start with "read," such as **readByte()**, **readFloat()**, etc.) This, along with its companion **DataOutputStream**, lets you move primitive data from one place to another via a stream. These "places" are determined by the classes in Table I/O-1.

The remaining **FilterInputStream** classes modify the way an **InputStream** behaves internally: whether it's buffered or unbuffered, whether it keeps track of the lines it's reading (allowing you to ask for line numbers or set the line number), and whether you can push back a single character. The last two classes look a lot like support for building a compiler (they were probably added to support the experiment of "building a Java compiler in Java"), so you probably won't use them in general programming.

You'll buffer your input almost every time, regardless of the connected

I/O device, so it would have made more sense for the I/O library to provide a special case (or simply a method call) for unbuffered input rather than forcing you to add buffering almost every time.

Table I/O-3. Types of FilterInputStream

Constructor	**Class**	**Function**	**Arguments**
Used in concert with **DataOutputStream**, to read primitives (**int**, **char**, **long**, etc.) from a stream in a portable fashion.	**DataInputStream**		
Use this to prevent a physical read every time	**InputStream**	**BufferedInputStream**	

you want more data.

with optional

You’re saying, “Use a

buffer size.

buffer.”

Keeps track of line

numbers in the input

LineNumberInputStream stream; you can call

InputStream

getLineNumber() and

setLineNumber(int).

Has a one-byte push-back

PushbackInputStream

buffer to push back the last

InputStream

character read.

Writing to an OutputStream

with FilterOutputStream

The complement to **DataInputStream** is **DataOutputStream**, which formats each of the primitive types and **String** objects onto a stream in such a way that any **DataInputStream**, on any machine, can read them. All the methods start with “write,” such as **writeByte()**, **writeFloat()**, etc.

The original intent of **PrintStream** was to print all primitive data types and **String** objects in a viewable format. This is different from **DataOutputStream**, whose goal is to put data elements on a stream in a way that **DataInputStream** can portably reconstruct them.

The two important methods in **PrintStream** are **print()** and **println()**, which are overloaded to print all the various types. The difference between **print()** and **println()** is that the latter adds a newline when it’s done.

PrintStream can be problematic because it traps all **IOException**s (you must explicitly test the error status with **checkError()**, which returns **true** if an error has occurred). Also, **PrintStream** doesn’t internationalize properly. These problems are solved with **PrintWriter**, described later.

BufferedOutputStream is a modifier and tells the stream to use buffering so you don’t get a physical write every time you write to the stream. You’ll probably always use this when doing output.

Table I/O-4. Types of FilterOutputStream

Constructor	**Class**	**Function**	**Arguments**
Used in concert with	**DataInputStream**	so you can write	**DataOutputStream**
primitives (**int**,	**OutputStream**	**char**, **long**, etc.) to a	**OutputStream**
stream in a portable		fashion.	
For producing	**OutputStream**	formatted output.	

with optional

While

boolean

PrintStream

DataOutputStream indicating that

handles the *storage* of

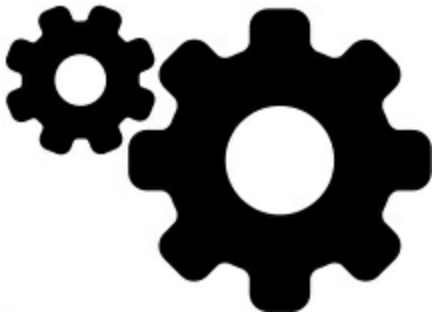
the buffer is

data, **PrintStream**

flushed with every

handles *display*.

newline.



Use this to prevent a

physical write every

time you send a piece

OutputStream

BufferedOutputStream of data. You’re saying,

with optional

“Use a buffer.” You can

buffer size.

call **flush()** to flush

the buffer.

Readers & Writers

Java 1.1 made significant modifications to the fundamental I/O stream library. When you see the **Reader** and **Writer** classes, your first thought (like mine) might be that these were meant to replace the **InputStream** and **OutputStream** classes. But that’s not the case. Although some aspects of the original streams library are deprecated (if you use them you receive a warning from the compiler), the **InputStream** and **OutputStream** classes still provide valuable functionality in the form of byte-oriented I/O, whereas the **Reader** and **Writer** classes provide Unicode-compliant, character-based I/O. In addition:

1. Java 1.1 added new classes into the **InputStream** and **OutputStream** hierarchy, so it’s obvious those hierarchies weren’t replaced.
2. There are times when you must use classes from the “byte”

hierarchy *in combination* with classes in the “character” hierarchy. To accomplish this, there are “adapter” classes: **InputStreamReader** converts an **InputStream** to a **Reader**, and **OutputStreamWriter** converts an

OutputStream to a **Writer**.

The most important reason for the **Reader** and **Writer** hierarchies is for internationalization. The old I/O stream hierarchy supports only 8-bit byte streams and doesn’t handle the 16-bit Unicode characters well. Since Unicode is used for internationalization (and Java’s native **char** is 16-bit Unicode), the **Reader** and **Writer** hierarchies were added to support Unicode in all I/O operations. In addition, the new libraries are designed for faster operations than the old.

Sources and Sinks of Data

Almost all the original Java I/O stream classes have corresponding **Reader** and **Writer** classes to provide native Unicode manipulation. However, there are some places where the byte-oriented **InputStream**s and **OutputStream**s are the correct

solution; in particular, the **java.util.zip** libraries are byte-oriented rather than **char**-oriented. So the most sensible approach to take is to *try* to use the **Reader** and **Writer** classes whenever you can. You'll discover the problems when you use the byte-oriented libraries because your code won't compile.

This table shows the correspondence between the sources and sinks of information (that is, where the data physically comes from or goes to) in the two hierarchies.

Sources & sinks: Java

Corresponding

1.0 class

Java 1.1 class

Reader adapter:

InputStream

InputStreamReader

Writer adapter:

OutputStream

OutputStreamWriter

FileInputStream

FileReader

FileOutputStream

FileWriter

StringBufferInputStream StringReader

(deprecated)

(No corresponding class)

StringWriter

ByteArrayInputStream

CharArrayReader

ByteArrayOutputStream

CharArrayWriter

PipedInputStream

PipedReader

PipedOutputStream

PipedWriter

In general, you'll find that the interfaces for the two different hierarchies are similar, if not identical.

Modifying Stream Behavior

For **InputStream**s and **OutputStream**s, streams were adapted for particular needs using “decorator” subclasses of **FilterInputStream** and **FilterOutputStream**. The **Reader** and **Writer** class hierarchies continue this idea—but not exactly.

In the following table, the correspondence is a rougher approximation than in the previous table. The difference is because of the class organization; although **BufferedOutputStream** is a subclass of **FilterOutputStream**, **BufferedWriter** is *not* a subclass of **FilterWriter** (which, even though it is **abstract**, has no subclasses and so appears be there as a placeholder or simply so you don’t wonder where it is). However, the interfaces to the classes are a close match.

Filters: Java 1.0

Corresponding

class

Java 1.1 class

FilterInputStream

FilterReader

FilterOutputStream

FilterWriter (abstract

class with no subclasses)

BufferedReader

BufferedInputStream

(also has **readLine()**)

BufferedOutputStream

BufferedWriter

Use **DataInputStream**

(except when you must use

DataInputStream

readLine(), when you

should use a

BufferedReader)

PrintStream

PrintWriter

LineNumberInputStream LineNumberReader

(deprecated)

StreamTokenizer

StreamTokenizer

(Use the constructor that

takes a **Reader** instead)

PushbackInputStream

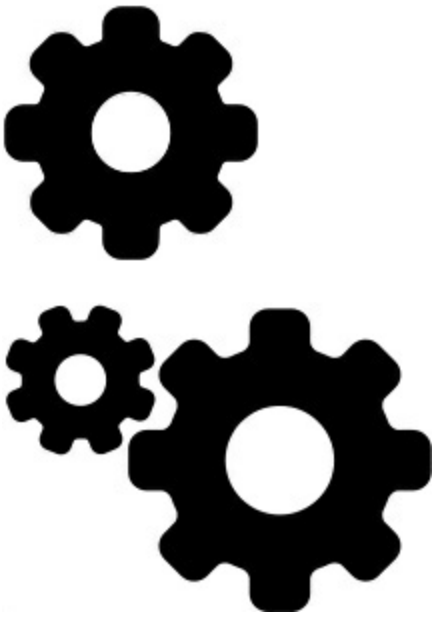
PushbackReader

There's one clear limitation: Whenever you use **readLine()**, don't do it with a **DataInputStream** (this is met with a deprecation message at compile time), but instead use a **BufferedReader**.

Other than this, **DataInputStream** is still a "preferred" member of the I/O library.

To make the transition to **PrintWriter** easier, it has constructors that take any **OutputStream** object as well as **Writer** objects.

PrintWriters formatting interface is virtually the same as



PrintStream.

In Java 5, **PrintWriter** constructors were added to simplify the

creation of files when writing output, as you shall see shortly.

One **PrintWriter** constructor also has an option to perform automatic flushing, which happens after every **println()** if the constructor flag is set.

Unchanged Classes

Some classes were left unchanged between Java 1.0 and Java 1.1:

Java 1.0 classes without corresponding Java 1.1 classes
DataOutputStream
File
RandomAccessFile
SequenceInputStream

DataOutputStream, in particular, is used without change, so for storing and retrieving data in a transportable format, you use the **InputStream** and **OutputStream** hierarchies.

Off By Itself:

RandomAccessFile

RandomAccessFile is used for files containing records of known size so you can move from one record to another using **seek()**, then read or change the records. The records don’t have to be the same size;

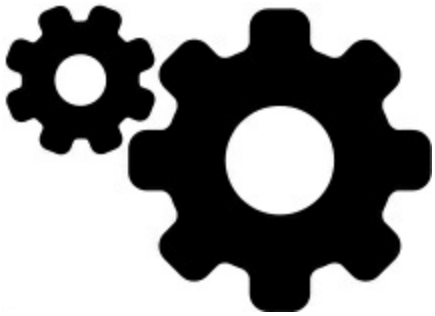
you just determine how big they are and where they are placed in the file.

At first it's a little bit hard to believe that **RandomAccessFile** is not part of the **InputStream** or **OutputStream** hierarchy. However, it has no association with those hierarchies other than it happens to implement the **DataInput** and **DataOutput** interfaces (which are also implemented by **DataInputStream** and **DataOutputStream**). It doesn't even use any of the functionality of the existing **InputStream** or **OutputStream** classes; it's a completely separate class, written from scratch, with all of its own (mostly native) methods. The reason for this might be that **RandomAccessFile** has essentially different behavior than the other I/O types, since you can move forward and backward within a file. In any event, it stands alone, as a direct descendant of **Object**.

Essentially, a **RandomAccessFile** works like a **DataInputStream** combined with a **DataOutputStream**, along with the methods **getFilePointer()** to find out where you are in the file, **seek()** to move to a new point in the file, and **length()** to determine the maximum size of the file. In addition, the constructors require a second argument (identical to **fopen()** in C) indicating

whether you are just randomly reading (**"r"**) or reading and writing (**"rw"**). There's no support for write-only files, which could suggest that **RandomAccessFile** might have worked well if it were inherited from **DataInputStream**.

The seeking methods are available only in **RandomAccessFile**,



which works for files only. **BufferedInputStream** does allow you to **mark()** a position (whose value is held in a single internal variable) and **reset()** to that position, but this is limited and not very useful.

Most, if not all, **RandomAccessFile** functionality is superseded as of Java 1.4 with the **nio** *memory-mapped files*, described in the Appendix: New I/O.

Typical Uses of I/O

Streams

Although you can combine the I/O stream classes in many different ways, you'll probably just use a few combinations. The following examples can be used as a basic reference for typical I/O usage. (After making sure you can't do what you want using the libraries described in the Files chapter.)

In these examples, exception handing is simplified by passing exceptions out to the console, but this is appropriate only in small examples and utilities. In your code, consider more sophisticated error-handling approaches.

Buffered Input File

To open a file for character input, you use a **FileReader** with a **String** or a **File** object as the file name. For speed, you'll want that file to be buffered so you give the resulting reference to the constructor for a **BufferedReader**. **BufferedReader** provides **lines()**, which produces a **Stream<String>** :

// iostreams/BufferedInputFile.java

```
// {VisuallyInspectOutput}
import java.io.*;
import java.util.stream.*;
public class BufferedInputFile {
public static String read(String filename) {
try(BufferedReader in = new BufferedReader(
new FileReader(filename))) {
return in.lines()
.collect(Collectors.joining("\n"));
} catch(IOException e) {
throw new RuntimeException(e);
}
}
public static void main(String[] args) {
System.out.print(
read("BufferedInputFile.java"));
}
}
```

Collectors.joining() uses a **StringBuilder** internally to accumulate its result. The file is automatically closed via the try-with-

resources clause.

Input from Memory

Here, the **String** result from **BufferedInputFile.read()** is used to create a **StringReader**. Then **read()** produces each character which is displayed on the console:

```
// iostreams/MemoryInput.java
// {VisuallyInspectOutput}
import java.io.*;
public class MemoryInput {
public static void
main(String[] args) throws IOException {
```

```
StringReader in = new StringReader(
BufferedInputFile.read("MemoryInput.java"));
int c;
while((c = in.read()) != -1)
System.out.print((char)c);
}
```

}

read() returns the next character as an **int** and thus the return value must be cast to a **char** to display properly.

Formatted Memory Input

To read “formatted” data, you use a **DataInputStream**, a byte-oriented I/O class (rather than **char**-oriented). Thus you must use all **InputStream** classes rather than **Reader** classes. You can read anything (such as a file) as bytes using **InputStream** classes, but here a **String** is used:

```
// iostreams/FormattedMemoryInput.java
// {VisuallyInspectOutput}
import java.io.*;
public class FormattedMemoryInput {
public static void main(String[] args) {
try(
DataInputStream in = new DataInputStream(
new ByteArrayInputStream(
BufferedInputFile.read(
"FormattedMemoryInput.java")
.getBytes()))
```

) {

while(**true**)

System.out.write((char)in.readByte());

} **catch**(EOFException e) {

System.out.println("\nEnd of stream");

} **catch**(IOException e) {

throw new RuntimeException(e);

}

}

}

A **ByteArrayInputStream** must receive an array of bytes, produced here with **String.getBytes()**. The resulting **ByteArrayInputStream** is an appropriate **InputStream** to hand to **DataInputStream**.

If you read the characters from a **DataInputStream** one **byte** at a time using **readByte()**, any **byte** value is a legitimate result, so the return value cannot be used to detect the end of input. Instead, use the **available()** method to find out how many more characters are available. This shows how to read a file one **byte** at a time:

// iostreams/TestEOF.java

```
// Testing for end of file
// {VisuallyInspectOutput}
import java.io.*;
public class TestEOF {
public static void main(String[] args) {
try(
DataInputStream in = new DataInputStream(
new BufferedInputStream(
new FileInputStream("TestEOF.java")))
) {
while(in.available() != 0)
System.out.write(in.readByte());
} catch(IOException e) {
throw new RuntimeException(e);
}
}
}
```

Note that **available()** works differently depending on what sort of

medium you're reading from; it's literally "the number of bytes that can be read *without blocking*." With a file, this means the whole file, but with a different kind of stream this might not be true, so use it thoughtfully.

You can also detect the end of input in cases like these by catching an exception. However, control flow is considered a misuse of exceptions.

Basic File Output

A **FileWriter** object writes data to a file. You'll virtually always buffer the output by wrapping it in a **BufferedWriter** (try removing this wrapping to see the impact on the performance—buffering tends to dramatically increase performance of I/O operations). Here, a **FileWriter** is decorated as a **PrintWriter** to provide formatting. The data file created this way is readable as an ordinary text file:

```
// iostreams/BasicFileOutput.java
// {VisuallyInspectOutput}
import java.io.*;
```

```
public class BasicFileOutput {
static String file = "BasicFileOutput.dat";
public static void main(String[] args) {
try(
BufferedReader in = new BufferedReader(
new StringReader(
BufferedInputFile.read(
"BasicFileOutput.java")));
PrintWriter out = new PrintWriter(
new BufferedWriter(new FileWriter(file)))
) {
in.lines().forEach(out::println);
} catch(IOException e) {
throw new RuntimeException(e);
}
// Show the stored file:
System.out.println(BufferedInputFile.read(file));
}
}
```

The try-with-resources flushes the buffers and closes the file.

Text File Output Shortcut

Java 5 added a helper constructor to **PrintWriter** so you don't have to decorate by hand every time you create a text file and write to it. Here's **BasicFileOutput.java** rewritten to use this shortcut:

// iostreams/FileOutputShortcut.java

```
// {VisuallyInspectOutput}
import java.io.*;
public class FileOutputShortcut {
static String file = "FileOutputShortcut.dat";
public static void main(String[] args) {
try(
BufferedReader in = new BufferedReader(
new StringReader(BufferedInputFile.read(
"FileOutputShortcut.java")));
// Here's the shortcut:
PrintWriter out = new PrintWriter(file)
) {
in.lines().forEach(out::println);
} catch(IOException e) {
throw new RuntimeException(e);
}
System.out.println(BufferedInputFile.read(file));
}
}
```

You still get buffering, you just don’t do it yourself. Unfortunately,

other commonly written tasks were not given shortcuts, so typical I/O streams still involve a lot of redundant text. The Files chapter shows how this and other tasks were greatly simplified by taking a different

approach.

Storing and Recovering Data

A **PrintWriter** formats human-readable data. To output data for recovery by another stream, you use a **DataOutputStream** to write the data and a **DataInputStream** to recover the data. These streams can be anything, but the following example uses a file, buffered for both reading and writing. **DataOutputStream** and **DataInputStream** are byte-oriented and thus require **InputStream**s and **OutputStream**s:

```
// iostreams/StoringAndRecoveringData.java
import java.io.*;
public class StoringAndRecoveringData {
public static void main(String[] args) {
try(
```

```
DataOutputStream out = new DataOutputStream(
new BufferedOutputStream(
new FileOutputStream("Data.txt")))
) {
out.writeDouble(3.14159);
out.writeUTF("That was pi");
out.writeDouble(1.41413);
out.writeUTF("Square root of 2");
} catch(IOException e) {
throw new RuntimeException(e);
}
try(
DataInputStream in = new DataInputStream(
new BufferedInputStream(
new FileInputStream("Data.txt")))
) {
System.out.println(in.readDouble());
// Only readUTF() will recover the
// Java-UTF String properly:
System.out.println(in.readUTF());
```

```
System.out.println(in.readDouble());
System.out.println(in.readUTF());
} catch(IOException e) {
throw new RuntimeException(e);
}
}
}
/* Output:
3.14159
That was pi
1.41413
Square root of 2
*/
```

If you use a **DataOutputStream** to write the data, then Java guarantees you can accurately recover the data using a **DataInputStream**—regardless of what different platforms write and read the data. This is valuable, as anyone knows who has spent time worrying about platform-specific data issues. That problem vanishes if you have Java on both platforms.2

The only reliable way to write a **String** using a

DataOutputStream so it can be recovered by a **DataInputStream** is to use UTF-8 encoding, accomplished in this example using **writeUTF()** and **readUTF()**. UTF-8 is a multi-byte format, and the length of encoding varies according to the actual character set in use. If you're working with ASCII or mostly ASCII characters (which occupy only seven bits), Unicode wastes space and/or bandwidth, so UTF-8 encodes ASCII characters in a single byte, and non-ASCII characters in two or three bytes. In addition, the length of the string is stored in the first two bytes of the UTF-8 string. However, **writeUTF()** and **readUTF()** use a special variation of UTF-8 for Java (completely described in the JDK documentation for those methods), so if you read a string written with **writeUTF()** using a non-Java program, you must write special code to read the

string properly.

With **writeUTF()** and **readUTF()**, you can intermingle **String**s and other types of data in a **DataOutputStream**, with the knowledge that the **String**s are properly stored as Unicode and are

easily recoverable with a **DataInputStream**.

The **writeDouble()** method stores the **double** number to the stream, and the complementary **readDouble()** method recovers it (there are similar methods for reading and writing the other types). But for any of the reading methods to work correctly, you must know the exact placement of the data item in the stream, since it is equally possible to read the stored **double** as a simple sequence of bytes, or as a **char**, etc. So you must either use a fixed format for the data in the file, or include extra information in the file you parse to determine where the data is located. Note that object serialization or XML (both described in the Appendix: Object Serialization) can be easier ways to store and retrieve complex data structures.

Reading and Writing

Random-Access Files

Using a **RandomAccessFile** is like using a combined **DataInputStream** and **DataOutputStream** (because it implements the same interfaces: **DataInput** and **DataOutput**). In addition, you can use **seek()** to move about in the file and change the values.

With **RandomAccessFile**, you must know the layout of the file to manipulate it properly. **RandomAccessFile** has specific methods

to read and write primitives and UTF-8 strings:

```
// iostreams/UsingRandomAccessFile.java
import java.io.*;
public class UsingRandomAccessFile {
static String file = "rtest.dat";
public static void display() {
try(
RandomAccessFile rf =
new RandomAccessFile(file, "r")
) {
for(int i = 0; i < 7; i++)
System.out.println(
"Value " + i + ": " + rf.readDouble());
System.out.println(rf.readUTF());
} catch(IOException e) {
throw new RuntimeException(e);
}
}
public static void main(String[] args) {
try(
```

```
RandomAccessFile rf =
new RandomAccessFile(file, "rw")
) {
for(int i = 0; i < 7; i++)
rf.writeDouble(i*1.414);
rf.writeUTF("The end of the file");
rf.close();
display();
} catch(IOException e) {
throw new RuntimeException(e);
}
try(
RandomAccessFile rf =
new RandomAccessFile(file, "rw")
) {
rf.seek(5*8);
rf.writeDouble(47.0001);
rf.close();
display();
} catch(IOException e) {
```

throw new RuntimeException(e);

}

}

}

/ *Output:*

Value 0: 0.0

Value 1: 1.414

Value 2: 2.828

Value 3: 4.242

Value 4: 5.656

Value 5: 7.069999999999999

Value 6: 8.484

The end of the file

Value 0: 0.0

Value 1: 1.414

Value 2: 2.828

Value 3: 4.242

Value 4: 5.656

Value 5: 47.0001

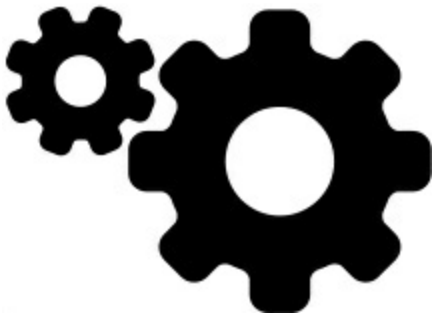
Value 6: 8.484

The end of the file

*/

The **display()** method opens a file and displays the elements within as **double** values. In **main()**, the file is created, opened and modified. Since a **double** is always eight bytes long, to **seek()** to **double** element 5 you multiply **5*8** to produce the seek value.

As previously noted, **RandomAccessFile** is effectively separate from the rest of the I/O hierarchy, save for the fact it implements **DataInput** and **DataOutput**. It doesn't support decoration, so you cannot combine it with any of the aspects of the **InputStream** and **OutputStream** subclasses. You must assume that a **RandomAccessFile** is properly buffered since you cannot add that. The one option you have is in the second constructor argument: You can open a **RandomAccessFile** to read (**"r"**) or read and write



(**"rw"**).

Consider using **nio** memory-mapped files instead of

RandomAccessFile. These are described in the Appendix: New I/O.

Summary

The Java I/O stream library does satisfy basic requirements: You can read and write with the console, a file, a block of memory, or even across the Internet. With inheritance, you can create new types of input and output objects. You can even add simple extensibility to the kinds of objects a stream will accept by redefining the **toString()** method that's automatically called when you pass an object to a method that's expecting a **String** (Java's limited "automatic type conversion").

There are questions left unanswered by the documentation and design of the I/O stream library. For example, it would be nice to say you want an exception thrown if you try to overwrite a file when opening it for output—some programming systems allow you to open an output file, but only if it doesn't already exist. In Java, it appears you are supposed to use a **File** object to determine whether a file exists, because if you open it as a **FileOutputStream** or **FileWriter**, it will always get overwritten.

The I/O stream library brings up mixed feelings; it does much of the

job and it’s portable. But if you don’t already understand the *Decorator* design pattern, the design is not intuitive, so there’s extra overhead in learning and teaching it. It’s also incomplete; for example, in the past I had to write utilities to read text files with a reasonable amount of code—fortunately Java 7 nio eliminates the need for such things.

Once you *do* understand the *Decorator* pattern and begin using the library in situations that require its flexibility, you can begin to benefit from this design, at which point its cost in extra lines of code might not bother you as much. Always check, however, to make sure you can’t instead solve your problem using the libraries and techniques shown in the Files chapter.

1. It’s not clear that this was a good design decision, especially compared to the simplicity of I/O libraries in other languages. But it’s the justification for the decision.↩

2. XML is another way to solve the problem of moving data across different computing platforms, and does not depend on having Java on all platforms. XML is introduced in the Appendix: Object Serialization.↩

Appendix: Standard I/O

The term *standard I/O* refers to the Unix concept of a single stream of information that is used by a program (this idea is reproduced in some form in most operating systems). All the program's input can come from *standard input*, all of its output can go to *standard output*, and all of its error messages can be sent to *standard error*. The value of standard I/O is that programs can easily be chained together, and one program's standard output can become the standard input for another program. This is a powerful tool.

Reading from Standard Input

Following the standard I/O model, Java has **System.in**, **System.out**, and **System.err**. Throughout this book, you've seen how to write to standard output using **System.out**, which is already pre-wrapped as a **PrintStream** object. **System.err** is likewise a **PrintStream**, but **System.in** is a raw **InputStream** with no wrapping. This means that although you can use **System.out** and

System.err right away, **System.in** must be wrapped before you

can read from it.

You'll typically read input a line at a time. To do this, wrap **System.in** in a **BufferedReader**, which requires you to convert **System.in** to a **Reader** using **InputStreamReader**. Here's an example that echoes each line you type in:

```
// standardio/Echo.java
// How to read from standard input
import java.io.*;
import onjava.TimedAbort;
public class Echo {
public static void main(String[] args) {
TimedAbort abort = new TimedAbort(2);
new BufferedReader(
new InputStreamReader(System.in))
.lines()
.peek(ln -> abort.restart())
```

```
.forEach(System.out::println);
// Ctrl-Z or two seconds inactivity
// terminates the program
}
}
```

BufferedReader has a **lines()** method that returns a **Stream<String>** , and this shows the flexibility of the stream model: it works just fine with standard input. The **peek()** method restarts the **TimedAbort** to keep the program open as long as there's input at least every two seconds.

Changing System.out to a PrintWriter

System.out is a **PrintStream**, which is an **OutputStream**.

PrintWriter has a constructor that takes an **OutputStream** as an argument. Thus, if you want, you can convert **System.out** into a **PrintWriter** using that constructor:

```
// standardio/ChangeSystemOut.java
```

```
// Turn System.out into a PrintWriter
import java.io.*;
public class ChangeSystemOut {
public static void main(String[] args) {
PrintWriter out =
new PrintWriter(System.out, true);
out.println("Hello, world");
}
}
/* Output:
Hello, world
*/
```

It’s important to use the two-argument version of the **PrintWriter** constructor and to set the second argument to **true** to enable automatic flushing. Otherwise, you might not see the output.

Redirecting Standard I/O

The Java **System** class can redirect the standard input, output, and error I/O streams using simple **static** method calls:

setIn(InputStream)

setOut(PrintStream)

setErr(PrintStream)

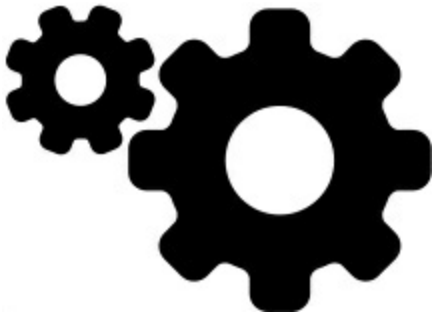
Redirecting output is especially useful if you suddenly start creating a large amount of output on your screen, and it's scrolling past faster than you can read it. Redirecting input is valuable for a command-line program to test a particular user-input sequence repeatedly. Here's a simple example that shows these methods:

```
// standardio/Redirecting.java
// Demonstrates standard I/O redirection
import java.io.*;
public class Redirecting {
public static void main(String[] args) {
PrintStream console = System.out;
try(
BufferedInputStream in = new BufferedInputStream(
new FileInputStream("Redirecting.java"));
PrintStream out = new PrintStream(
new BufferedOutputStream(
new FileOutputStream("Redirecting.txt")))
) {
System.setIn(in);
```

```
System.setOut(out);
System.setErr(out);
new BufferedReader(
new InputStreamReader(System.in))
.lines()
.forEach(System.out::println);
} catch(IOException e) {
throw new RuntimeException(e);
} finally {
System.setOut(console);
}
}
}
```

This program attaches standard input to a file and redirects standard output and standard error to another file. It stores a reference to the original **System.out** object at the beginning of the program, and restores the system output to that object at the end.

I/O redirection manipulates streams of bytes, not streams of



characters; thus, **InputStream**s and **OutputStream**s are used rather than **Reader**s and **Writer**s.

Process Control

The Java library provides classes to execute operating system programs from inside Java, and control the input and output from such programs.

A common task is to run a program and send the resulting output to the console. This section contains a utility to simplify this task.

Two types of errors can occur with this utility: the normal errors that result in exceptions—for these we just rethrow a **RuntimeException**—and errors from the execution of the process itself. We report these errors with a separate exception:

// onjava/OSExecuteException.java

package onjava;

public class

OSExecuteException **extends** RuntimeException {

public OSExecuteException(String why) {

super(why);

}

}

To run a program, you pass **OSExecute.command()** a **String command**, the same command you would type to run the program on the console. This command is passed to the **java.lang.ProcessBuilder** constructor (which requires it as a sequence of **String** objects), and the resulting **ProcessBuilder** object is started:

// onjava/OSExecute.java

// Run an operating system command

// and send the output to the console

package onjava;

import java.io.*;

public class OSExecute {

public static void command(String command) {

boolean err = **false**;

try {

Process process = **new** ProcessBuilder(

```
command.split(" ")).start();
try(
BufferedReader results = new BufferedReader(
new InputStreamReader(
process.getInputStream()));
BufferedReader errors = new BufferedReader(
new InputStreamReader(
process.getErrorStream()))
) {
results.lines()
.forEach(System.out::println);
err = errors.lines()
.peek(System.err::println)
.count() > 0;
}
} catch(IOException e) {
throw new RuntimeException(e);
}
if(err)
throw new OSExecuteException(
```

"Errors executing " + command);

}

}

To capture the standard output stream from the program as it executes, you call **getInputStream()**. This is because an **InputStream** is something we can read from.

Here the lines are only displayed, but you might also capture and return them from **command()**.

The program's errors are sent to the standard error stream, and are captured by calling **getErrorStream()**. If there are any errors, they are displayed and an **OSExecuteException** is thrown so the calling program will handle the problem.

Here's an example that shows how to use **OSExecute**:

```
// standardio/OSExecuteDemo.java
// Demonstrates standard I/O redirection
// {javap -cp build/classes/main OSExecuteDemo}
import onjava.*;
public class OSExecuteDemo {}
/* Output:
Compiled from "OSExecuteDemo.java"
```

public class OSExecuteDemo {

public OSExecuteDemo();

}

**/*

This uses the **javap** decompiler (that comes with the JDK) to decompile the program.

Appendix: New I/O

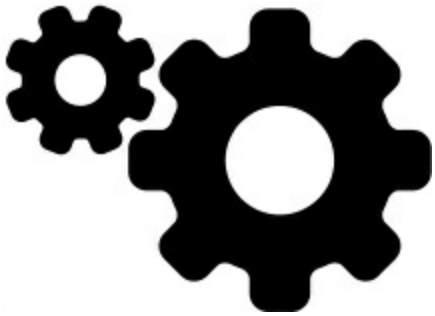
The Java “new” I/O library, introduced in Java 1.4 in the **java.nio.*** packages, has one goal: speed.

In fact, the “old” I/O packages were reimplemented using **nio** to take advantage of this speed increase, so you benefit even if you don’t explicitly write code with **nio**. The speed increase occurs both in file I/O, explored here, and in network I/O, used for example with Internet programming.

The speed comes from using structures that are closer to the operating system’s way of performing I/O: *channels* and *buffers*. Think of it as a coal mine; the channel is the mine containing the seam of coal (the

data), and the buffer is the cart you send into the mine. The cart comes back full of coal, and you get the coal from the cart. That is, you don't interact directly with the channel; you interact with the buffer and send the buffer into the channel. The channel either pulls data from the buffer, or puts data into the buffer.

This appendix goes into some depth exploring the **nio** package. Higher-level libraries like I/O streams use **nio**, but most of the time you won't need to work with I/O at this level. With Java 7 & 8, you



(ideally) not even have to bother with I/O streams except in special cases. Ideally, everything you'll regularly use is covered in the Files chapter. Understanding **nio** is only necessary when you're struggling with performance (when you might need, for example, memory-mapped files) or creating your own I/O library.

ByteBuffers

The only type of buffer that communicates directly with a channel is a **ByteBuffer**—that is, a buffer that holds raw bytes. If you look at the

JDK documentation for **java.nio.ByteBuffer**, you'll see it's fairly basic: You create one by telling it how much storage to allocate, and there are methods to put and get data, in either raw byte form or as primitive data types. But there's no way to put or get an object, or even a **String**. It's fairly low-level, precisely because this makes a more efficient mapping with most operating systems.

Three of the classes in the "old" I/O were modified to produce a **FileChannel**: **FileInputStream**, **FileOutputStream**, and, for both reading and writing, **RandomAccessFile**. Notice that these are the byte manipulation streams, in keeping with the low-level nature of **nio**. The **Reader** and **Writer** character-mode classes do not produce channels, but the **java.nio.channels.Channels** class has utility methods to produce **Reader**s and **Writer**s from channels.

Here we exercise all three types of stream to produce channels that are writeable, read/writeable, and readable:

```
// newio/GetChannel.java
// Getting channels from streams
import java.nio.*;
import java.nio.channels.*;
```

```
import java.io.*;
public class GetChannel {
private static String name = "data.txt";
private static final int BSIZE = 1024;
public static void main(String[] args) {
// Write a file:
try(
FileChannel fc = new FileOutputStream(name)
.getChannel()
) {
fc.write(ByteBuffer
.wrap("Some text ".getBytes()));
} catch(IOException e) {
throw new RuntimeException(e);
}
// Add to the end of the file:
try(
FileChannel fc = new RandomAccessFile(
name, "rw").getChannel()
) {
```

```
fc.position(fc.size()); // Move to the end
fc.write(ByteBuffer
.wrap("Some more".getBytes()));
} catch(IOException e) {
throw new RuntimeException(e);
}
// Read the file:
try(
FileChannel fc = new FileInputStream(name)
.getChannel()
) {
ByteBuffer buff = ByteBuffer.allocate(BSIZE);
fc.read(buff);
buff.flip();
while(buff.hasRemaining())
System.out.write(buff.get());
} catch(IOException e) {
throw new RuntimeException(e);
}
System.out.flush();
```

}

}

/ *Output:*

Some text Some more

**/*

For any of the stream classes shown here, **getChannel()** will produce a **FileChannel**. A channel is fairly basic: Hand it a **ByteBuffer** for reading or writing, and lock regions of the file for exclusive access (this is described later).

One way to put bytes into a **ByteBuffer** is to stuff them in directly using one of the "put" methods, to put one or more bytes, or values of primitive types. However, as seen here, you can also "wrap" an existing **byte** array in a **ByteBuffer** using the **wrap()** method. When you do this, the underlying array is not copied, but instead is used as the storage for the generated **ByteBuffer**. We say that the **ByteBuffer** is "backed by" the array.

The **data.txt** file is reopened using a **RandomAccessFile**.

Notice you can move the **FileChannel** around in the file; here, it is moved to the end so additional writes are appended.

For read-only access, you must explicitly allocate a **ByteBuffer**

using the **static allocate()** method. The goal of **nio** is to rapidly move large amounts of data, so the size of the **ByteBuffer** should be significant—in fact, the 1K used here is probably quite a bit smaller than you'd normally use (you'll have to experiment with your working application to find the best size).

It's also possible to go for even more speed by using **allocateDirect()** instead of **allocate()** to produce a "direct" buffer that can have an even higher coupling with the operating system. However, the overhead in such an allocation is greater, and the actual implementation varies from one operating system to another, so again, you must experiment with your working application to discover whether direct buffers will buy you any advantage in speed.

Once you call **read()** to tell the **FileChannel** to store bytes into the **ByteBuffer**, you must call **flip()** on the buffer to tell it to get ready to have its bytes extracted (yes, this seems a bit crude, but remember it's very low-level and is done for maximum speed). And if we were to use the buffer for further **read()** operations, we'd also call **clear()** to prepare it for each **read()**. This simple file-copying program demonstrates:

// newio/ChannelCopy.java

```
// Copying a file using channels and buffers
// {java ChannelCopy ChannelCopy.java test.txt}
import java.nio.*;
import java.nio.channels.*;
import java.io.*;
public class ChannelCopy {
private static final int BSIZE = 1024;
public static void main(String[] args) {
if(args.length != 2) {
System.out.println(
"arguments: sourcefile destfile");
System.exit(1);
}
try(
FileChannel in = new FileInputStream(
args[0]).getChannel();
FileChannel out = new FileOutputStream(
args[1]).getChannel()
) {
ByteBuffer buffer = ByteBuffer.allocate(BSIZE);
```

```
while(in.read(buffer) != -1) {
buffer.flip(); // Prepare for writing
out.write(buffer);
buffer.clear(); // Prepare for reading
}
} catch(IOException e) {
throw new RuntimeException(e);
}
}
}
```

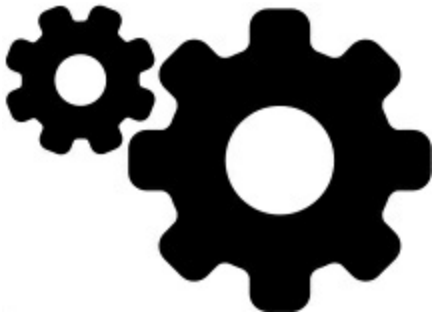
One **FileChannel** is opened for reading, and one for writing. A **ByteBuffer** is allocated, and when **FileChannel.read()** returns **-1** (a holdover, no doubt, from Unix and C), it means you've reached the end of the input. After each **read()**, which puts data into the buffer, **flip()** prepares the buffer so its information can be extracted by the **write()**. After the **write()**, the information is still in the buffer, and **clear()** resets all the internal pointers so it's ready to accept data during another **read()**.

The preceding program is not the ideal way to handle this kind of operation, however. Special methods **transferTo()** and

transferFrom() allow you to connect one channel directly to another:

```
// newio/TransferTo.java
// Using transferTo() between channels
// {java TransferTo TransferTo.java TransferTo.txt}
import java.nio.channels.*;
import java.io.*;
public class TransferTo {
public static void main(String[] args) {
if(args.length != 2) {
System.out.println(
"arguments: sourcefile destfile");
System.exit(1);
}
try(
FileChannel in = new FileInputStream(
args[0]).getChannel();
FileChannel out = new FileOutputStream(
args[1]).getChannel()
) {
```

```
in.transferTo(0, in.size(), out);
```



```
// Or:
// out.transferFrom(in, 0, in.size());
} catch(IOException e) {
throw new RuntimeException(e);
}
}
}
```

You won’t do this very often, but it’s good to know about.

Converting Data

To print the information in the file in **GetChannel.java**, we pull the data out one **byte** at a time and cast each **byte** to a **char**. This seems primitive—if you look at the **java.nio.CharBuffer** class, you’ll see it has a **toString()** method that says, “Returns a **String** containing the characters in this buffer.” Since a **ByteBuffer** can be viewed as a **CharBuffer** with the

asCharBuffer() method, why not use that? As you see from the first line in the output statement below, this doesn't work out:

```
// newio/BufferToText.java
// Converting text to and from ByteBuffers
import java.nio.*;
import java.nio.channels.*;
import java.nio.charset.*;
import java.io.*;
public class BufferToText {
private static final int BSIZE = 1024;
public static void main(String[] args) {
try(
FileChannel fc = new FileOutputStream(
"data2.txt").getChannel()
) {
fc.write(ByteBuffer.wrap("Some text".getBytes()));
} catch(IOException e) {
throw new RuntimeException(e);
}
ByteBuffer buff = ByteBuffer.allocate(BSIZE);
```

```
try(
FileChannel fc = new FileInputStream(
"data2.txt").getChannel()
) {
fc.read(buff);
} catch(IOException e) {
throw new RuntimeException(e);
}
buff.flip();
// Doesn't work:
System.out.println(buff.asCharBuffer());
// Decode using this system's default Charset:
buff.rewind();
String encoding =
System.getProperty("file.encoding");
System.out.println("Decoded using " +
encoding + ": "
+ Charset.forName(encoding).decode(buff));
// Encode with something that prints:
try(
```

```
FileChannel fc = new FileOutputStream(
"data2.txt").getChannel()
) {
fc.write(ByteBuffer.wrap(
"Some text".getBytes("UTF-16BE")));
} catch(IOException e) {
throw new RuntimeException(e);
}
// Now try reading again:
buff.clear();
try(
FileChannel fc = new FileInputStream(
"data2.txt").getChannel()
) {
fc.read(buff);
} catch(IOException e) {
throw new RuntimeException(e);
}
buff.flip();
System.out.println(buff.asCharBuffer());
```

```
// Use a CharBuffer to write through:
buff = ByteBuffer.allocate(24);
buff.asCharBuffer().put("Some text");
try(
FileChannel fc = new FileOutputStream(
"data2.txt").getChannel()
) {
fc.write(buff);
} catch(IOException e) {
throw new RuntimeException(e);
}
// Read and display:
buff.clear();
try(
FileChannel fc = new FileInputStream(
"data2.txt").getChannel()
) {
fc.read(buff);
} catch(IOException e) {
throw new RuntimeException(e);
```

```
}
buff.flip();
System.out.println(buff.asCharBuffer());
}
}
/* Output:
????
Decoded using windows-1252: Some text
Some text
Some textNULNULNUL
*/
```

The buffer contains plain bytes, and to turn these into characters, we must either *encode* them as we put them in (so they are meaningful when they come out) or *decode* them as they come out of the buffer. This can be accomplished using the **java.nio.charset.Charset** class, which provides tools for encoding into many different types of character sets:

```
// newio/AvailableCharSets.java
// Displays Charsets and aliases
import java.nio.charset.*;
```

```
import java.util.*;
public class AvailableCharSets {
public static void main(String[] args) {
SortedMap<String,Charset> charSets =
Charset.availableCharsets();
for(String csName : charSets.keySet()) {
System.out.print(csName);
Iterator aliases = charSets.get(csName)
.aliases().iterator();
if(aliases.hasNext())
System.out.print(": ");
while(aliases.hasNext()) {
System.out.print(aliases.next());
if(aliases.hasNext())
System.out.print(", ");
}
System.out.println();
}
}
}
```

/ *Output: (First 7 Lines)*

Big5: csBig5

Big5-HKSCS: big5-hkscs, big5hk, Big5_HKSCS, big5hkscs

CESU-8: CESU8, csCESU-8

EUC-JP: csEUCPkdFmtjapanese, x-euc-jp, eucjis,

Extended_UNIX_Code_Packed_Format_for_Japanese, euc_jp,

eucjp, x-eucjp

EUC-KR: ksc5601-1987, csEUCKR, ksc5601_1987, ksc5601,

5601,

euc_kr, ksc_5601, ks_c_5601-1987, euckr

GB18030: gb18030-2000

GB2312: gb2312, euc-cn, x-EUC-CN, euccn, EUC_CN,

gb2312-80,

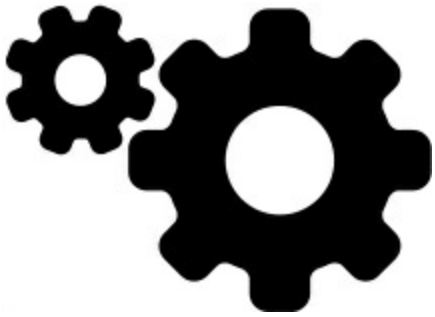
gb2312-1980

...

**/*

So, returning to **BufferToText.java**, if you **rewind()** the

buffer (to go back to the beginning of the data), then use that



platform’s default character set to **decode()** the data, the resulting **CharBuffer** will display on the console just fine. To discover the default character set, use **System.getProperty("file.encoding")**, which produces the **String** that names the character set. Passing this to **Charset.forName()** produces the **Charset** object that decodes the **String**.

Another alternative is to **encode()** using a character set that produces something printable when the file is read, as you see in the third part of **BufferToText.java**. Here, UTF-16BE is used to write the text into the file, and when it is read, all you must do is convert it to a **CharBuffer**, and it produces the expected text.

Finally, you see what happens if you *write* to the **ByteBuffer** through a **CharBuffer** (you’ll learn more about this later). Note that 24 bytes are allocated for the **ByteBuffer**. Since each **char** requires two bytes, this is enough for 12 **char**s, but “Some text” only

has 9. The remaining zero bytes still appear in the representation of the **CharBuffer** produced by its **toString()**, as shown in the output.

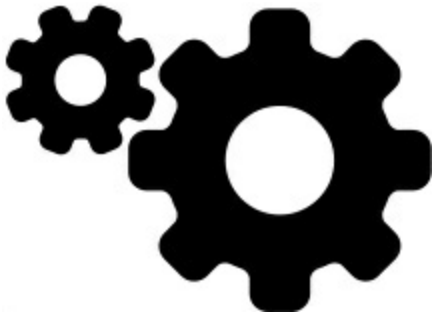
Fetching Primitives

Although a **ByteBuffer** only holds bytes, it contains methods to produce each different type of primitive value from the bytes it contains. This example shows the insertion and extraction of various values using these methods:

```
// newio/GetData.java
// Getting different representations from a ByteBuffer
import java.nio.*;
public class GetData {
private static final int BSIZE = 1024;
public static void main(String[] args) {
ByteBuffer bb = ByteBuffer.allocate(BSIZE);
// Allocation automatically zeroes the ByteBuffer:
int i = 0;
while(i++ < bb.limit())
if(bb.get() != 0)
System.out.println("nonzero");
```

```
System.out.println("i = " + i);
bb.rewind();
// Store and read a char array:
bb.asCharBuffer().put("Howdy!");
char c;
while((c = bb.getChar()) != 0)
System.out.print(c + " ");
System.out.println();
bb.rewind();
// Store and read a short:
bb.asShortBuffer().put((short)471142);
System.out.println(bb.getShort());
bb.rewind();
// Store and read an int:
bb.asIntBuffer().put(99471142);
System.out.println(bb.getInt());
bb.rewind();
// Store and read a long:
bb.asLongBuffer().put(99471142);
System.out.println(bb.getLong());
```

```
bb.rewind();
// Store and read a float:
bb.asFloatBuffer().put(99471142);
System.out.println(bb.getFloat());
bb.rewind();
// Store and read a double:
bb.asDoubleBuffer().put(99471142);
System.out.println(bb.getDouble());
bb.rewind();
}
}
/* Output:
```



```
i = 1025
H o w d y !
12390
99471142
```

99471142

9.9471144E7

9.9471142E7

/

After a **ByteBuffer** is allocated, its values are checked to see whether buffer allocation automatically zeroes the contents—and it does. All 1,024 values are checked (up to the **limit()** of the buffer), and all are zero.

The easiest way to insert primitive values into a **ByteBuffer** is to get the appropriate "view" on that buffer using **asCharBuffer()**, **asShortBuffer()**, etc., then to use that view's **put()** method.

This is performed for each of the primitive data types. The only one of these that is slightly odd is the **put()** for the **ShortBuffer**, which requires a cast (the cast truncates and changes the resulting value). All the other view buffers do not require casting in their **put()** methods.

View Buffers

A "view buffer" looks at an underlying **ByteBuffer** through the window of a particular primitive type. The **ByteBuffer** is still the actual storage that's "backing" the view, so any changes you make to the view are reflected in modifications to the data in the

ByteBuffer. As seen in the previous example, this conveniently inserts primitive types into a **ByteBuffer**. A view can also read primitive values from a **ByteBuffer**, either one at a time (as **ByteBuffer** allows) or in batches (into arrays). Here's an example that manipulates **int**s in a **ByteBuffer** via an **IntBuffer**:

```
// newio/IntBufferDemo.java
// Manipulating ints in a ByteBuffer with an IntBuffer
import java.nio.*;
public class IntBufferDemo {
private static final int BSIZE = 1024;
public static void main(String[] args) {
ByteBuffer bb = ByteBuffer.allocate(BSIZE);
IntBuffer ib = bb.asIntBuffer();
// Store an array of int:
ib.put(new int[]{ 11, 42, 47, 99, 143, 811, 1016 });
// Absolute location read and write:
System.out.println(ib.get(3));
ib.put(3, 1811);
// Setting a new limit before rewinding the buffer.
ib.flip();
```

```
while(ib.hasRemaining()) {
int i = ib.get();
System.out.println(i);
}
}
}
/* Output:
99
11
42
47
1811
143
811
1016
*/
```

The overloaded **put()** method is first used to store an array of **int**.

The following **get()** and **put()** method calls directly access an **int** location in the underlying **ByteBuffer**. Note that these absolute location accesses are available for primitive types by talking directly to

a **ByteBuffer**, as well.

Once the underlying **ByteBuffer** is filled with **int**s or some other primitive type via a view buffer, then that **ByteBuffer** can be

written directly to a channel. You can just as easily read from a

channel and use a view buffer to convert everything to a particular

type of primitive. Here’s an example that interprets the same sequence

of bytes as **short**, **int**, **float**, **long**, and **double** by producing different view buffers on the same **ByteBuffer**:

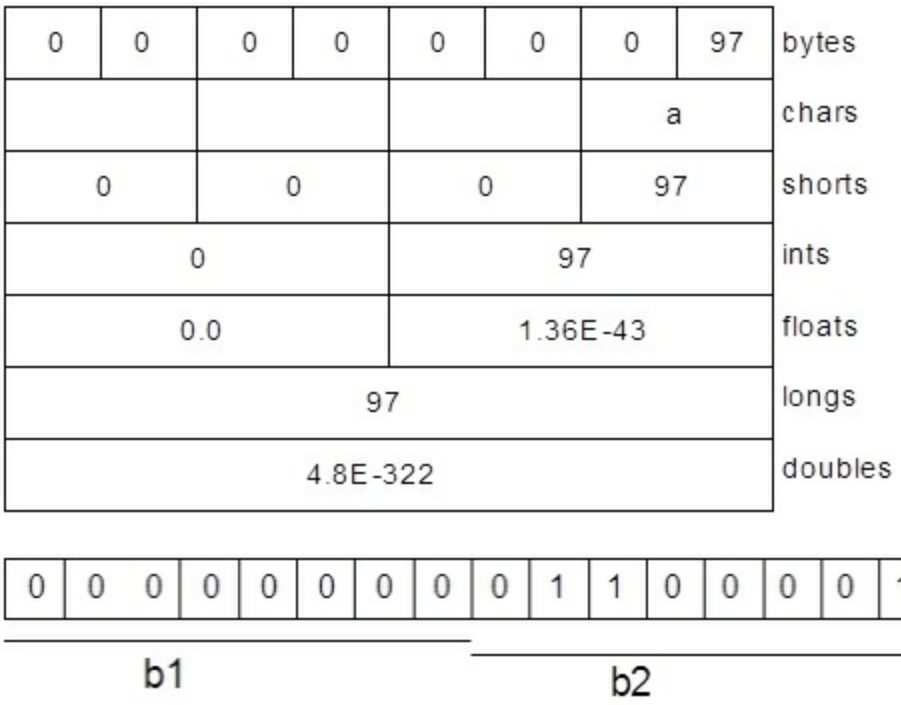
```
// newio/ViewBuffers.java

import java.nio.*;

public class ViewBuffers {

public static void main(String[] args) {

ByteBuffer bb = ByteBuffer.wrap(

new byte[]{ 0, 0, 0, 0, 0, 0, 0, 'a' });

bb.rewind();

System.out.print("Byte Buffer ");

while(bb.hasRemaining())

System.out.print(

bb.position()+ " -> " + bb.get() + ", ");

System.out.println();

CharBuffer cb =
```

```
((ByteBuffer)bb.rewind()).asCharBuffer();
System.out.print("Char Buffer ");
while(cb.hasRemaining())
System.out.print(
cb.position() + " -> " + cb.get() + ", ");
System.out.println();
FloatBuffer fb =
((ByteBuffer)bb.rewind()).asFloatBuffer();
System.out.print("Float Buffer ");
while(fb.hasRemaining())
System.out.print(
fb.position()+ " -> " + fb.get() + ", ");
System.out.println();
IntBuffer ib =
((ByteBuffer)bb.rewind()).asIntBuffer();
System.out.print("Int Buffer ");
while(ib.hasRemaining())
System.out.print(
ib.position()+ " -> " + ib.get() + ", ");
System.out.println();
```

```
LongBuffer lb =
((ByteBuffer)bb.rewind()).asLongBuffer();
System.out.print("Long Buffer ");
while(lb.hasRemaining())
System.out.print(
lb.position()+ " -> " + lb.get() + ", ");
System.out.println();
ShortBuffer sb =
((ByteBuffer)bb.rewind()).asShortBuffer();
System.out.print("Short Buffer ");
while(sb.hasRemaining())
System.out.print(
sb.position()+ " -> " + sb.get() + ", ");
System.out.println();
DoubleBuffer db =
((ByteBuffer)bb.rewind()).asDoubleBuffer();
System.out.print("Double Buffer ");
while(db.hasRemaining())
System.out.print(
db.position()+ " -> " + db.get() + ", ");
```

```
}
}
/* Output:
Byte Buffer 0 -> 0, 1 -> 0, 2 -> 0, 3 -> 0, 4 -> 0, 5
-> 0, 6 -> 0, 7 -> 97,
Char Buffer 0 -> NUL, 1 -> NUL, 2 -> NUL, 3 -> a,
Float Buffer 0 -> 0.0, 1 -> 1.36E-43,
Int Buffer 0 -> 0, 1 -> 97,
Long Buffer 0 -> 97,
Short Buffer 0 -> 0, 1 -> 0, 2 -> 0, 3 -> 97,
Double Buffer 0 -> 4.8E-322,
*/
```

The **ByteBuffer** is produced by “wrapping” an eight-**byte** array, which is then displayed via view buffers of all the different primitive types. The following diagram shows how the data appears differently when read from the different types of buffers:



This corresponds to the output from the program.

Endians

Different machines can use different byte-ordering approaches to store data. “Big endian” places the most significant byte in the lowest memory address, and “little endian” places the most significant byte in the highest memory address. When storing a quantity that is greater than one **byte**, like **int**, **float**, etc., you might need to consider byte ordering. A **ByteBuffer** stores data in big endian form, and data sent over a network always uses big endian order. You can change the endian-ness of a **ByteBuffer** using **order()** with an argument of **ByteOrder.BIG_ENDIAN** or **ByteOrder.LITTLE_ENDIAN**.

Consider a **ByteBuffer** containing the following two bytes:

Reading the data as a **short** (**ByteBuffer.asShortBuffer()**)

produces the number 97 (00000000 01100001). Changing to little

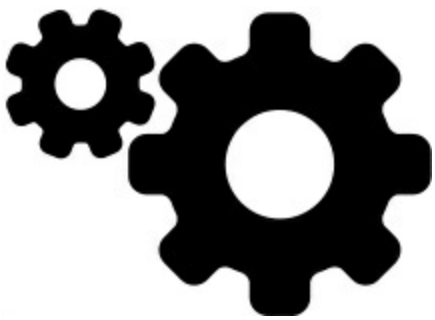
endian produces the number 24832 (01100001 00000000).

This shows byte ordering changing depending on the endian setting:

```
// newio/Endians.java
// Endian differences and data storage
import java.nio.*;
import java.util.*;
public class Endians {
public static void main(String[] args) {
ByteBuffer bb = ByteBuffer.wrap(new byte[12]);
bb.asCharBuffer().put("abcdef");
System.out.println(Arrays.toString(bb.array()));
bb.rewind();
bb.order(ByteOrder.BIG_ENDIAN);
bb.asCharBuffer().put("abcdef");
System.out.println(Arrays.toString(bb.array()));
bb.rewind();
bb.order(ByteOrder.LITTLE_ENDIAN);
```

```
bb.asCharBuffer().put("abcdef");
System.out.println(Arrays.toString(bb.array()));
}
}
/* Output:
[0, 97, 0, 98, 0, 99, 0, 100, 0, 101, 0, 102]
[0, 97, 0, 98, 0, 99, 0, 100, 0, 101, 0, 102]
[97, 0, 98, 0, 99, 0, 100, 0, 101, 0, 102, 0]
*/
```

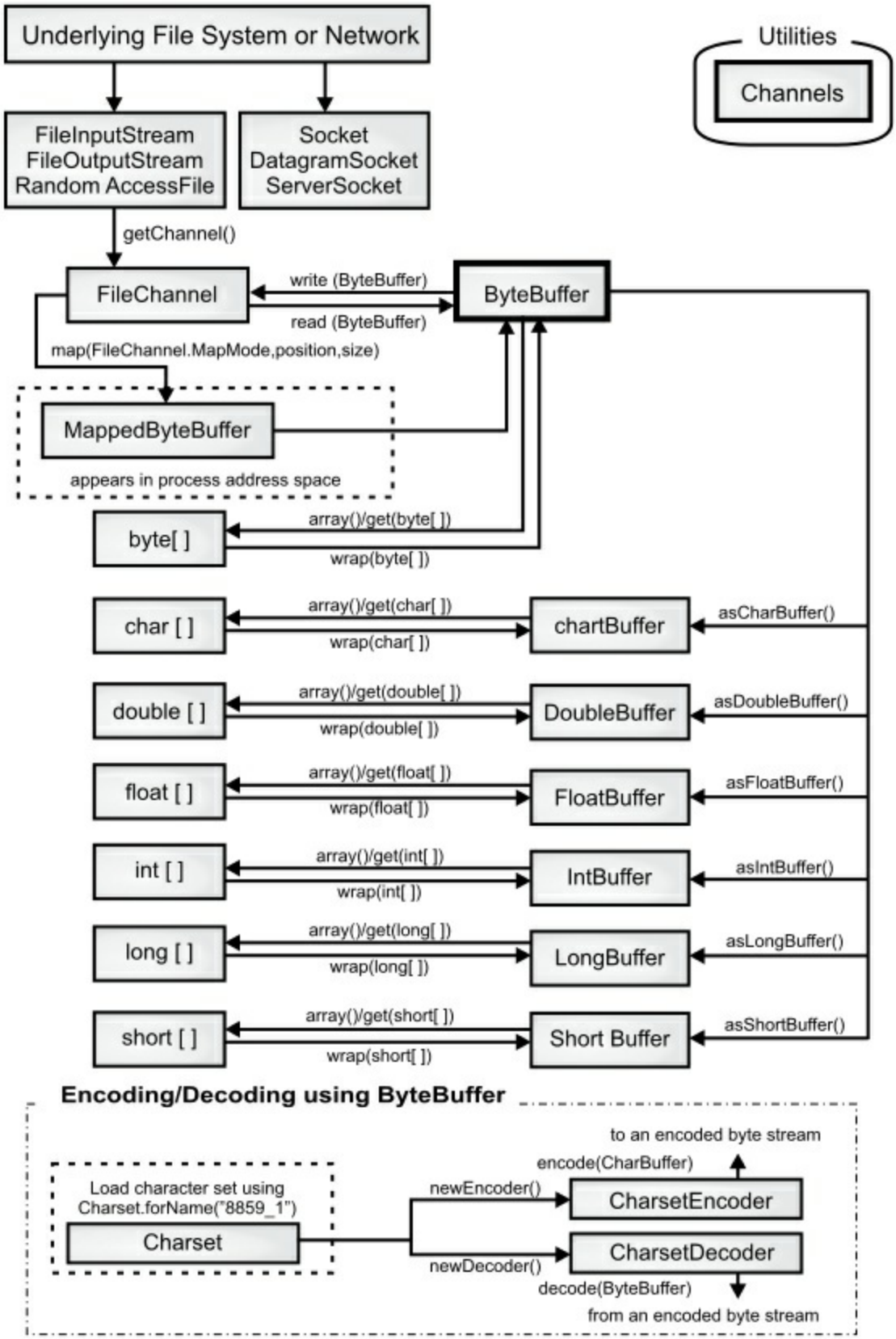
The **ByteBuffer** allocates space to hold all the bytes in **charArray** as an external buffer so the **array()** method can be called to display the underlying bytes. The **array()** method is "optional," and you can only call it on a buffer backed by an array, otherwise you'll get an **UnsupportedOperationException**. **charArray** is inserted into the **ByteBuffer** via a **CharBuffer** view. When the underlying bytes are displayed, the default ordering is



the same as the subsequent big endian order, whereas the little endian order swaps the bytes.

Data Manipulation with Buffers

The following diagram illustrates the relationships between the **nio** classes, showing how to move and convert data. For example, to write a **byte** array to a file, wrap the **byte** array using the **ByteBuffer.wrap()** method, open a channel on the **FileOutputStream** using **getChannel()**, then write data into **FileChannel** from the **ByteBuffer**.


Underlying File System or Network
Utilities
Channels
FileInputStream
FileOutputStream
Random AccessFile
Socket
DatagramSocket
ServerSocket
getChannel()
FileChannel
write (ByteBuffer)
read (ByteBuffer)
ByteBuffer
map(FileChannel.MapMode,position,size)
MappedByteBuffer
appears in process address space
byte[ ]
array()/get(byte[ ])
wrap(byte[ ])
char [ ]
array()/get(char[ ])
wrap(char[ ])
chartBuffer
asCharBuffer()
double [ ]
array()/get(double[ ])
wrap(double[ ])
DoubleBuffer
asDoubleBuffer()
float [ ]
array()/get(float[ ])
wrap(float[ ])
FloatBuffer
asFloatBuffer()
int [ ]
array()/get(int[ ])
wrap(int[ ])
IntBuffer
asIntBuffer()
long [ ]
array()/get(long[ ])
wrap(long[ ])
LongBuffer
asLongBuffer()
short [ ]
array()/get(short[ ])
wrap(short[ ])
Short Buffer
asShortBuffer()
Encoding/Decoding using ByteBuffer
Load character set using
Charset.forName("8859_1")
Charset
newEncoder()
newDecoder()
CharsetEncoder
CharsetDecoder
encode(CharBuffer)
to an encoded byte stream
decode(ByteBuffer)
from an encoded byte stream

ByteBuffer is the only way to move data into and out of channels,

and you can only create a standalone primitive-typed buffer, or get one

from a **ByteBuffer** using an “as” method. That is, you cannot

convert a primitive-typed buffer *to* a **ByteBuffer**. However, since

you are able to move primitive data into and out of a **ByteBuffer**

via a view buffer, this is not really a restriction.

Buffer Details

A **Buffer** consists of data and four indexes to access and manipulate

this data efficiently: *mark*, *position*, *limit* and *capacity*. There are methods to set and reset these indexes and to query their value.

capacity()

Returns the buffer’s *capacity*.

Clears the buffer, sets the

position to zero, and *limit* to

clear()

capacity. You call this method to

overwrite an existing buffer.

Sets *limit* to *position* and

position to zero. This method is

flip()

used to prepare the buffer for a

read after data has been written

into it.

limit()

Returns the value of *limit*.

limit(int lim)

Sets the value of *limit*.

mark()

Sets *mark* at *position*.

position()

Returns the value of *position*.

position(int

Sets the value of *position*.

pos)

remaining()

Returns *limit - position*.

Returns **true** if there are any

hasRemaining()

elements between *position* and

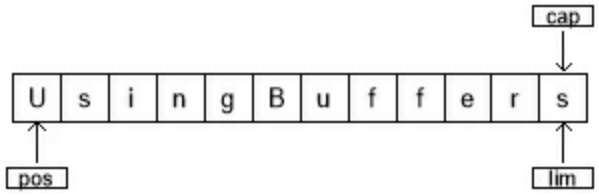
limit.

Methods that insert and extract data from the buffer update these indexes to reflect the changes.

This example uses a very simple algorithm (swapping adjacent characters) to scramble and unscramble characters in a **CharBuffer**:

```
// newio/UsingBuffers.java
import java.nio.*;
public class UsingBuffers {
private static
void symmetricScramble(CharBuffer buffer) {
while(buffer.hasRemaining()) {
buffer.mark();
char c1 = buffer.get();
char c2 = buffer.get();
buffer.reset();
buffer.put(c2).put(c1);
}
```

```
}
public static void main(String[] args) {
char[] data = "UsingBuffers".toCharArray();
```




```
ByteBuffer bb =
ByteBuffer.allocate(data.length * 2);
CharBuffer cb = bb.asCharBuffer();
cb.put(data);
System.out.println(cb.rewind());
symmetricScramble(cb);
System.out.println(cb.rewind());
symmetricScramble(cb);
System.out.println(cb.rewind());
}
}
/* Output:
UsingBuffers
sUniBgfuefsr
```

UsingBuffers

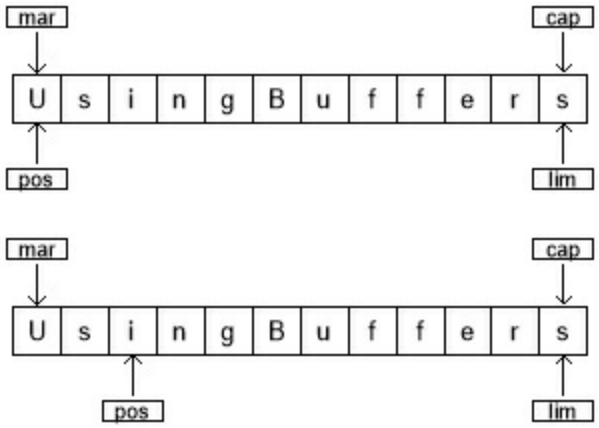
*/

Although you can produce a **CharBuffer** directly by calling **wrap()** with a **char** array, an underlying **ByteBuffer** is allocated instead, and a **CharBuffer** is produced as a view on the **ByteBuffer**. This emphasizes that the goal is always to manipulate a **ByteBuffer**, since that interacts with a channel.

Here's what the buffer looks like at the entrance of the **symmetricScramble()** method:

The *position* points to the first element in the buffer, and the *capacity* and *limit* point immediately after the last element.

In **symmetricScramble()**, the **while** loop iterates until *position*



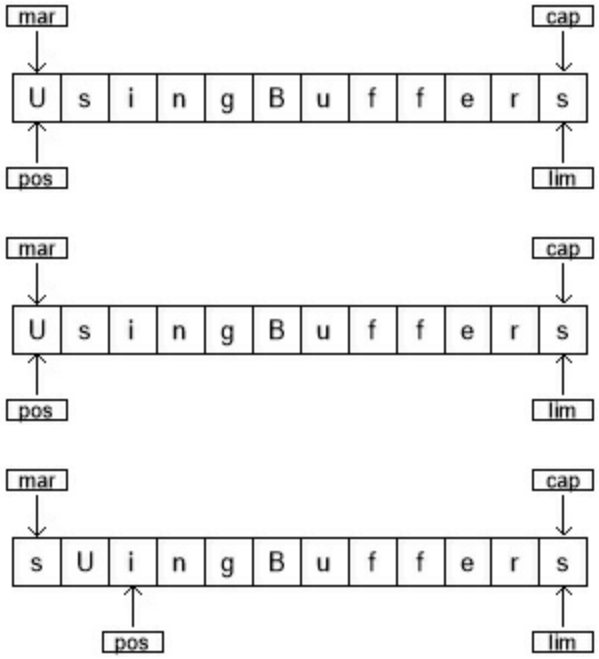
is equivalent to *limit*. The *position* of the buffer changes when a relative **get()** or **put()** function is called on it. You can also call absolute **get()** and **put()** methods that include an index argument:

the location where the **get()** or **put()** takes place. These methods do not modify the value of the buffer's *position*.

When the control enters the **while** loop, the value of *mark* is set using a **mark()** call. The state of the buffer is then:

The two relative **get()** calls save the value of the first two characters in variables **c1** and **c2**. After these two calls, the buffer looks like this:

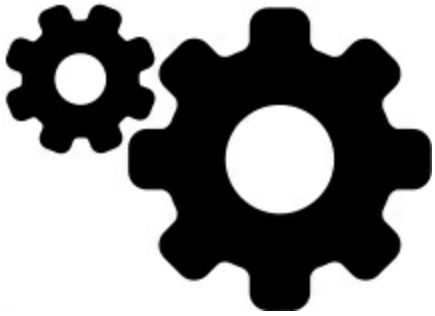
To perform the swap, we write **c2** at *position* 0 and **c1** at *position* 1. We can either use the absolute put method to achieve this, or set the value of *position* to *mark*, which **reset()** does:

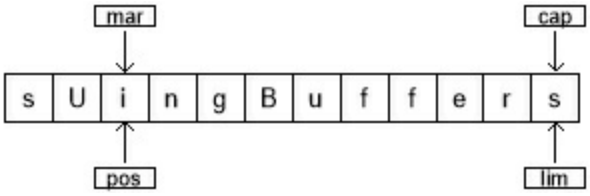


The two **put()** methods write **c2** and then **c1**:

During the next iteration of the loop, *mark* is set to the current value of *position*:

The process continues until the entire buffer is traversed. At the end of the **while** loop, *position* is at the end of the buffer. If you display the buffer, only the characters between the *position* and *limit* are displayed. Thus, to show the entire contents of the buffer, you must set *position* to the start of the buffer using **rewind()**. Here is the state of buffer after the **rewind()** call (the value of *mark* becomes undefined):





When the function **symmetricScramble()** is called again, the **CharBuffer** undergoes the same process and is restored to its original state.

Memory-Mapped Files

Memory-mapped files allow you to create and modify files that are too big to bring into memory. With a memory-mapped file, you can

pretend the entire file is in memory and you can access it by treating it as a very large array. This approach greatly simplifies the code you write to modify the file:

```
// newio/LargeMappedFiles.java
// Creating a very large file using mapping
import java.nio.*;
import java.nio.channels.*;
import java.io.*;
public class LargeMappedFiles {
static int length = 0x8000000; // 128 MB
public static void
main(String[] args) throws Exception {
try(
RandomAccessFile tdat =
new RandomAccessFile("test.dat", "rw")
) {
MappedByteBuffer out = tdat.getChannel().map(
FileChannel.MapMode.READ_WRITE, 0, length);
for(int i = 0; i < length; i++)
out.put((byte)'x');
```

```
System.out.println("Finished writing");
for(int i = length/2; i < length/2 + 6; i++)
System.out.print((char)out.get(i));
}
}
}
/* Output:
Finished writing
xxxxxx
*/
```

To write and read, we start with a **RandomAccessFile**, get a channel for that file, then call **map()** to produce a **MappedByteBuffer**, a particular kind of direct buffer. You must specify the starting point and the length of the region to map in the file —this means you have the option to map smaller regions of a large file. **MappedByteBuffer** inherits **ByteBuffer**, so it has all of **ByteBuffer**s methods. Only the simplest uses of **put()** and

get() are shown here, but you can also use methods like **asCharBuffer()**, etc.

The file created with the preceding program is 128 MB long, probably larger than your OS will allow in memory at one time. The file appears to be accessible all at once because only portions of it are brought into memory, and other parts are swapped out. This way a very large file (up to 2 GB) can easily be modified. Note that the file-mapping facilities of the underlying operating system are used to maximize performance.

Performance

Although the performance of "old" stream I/O is improved by implementing it with **nio**, mapped file access tends to be dramatically faster. This program does a simple performance comparison:

```
// newio/MappedIO.java
import java.util.*;
import java.nio.*;
import java.nio.channels.*;
import java.io.*;
public class MappedIO {
private static int numOfInts = 4_000_000;
```

```
private static int numOfUbuffInts = 100_000;
private abstract static class Tester {
private String name;
Tester(String name) {
this.name = name;
}
public void runTest() {
System.out.print(name + ": ");
long start = System.nanoTime();
test();
double duration = System.nanoTime() - start;
System.out.format("%.3f%n", duration/1.0e9);
}
public abstract void test();
}
private static Tester[] tests = {
new Tester("Stream Write") {
@Override
public void test() {
try(
```

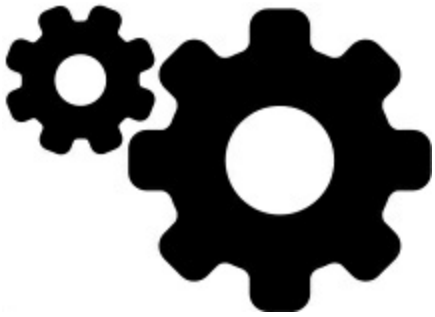
```
DataOutputStream dos =
new DataOutputStream(
new BufferedOutputStream(
new FileOutputStream(
new File("temp.tmp"))))
) {
for(int i = 0; i < numOfInts; i++)
dos.writeInt(i);
} catch(IOException e) {
throw new RuntimeException(e);
}
}
},
new Tester("Mapped Write") {
@Override
public void test() {
try(
FileChannel fc =
new RandomAccessFile("temp.tmp", "rw")
.getChannel()
```

```
) {
IntBuffer ib =
fc.map(FileChannel.MapMode.READ_WRITE,
0, fc.size()).asIntBuffer();
for(int i = 0; i < numOfInts; i++)
ib.put(i);
} catch(IOException e) {
throw new RuntimeException(e);
}
}
},
new Tester("Stream Read") {
@Override
public void test() {
try(
DataInputStream dis =
new DataInputStream(
new BufferedInputStream(
new FileInputStream("temp.tmp")))
) {
```

```
for(int i = 0; i < numOfInts; i++)
dis.readInt();
} catch(IOException e) {
throw new RuntimeException(e);
}
}
},
new Tester("Mapped Read") {
@Override
public void test() {
try(
FileChannel fc = new FileInputStream(
new File("temp.tmp")).getChannel()
) {
IntBuffer ib =
fc.map(FileChannel.MapMode.READ_ONLY,
0, fc.size()).asIntBuffer();
while(ib.hasRemaining())
ib.get();
} catch(IOException e) {
```

```
throw new RuntimeException(e);
}
}
},
new Tester("Stream Read/Write") {
@Override
public void test() {
try(
RandomAccessFile raf =
new RandomAccessFile(
new File("temp.tmp"), "rw")
) {
raf.writeInt(1);
for(int i = 0; i < numOfUbuffInts; i++) {
raf.seek(raf.length() - 4);
raf.writeInt(raf.readInt());
}
} catch(IOException e) {
throw new RuntimeException(e);
}
```

```
}
},
new Tester("Mapped Read/Write") {
@Override
public void test() {
try(
FileChannel fc = new RandomAccessFile(
new File("temp.tmp"), "rw").getChannel()
) {
IntBuffer ib =
fc.map(FileChannel.MapMode.READ_WRITE,
0, fc.size()).asIntBuffer();
ib.put(0);
for(int i = 1; i < numOfUbuffInts; i++)
ib.put(ib.get(i - 1));
} catch(IOException e) {
throw new RuntimeException(e);
}
}
```



```
}
};
public static void main(String[] args) {
Arrays.stream(tests).forEach(Tester::runTest);
}
}
/* Output:
Stream Write: 0.615
Mapped Write: 0.050
Stream Read: 0.577
Mapped Read: 0.015
Stream Read/Write: 4.069
Mapped Read/Write: 0.013
*/
```

Tester is a *Template Method* pattern that creates a test framework for various implementations of **test()** defined in anonymous inner

subclasses. Each of these subclasses performs one kind of test, so the **test()** methods also give you a prototype for performing the various I/O activities.

Although a mapped write would seem to use a **FileOutputStream**, all output in file mapping must use a **RandomAccessFile**, just as read/write does in the preceding code.

Note that the **test()** methods include the time for initialization of the various I/O objects, so even though the setup for mapped files can be expensive, the overall gain compared to stream I/O is dramatic.

File Locking

File locking synchronizes access so a file can be a shared resource. However, two threads that contend for the same file might be in different JVMs, or one might be a Java thread and the other some native thread in the operating system. The file locks are visible to other operating system processes because Java file locking maps directly to the native operating system locking facility.

This shows basic file locking:

```
// newio/FileLocking.java
import java.nio.channels.*;
import java.util.concurrent.*;
```

```
import java.io.*;
public class FileLocking {
public static void main(String[] args) {
try(
FileOutputStream fos =
new FileOutputStream("file.txt");
FileLock fl = fos.getChannel().tryLock()
) {
if(fl != null) {
System.out.println("Locked File");
TimeUnit.MILLISECONDS.sleep(100);
fl.release();
System.out.println("Released Lock");
}
} catch(IOException | InterruptedException e) {
throw new RuntimeException(e);
}
}
}
/* Output:
```

Locked File

Released Lock

*/

You get a **FileLock** on the entire file by calling either **tryLock()** or **lock()** on a **FileChannel**. (**SocketChannel**, **DatagramChannel**, and **ServerSocketChannel** do not need locking since they are inherently single-process entities; you don't generally share a network socket between two processes.)

tryLock() is non-blocking. It tries to grab the lock, but if it

cannot (when some other process already holds the same lock and it is not shared), it simply returns from the method call.

lock() blocks until the lock is acquired, or the thread that invoked **lock()** is interrupted, or the channel on which the **lock()** method is called is closed. A lock is released using **FileLock.release()**.

It is also possible to lock a part of the file by using

tryLock(long position, long size, boolean shared)

or

lock(long position, long size, boolean shared)

which locks the region **(size-position)**. The third argument specifies whether this lock is shared.

Although the zero-argument locking methods adapt to changes in the size of a file, locks with a fixed size do not change if the file size changes. If a lock is acquired for a region from **position** to **position + size** and the file increases beyond **position + size**, then the section beyond **position + size** is not locked.

The zero-argument locking methods lock the entire file, even if it grows.

Support for exclusive or shared locks must be provided by the underlying operating system. If the operating system does not support shared locks and a request is made for one, an exclusive lock is used instead. The type of lock (shared or exclusive) can be queried using **FileLock.isShared()**.

Locking Portions of a Mapped File

File mapping is typically used for very large files. You might need to lock portions of such a file so other processes can modify unlocked

parts. A database, for example, must be available to many users at once.

Here you see two threads, each of which locks a distinct portion of a file:

```
// newio/LockingMappedFiles.java
// Locking portions of a mapped file
import java.nio.*;
import java.nio.channels.*;
import java.io.*;
public class LockingMappedFiles {
static final int LENGTH = 0x8FFFFFF; // 128 MB
static FileChannel fc;
public static void
main(String[] args) throws Exception {
fc = new RandomAccessFile("test.dat", "rw")
.getChannel();
MappedByteBuffer out = fc.map(
FileChannel.MapMode.READ_WRITE, 0, LENGTH);
for(int i = 0; i < LENGTH; i++)
out.put((byte)'x');
```

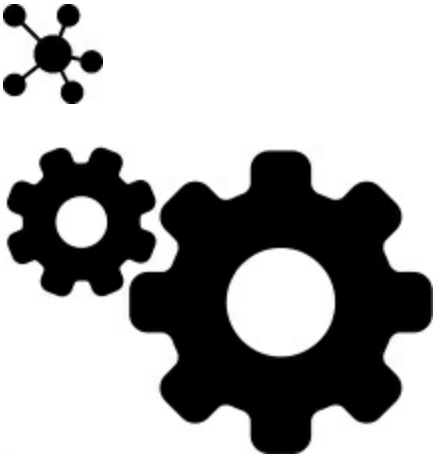
```
new LockAndModify(out, 0, 0 + LENGTH/3);
new LockAndModify(
out, LENGTH/2, LENGTH/2 + LENGTH/4);
}
private static class LockAndModify extends Thread {
private ByteBuffer buff;
private int start, end;
LockAndModify(ByteBuffer mbb, int start, int end) {
this.start = start;
this.end = end;
mbb.limit(end);
mbb.position(start);
buff = mbb.slice();
start();
}
@Override
public void run() {
try {
// Exclusive lock with no overlap:
FileLock fl = fc.lock(start, end, false);
```

```
System.out.println(
"Locked: "+ start +" to "+ end);
// Perform modification:
while(buff.position() < buff.limit() - 1)
buff.put((byte)(buff.get() + 1));
fl.release();
System.out.println(
"Released: " + start + " to " + end);
} catch(IOException e) {
throw new RuntimeException(e);
}
}
}
}
/* Output:
Locked: 75497471 to 113246206
Locked: 0 to 50331647
Released: 75497471 to 113246206
Released: 0 to 50331647
*/
```

The **LockAndModify** thread class sets up the buffer region and creates a **slice()** to be modified, and in **run()**, the lock is acquired on the file channel (you can't acquire a lock on the buffer—only the channel). The call to **lock()** is very similar to acquiring a threading lock on an object—you now have a "critical section" with exclusive access to that portion of the file. 1

The locks are automatically released when the JVM exits, or the channel on which it was acquired is closed, but you can also explicitly call **release()** on the **FileLock** object, as shown here.

1. You can find more details about threads in the Appendix: Low-Level Concurrency.↩



Appendix:

Understanding equals()

and hashCode()

When you create a class for use in any container that utilizes *hashing*, you must not only define the **hashCode()** method (which we shall explore later in this appendix), but also the **equals()** method. The two methods are used together to perform a lookup into a hashed container.

A Canonical equals()

When you create a new class, it automatically inherits class **Object**. If you don't override **equals()**, you'll get **Object**s **equals()** method. By default this compares addresses, so only if you are comparing the *exact same* objects will you get **true**. The default case is the "most discriminating."

```
// equalshashcode/DefaultComparison.java
class DefaultComparison {
private int i, j, k;
DefaultComparison(int i, int j, int k) {
this.i = i;
this.j = j;
this.k = k;
}
public static void main(String[] args) {
```

DefaultComparison

a = **new** DefaultComparison(1, 2, 3),

b = **new** DefaultComparison(1, 2, 3);

System.out.println(a == a);

System.out.println(a == b);

}

}

/* *Output:*

true

false

*/

Normally you'll want to relax this restriction. Typically, if two objects are the same type and have fields with identical values, you'll consider those objects equal, but there may also be fields that you don't want to include in the **equals()** comparison. This is part of the class design process.

A proper **equals()** must satisfy the following five conditions:

1. Reflexive: For any **x**, **x.equals(x)** should return **true**.

2. Symmetric: For any **x** and **y**, **x.equals(y)** should return **true** if and only if **y.equals(x)** returns **true**.

3. Transitive: For any **x**, **y**, and **z**, if **x.equals(y)** returns **true** and **y.equals(z)** returns **true**, then **x.equals(z)** should

return **true**.

4. Consistent: For any **x** and **y**, multiple invocations of

x.equals(y) consistently return **true** or consistently return

false, provided no information used in equals comparisons on

the object is modified.

5. For any non-**null x**, **x.equals(null)** should return

false.

Here are the tests that satisfy those conditions and determine whether

the object you're comparing yourself to (which we'll call here the **rval**)

is equal to this object:

1. If the **rval** is **null**, it's not equal.

2. If the **rval** is **this** (you're comparing yourself to yourself), the

two objects are equal.

3. If the **rval** is not the same class or subclass, the two objects are

not equal.

4. If all the above checks pass, then you must decide which fields in

the **rval** are important (and consistent), and compare those.

Java 7 introduced the **Objects** class to help with this process, which

we use to write a better **equals()**.

The following examples compare different versions of the **Equality** class. To prevent duplicate code we'll build the examples using the *Factory Method* (see Factories: Encapsulating Object Creation). The **EqualityFactory** interface simply provides a **make()** method to produce an **Equality** object, so a different **EqualityFactory** can produce a different subtype of **Equality**:

```
// equalshashcode/EqualityFactory.java
import java.util.*;
interface EqualityFactory {
Equality make(int i, String s, double d);
}
```

Now we'll define **Equality** containing three fields (all of which we consider important during comparison) and an **equals()** method that fulfills the four checks described above. The constructor displays its type name to ensure we are performing the tests we think we are:

```
// equalshashcode/Equality.java
import java.util.*;
public class Equality {
protected int i;
protected String s;
protected double d;
```

```
public Equality(int i, String s, double d) {
this.i = i;
this.s = s;
this.d = d;
System.out.println("made 'Equality'");
}
@Override
public boolean equals(Object rval) {
if(rval == null)
return false;
if(rval == this)
return true;
if(!(rval instanceof Equality))
return false;
Equality other = (Equality)rval;
if(!Objects.equals(i, other.i))
return false;
if(!Objects.equals(s, other.s))
return false;
if(!Objects.equals(d, other.d))
```

```
return false;
return true;
}
public void
test(String descr, String expected, Object rval) {
System.out.format("-- Testing %s --%n" +
"%s instanceof Equality: %s%n" +
"Expected %s, got %s%n",
descr, descr, rval instanceof Equality,
expected, equals(rval));
}
public static void testAll(EqualityFactory eqf) {
Equality
e = eqf.make(1, "Monty", 3.14),
eq = eqf.make(1, "Monty", 3.14),
neq = eqf.make(99, "Bob", 1.618);
e.test("null", "false", null);
e.test("same object", "true", e);
e.test("different type",
"false", Integer.valueOf(99));
```

```
e.test("same values", "true", eq);
e.test("different values", "false", neq);
}
public static void main(String[] args) {
testAll( (i, s, d) -> new Equality(i, s, d));
}
}
/* Output:
made 'Equality'
made 'Equality'
made 'Equality'
-- Testing null --
null instanceof Equality: false
Expected false, got false
-- Testing same object --
same object instanceof Equality: true
Expected true, got true
-- Testing different type --
different type instanceof Equality: false
Expected false, got false
```

-- Testing same values --

same values instanceof Equality: true

Expected true, got true

-- Testing different values --

different values instanceof Equality: true

Expected false, got false

**/*

testAll() performs comparisons with all different types of objects we ever expect to encounter. It creates **Equality** objects using the factory.

In **main()**, notice the simplicity of the call to **testAll()**. Because **EqualityFactory** has a single method, it can be used with a lambda expression as the **make()** method.

The above **equals()** method is annoyingly verbose, and it turns out we can simplify it into a canonical form. Observe:

1. The **instanceof** check eliminates the need to test for **null**
2. The comparison to **this** is redundant. A correctly-written **equals()** will work properly with self comparison.

Because **&&** is a short-circuiting comparison, it quits and produces **false** the first time it encounters a failure. So, by chaining the checks

together with **&&** , we can write **equals()** much more succinctly:

```
// equalshashcode/SuccinctEquality.java
import java.util.*;
public class SuccinctEquality extends Equality {
public SuccinctEquality(int i, String s, double d) {
super(i, s, d);
System.out.println("made 'SuccinctEquality'");
}
@Override
public boolean equals(Object rval) {
return rval instanceof SuccinctEquality &&
Objects.equals(i, ((SuccinctEquality)rval).i) &&
Objects.equals(s, ((SuccinctEquality)rval).s) &&
Objects.equals(d, ((SuccinctEquality)rval).d);
}
public static void main(String[] args) {
Equality.testAll( (i, s, d) ->
new SuccinctEquality(i, s, d));
}
}
```

/ Output:*

made 'Equality'

made 'SuccinctEquality'

made 'Equality'

made 'SuccinctEquality'

made 'Equality'

made 'SuccinctEquality'

-- Testing null --

null instanceof Equality: false

Expected false, got false

-- Testing same object --

same object instanceof Equality: true

Expected true, got true

-- Testing different type --

different type instanceof Equality: false

Expected false, got false

-- Testing same values --

same values instanceof Equality: true

Expected true, got true

-- Testing different values --

different values instanceof Equality: true

Expected false, got false

*/

For each **SuccinctEquality**, the base-class constructor is called before the derived-class constructor. The output shows that we still get the correct result. You can tell that short-circuiting happens because both the **null** test and the "different type" test would otherwise throw exceptions during the casts that occur further down the list of comparisons in **equals()**.

Objects.equals() shines when you compose your new class using another class:

```
// equalshashcode/ComposedEquality.java
import java.util.*;
class Part {
String ss;
double dd;
Part(String ss, double dd) {
this.ss = ss;
this.dd = dd;
}
```

```
@Override
public boolean equals(Object rval) {
return rval instanceof Part &&
Objects.equals(ss, ((Part)rval).ss) &&
Objects.equals(dd, ((Part)rval).dd);
}
}
public class ComposedEquality extends SuccinctEquality {
Part part;
public ComposedEquality(int i, String s, double d) {
super(i, s, d);
part = new Part(s, d);
System.out.println("made 'ComposedEquality'");
}
@Override
public boolean equals(Object rval) {
return rval instanceof ComposedEquality &&
super.equals(rval) &&
Objects.equals(part,
((ComposedEquality)rval).part);
```

```
}
public static void main(String[] args) {
Equality.testAll( (i, s, d) ->
new ComposedEquality(i, s, d));
}
}
/* Output:
made 'Equality'
made 'SuccinctEquality'
made 'ComposedEquality'
made 'Equality'
made 'SuccinctEquality'
```

```
made 'ComposedEquality'
made 'Equality'
made 'SuccinctEquality'
made 'ComposedEquality'
-- Testing null --
```

null instanceof Equality: false

Expected false, got false

-- Testing same object --

same object instanceof Equality: true

Expected true, got true

-- Testing different type --

different type instanceof Equality: false

Expected false, got false

-- Testing same values --

same values instanceof Equality: true

Expected true, got true

-- Testing different values --

different values instanceof Equality: true

Expected false, got false

*/

Notice the call to **super.equals()**—no need to reinvent it (plus you don't always have access to all necessary parts of a base class).

Equality Across Subtypes

Inheritance suggests that objects of two different subtypes can be "the same" when they are upcast. Suppose you have a collection of **Animal**

objects. This collection naturally accepts subtypes of **Animal**—in this example, **Dog**s and **Pig**s. Each **Animal** has a **name** and a **size**, as well as a unique internal **id** number.

We define **equals()** and **hashCode()** using the canonical form via the **Objects** class, but we only define them in the base class **Animal**, and we do not include the unique **id** number in either one. From the standpoint of **equals()**, this means we only care if something is a **Animal**, not whether it is a specific type of **Animal**:

```
// equalshashcode/SubtypeEquality.java
import java.util.*;
enum Size { SMALL, MEDIUM, LARGE }
class Animal {
private static int counter = 0;
private final int id = counter++;
private final String name;
private final Size size;
Animal(String name, Size size) {
this.name = name;
this.size = size;
}
@Override
```

```
public boolean equals(Object rval) {
return rval instanceof Animal &&
// Objects.equals(id, ((Animal)rval).id) && // [1]
Objects.equals(name, ((Animal)rval).name) &&
Objects.equals(size, ((Animal)rval).size);
}
@Override
public int hashCode() {
return Objects.hash(name, size);
// return Objects.hash(name, size, id); // [2]
}
@Override
public String toString() {
return String.format("%s[%d]: %s %s %x",
getClass().getSimpleName(), id,
name, size, hashCode());
}
}
class Dog extends Animal {
Dog(String name, Size size) {
```

```
super(name, size);
}
}
class Pig extends Animal {
Pig(String name, Size size) {
super(name, size);
}
}
public class SubtypeEquality {
public static void main(String[] args) {
Set<Animal> pets = new HashSet<>();
pets.add(new Dog("Ralph", Size.MEDIUM));
pets.add(new Pig("Ralph", Size.MEDIUM));
pets.forEach(System.out::println);
}
}
/* Output:
Dog[0]: Ralph MEDIUM a752aeee
*/
```

If we are just thinking about types, it does make sense—sometimes—to

only consider the classes from the standpoint of their base type, which is the foundation of the *Liskov Substitution Principle*. This code fits nicely with that principle because the derived types don't add any extra functionality (methods) that isn't in the base class. The derived types only differ in behavior, not in interface (which of course is not the general case).

But when we provide two different object types with identical data and place them in a **HashSet<Animal>** , only one of these objects survives. This emphasizes that **equals()** is not a perfectly mathematical concept but (at least partially) a mechanical one. **hashCode()** and **equals()** must be defined hand-in-hand in order to allow types to work properly in a hashed data structure.

In the example, both the **Dog** and **Pig** hash to the same bucket in the **HashSet**. At this point, the **HashSet** falls back to **equals()** to differentiate the objects, but **equals()** also declares the objects to be the same. The **HashSet** doesn't add the **Pig** because it's already got an identical object.

We can still make the example work by forcing uniqueness on otherwise identical objects. Here, each **Animal** already has a unique **id** so you can either uncomment line **[1]** in **equals()** or switch to line **[2]** in **hashCode()**. In the canonical form you would do both, to

involve all “unchanging” fields in both operations (“unchanging” so that the **equals()** and **hashCode()** don’t produce different values between storing and retrieving in a hashed data structure. I put “unchanging” in quotes because you must evaluate whether modification might happen).

Side note: in **hashCode()**, if you are only working with a single field, use **Objects.hashCode()** and if you are using multiple fields use **Objects.hash()**.

We can also solve the issue by following the standard form and defining **equals()** in the subclasses (but still not including the unique **id**):

```
// equalshashcode/SubtypeEquality2.java
import java.util.*;
class Dog2 extends Animal {
Dog2(String name, Size size) {
super(name, size);
}
@Override
public boolean equals(Object rval) {
return rval instanceof Dog2 &&
```

```
super.equals(rval);
}
}
class Pig2 extends Animal {
Pig2(String name, Size size) {
super(name, size);
}
@Override
public boolean equals(Object rval) {
return rval instanceof Pig2 &&
super.equals(rval);
}
}
public class SubtypeEquality2 {
public static void main(String[] args) {
Set<Animal> pets = new HashSet<>();
pets.add(new Dog2("Ralph", Size.MEDIUM));
pets.add(new Pig2("Ralph", Size.MEDIUM));
pets.forEach(System.out::println);
}
```

}

/ *Output:*

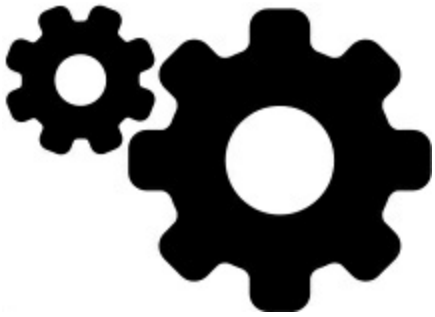
Dog2[0]: Ralph MEDIUM a752aeee

Pig2[1]: Ralph MEDIUM a752aeee

**/*

Notice that the **hashCode()**s are identical, but because the objects are no longer **equals()**, both now appear in the **HashSet**. Also, **super.equals()** means we don't need access to the **private** fields in the base class.

One way to look at this is to say that Java separates substitutability from the definition of **equals()** and **hashCode()**. We can still place **Dog**s and **Pig**s into a **Set<Animal>** regardless of how **equals()** and **hashCode()** are defined, but the objects won't behave correctly in hashed data structures unless those methods are defined with hashed structures in mind. Unfortunately, **equals()** is not only used in conjunction with **hashCode()**. This complicates things when you try to avoid defining it for specific classes, and it's why it's worth following the canonical form. However, this is further



complicated because there are times when you don’t need to define either method.

Hashing and Hash Codes

The examples in the Collections chapter used predefined classes as **HashMap** keys. These examples worked because the predefined classes had all the necessary wiring to make them behave correctly as keys.

A common pitfall occurs when you create your own classes as keys for **HashMap**s, and forget to put in the necessary wiring. For example, consider a weather predicting system that matches **Groundhog** objects to **Prediction** objects. This seems fairly straightforward: use **Groundhog** as the key and **Prediction** as the value:

```
// equalshashcode/Groundhog.java
// Looks plausible, but doesn't work as a HashMap key
public class Groundhog {
```

```
protected int number;
public Groundhog(int n) { number = n; }
@Override
public String toString() {
return "Groundhog #" + number;
}
}
// equalshashcode/Prediction.java
// Predicting the weather
import java.util.*;
public class Prediction {
private static Random rand = new Random(47);
@Override
public String toString() {
return rand.nextBoolean() ?
"Six more weeks of Winter!" : "Early Spring!";
}
}
// equalshashcode/SpringDetector.java
// What will the weather be?
```

```
import java.util.*;
import java.util.stream.*;
import java.util.function.*;
import java.lang.reflect.*;
public class SpringDetector {
public static <T extends Groundhog>
void detectSpring(Class<T> type) {
try {
Constructor<T> ghog =
type.getConstructor(int.class);
Map<Groundhog, Prediction> map =
IntStream.range(0, 10)
.mapToObj(i -> {
try {
return ghog.newInstance(i);
} catch(Exception e) {
throw new RuntimeException(e);
}
})
.collect(Collectors.toMap(
```

```
Function.identity(),
gh -> new Prediction()));
map.forEach((k, v) ->
System.out.println(k + ": " + v));
Groundhog gh = ghog.newInstance(3);
System.out.println(
"Looking up prediction for " + gh);
if(map.containsKey(gh))
System.out.println(map.get(gh));
else
System.out.println("Key not found: " + gh);
} catch(NoSuchMethodException |
IllegalAccessException |
InvocationTargetException |
InstantiationException e) {
throw new RuntimeException(e);
}
}
public static void main(String[] args) {
detectSpring(Groundhog.class);
```

}

}

/ Output:*

Groundhog #3: Six more weeks of Winter!

Groundhog #0: Early Spring!

Groundhog #8: Six more weeks of Winter!

Groundhog #6: Early Spring!

Groundhog #4: Early Spring!

Groundhog #2: Six more weeks of Winter!

Groundhog #1: Early Spring!

Groundhog #9: Early Spring!

Groundhog #5: Six more weeks of Winter!

Groundhog #7: Six more weeks of Winter!

Looking up prediction for Groundhog #3

Key not found: Groundhog #3

/

Each **Groundhog** is given an identity number, so you can look up a **Prediction** in the **HashMap** by saying, "Give me the **Prediction** associated with **Groundhog #3**." The **Prediction** chooses the weather by generating a random **boolean**. The

detectSpring() method uses reflection to instantiate and use the **class Groundhog** or any class derived from **Groundhog**. This comes in handy later, when we inherit a new type of **Groundhog** to solve the problem demonstrated here.

A **HashMap** is filled with **Groundhog**s and their associated

Predictions. Displaying **HashMap** shows it was filled. Then a **Groundhog** with an identity number of 3 is used as a key to find the prediction for **Groundhog #3** (which therefore must be in the **Map**).

It seems simple enough, but it doesn't work—it can't find the key for **#3**. The problem is that **Groundhog** automatically inherits class **Object**, and it is **Object**s **hashCode()** method that is used to generate the hash code for each object. By default this just uses the address of its object. Thus, the first instance of **Groundhog(3)** does *not* produce a hash code equal to the hash code for the second instance of **Groundhog(3)** that we tried to use as a lookup.

We need an appropriate override for **hashCode()**. But that still won't work until you've done one more thing: override the **equals()** that is also part of **Object**. **equals()** is used by the **HashMap** when trying to determine if your key is equal to any of the keys in the table.

Because the default **Object.equals()** compares object addresses, one **Groundhog(3)** is not equal to another **Groundhog(3)**. Thus, to use your own classes as keys in a **HashMap**, you must override both **hashCode()** and **equals()**, as shown in the following solution to the groundhog problem:

```
// equalshashcode/Groundhog2.java
// A class that's used as a key in a HashMap
// must override hashCode() and equals()
import java.util.*;
public class Groundhog2 extends Groundhog {
public Groundhog2(int n) { super(n); }
@Override
public int hashCode() { return number; }
@Override
public boolean equals(Object o) {
return o instanceof Groundhog2 &&
Objects.equals(
number, ((Groundhog2)o).number);
}
}
// equalshashcode/SpringDetector2.java
// A working key
public class SpringDetector2 {
public static void main(String[] args) {
SpringDetector.detectSpring(Groundhog2.class);
```

}

}

/ Output:*

Groundhog #0: Six more weeks of Winter!

Groundhog #1: Early Spring!

Groundhog #2: Six more weeks of Winter!

Groundhog #3: Early Spring!

Groundhog #4: Early Spring!

Groundhog #5: Six more weeks of Winter!

Groundhog #6: Early Spring!

Groundhog #7: Early Spring!

Groundhog #8: Six more weeks of Winter!

Groundhog #9: Six more weeks of Winter!

Looking up prediction for Groundhog #3

Early Spring!

**/*

Groundhog2.hashCode() returns the groundhog number as a hash value. In this example, the programmer is responsible for ensuring that no two groundhogs exist with the same ID number. The **hashCode()** is not required to return a unique identifier (something

you'll understand later in this appendix), but the **equals()** method must strictly determine whether two objects are equivalent. Here, **equals()** is based on the groundhog number, so if two

Groundhog2 objects exist as keys in the **HashMap** with the same groundhog number, it will fail.

Defining **equals()** was covered in A Canonical **equals()**. The output shows that the behavior is now correct.

Understanding hashCode()

The preceding example is only a start toward solving the problem correctly. It shows that if you do not override **hashCode()** and **equals()** for your key, the hashed data structure (for example: **HashSet**, **HashMap**, **LinkedHashSet**, or **LinkedHashMap**) probably won't deal with your key properly. For a *good* solution to the problem, however, you must understand what's going on inside the hashed data structure.

First, consider the motivation behind hashing: To look up an object using another object. But you can also accomplish this with a

TreeMap, or you can even implement your own **Map**. In contrast to a hashed implementation, the following example implements a **Map** using a pair of **ArrayList**s. Unlike **AssociativeArray.java**, this includes a full implementation of the **Map** interface, which accounts for the **entrySet()** method:

```
// equalshashcode/SlowMap.java
// A Map implemented with ArrayLists
import java.util.*;
import onjava.*;
public class SlowMap<K, V> extends AbstractMap<K, V> {
private List<K> keys = new ArrayList<>();
private List<V> values = new ArrayList<>();
@Override
public V put(K key, V value) {
V oldValue = get(key); // The old value or null
if(!keys.contains(key)) {
keys.add(key);
values.add(value);
} else
values.set(keys.indexOf(key), value);
```

```
return oldValue;
}
@Override
public V get(Object key) { // key: type Object, not K
if(!keys.contains(key))
return null;
return values.get(keys.indexOf(key));
}
@Override
public Set<Map.Entry<K, V>> entrySet() {
Set<Map.Entry<K, V>> set= new HashSet<>();
Iterator<K> ki = keys.iterator();
Iterator<V> vi = values.iterator();
while(ki.hasNext())
set.add(new MapEntry<>(ki.next(), vi.next()));
return set;
}
public static void main(String[] args) {
SlowMap<String,String> m= new SlowMap<>();
m.putAll(Countries.capitals(8));
```

```
m.forEach((k, v) ->
System.out.println(k + "=" + v));
System.out.println(m.get("BENIN"));
m.entrySet().forEach(System.out::println);
}
}
/* Output:
CAMEROON=Yaounde
ANGOLA=Luanda
BURKINA FASO=Ouagadougou
BURUNDI=Bujumbura
ALGERIA=Algiers
BENIN=Porto-Novo
CAPE VERDE=Praia
BOTSWANA=Gaberone
Porto-Novo
CAMEROON=Yaounde
ANGOLA=Luanda
BURKINA FASO=Ouagadougou
BURUNDI=Bujumbura
```

ALGERIA=Algiers

BENIN=Porto-Novo

CAPE VERDE=Praia

BOTSWANA=Gaberone

*/

The **put()** method places the keys and values in corresponding **ArrayList**s. In accordance with the **Map** interface, it must return the old key or **null** if there was no old key.

Following the specifications for **Map**, **get()** produces **null** if the key is not in the **SlowMap**. If the key exists, it is used to look up the numerical index indicating its location in the **keys List**, and this number is used as an index to produce the associated value from the **values List**. Notice that the type of **key** is **Object** in **get()**, rather than the parameterized type **K** as you might expect (and which was indeed used in **AssociativeArray.java**). This is a result of the injection of generics into the Java language at such a late date—if generics had been an original feature in the language, **get()** could have specified the type of its parameter.

The **String** representation of the contents of **SlowMap** is automatically produced by the **toString()** method defined in

AbstractMap.

In **SlowMap.main()**, a **SlowMap** is loaded, then the contents are displayed. A call to **get()** shows it works.

Map.entrySet() produces a set of **Map.Entry** objects. However, **Map.Entry** is an interface describing an implementation-dependent structure, so to make your own type of **Map**, you must also define an implementation of **Map.Entry**:

```
// equalshashcode/MapEntry.java
// A simple Map.Entry for sample Map implementations
import java.util.*;
public class MapEntry<K, V> implements Map.Entry<K, V> {
private K key;
private V value;
public MapEntry(K key, V value) {
this.key = key;
this.value = value;
}
@Override
public K getKey() { return key; }
@Override
```

```
public V getValue() { return value; }
@Override
public V setValue(V v) {
V result = value;
value = v;
return result;
}
@Override
public int hashCode() {
return Objects.hash(key, value);
}
@SuppressWarnings("unchecked")
@Override
public boolean equals(Object rval) {
return rval instanceof MapEntry &&
Objects.equals(key,
((MapEntry<K, V>)rval).getKey()) &&
Objects.equals(value,
((MapEntry<K, V>)rval).getValue());
}
```

@Override

public String toString() {

return key + "=" + value;

}

}

The **equals()** method follows A Canonical **equals()**. There is a similar method in the **Objects** class for creating a **hashCode()**:

Objects.hash(). Use this when you are defining a **hashCode()**

involving *more than one field*. If you are only using a single field, use

Objects.hashCode() instead.

Although this solution is simple, and appears to work for the trivial

test in **SlowMap.main()**, it is not a correct implementation because

it makes a copy of the keys and values. A proper implementation of

entrySet() provides a *view* into the **Map**, rather than a copy, and

this view allows modification of the original map (which a copy

doesn't).

Hashing for Speed

SlowMap.java shows it's not that hard to produce a new type of **Map**. But as the name suggests, a **SlowMap** isn't very fast, so you won't use it if you have an alternative. The problem happens during lookup: the keys are not kept in any particular order, so a simple linear search is used. A linear search is the slowest way to find something. The whole point of hashing is speed, because hashing looks up values very quickly. Since the bottleneck is in the speed of the key lookup, one solution is to keep the keys sorted, then use **Collections.binarySearch()** to perform the lookup.

Hashing goes further by only storing the key *somewhere* in a way it can be found quickly. The fastest structure for storing a group of elements is an array, so that is used for representing the key information (note I say "key information," and not the key itself). But because an array cannot be resized, we have a problem: We want to store an indeterminate number of values in the **Map**, but if the number of keys is fixed by the array size, how can this be?

The array does not hold the keys. From the key object, a number is derived to index into the array. This number is the *hash code*, produced by the **hashCode()** method (using a *hash function*) defined in **Object** and presumably overridden by your class.

To solve the problem of the fixed-size array, more than one key can produce the same index. That is, there can be *collisions*. Because of this, it doesn't matter how big the array is; any key object's hash code will land somewhere in that array.

So the process of looking up a value starts by computing the hash code and using it to index into the array. If you could guarantee there were no collisions (possible with a fixed number of values), you'd have a *perfect hashing function*, but that's a special case. 1 In all other cases, collisions are handled with *external chaining*: The array doesn't point directly to a value, but instead to a list of values. These values are searched in a linear fashion using the **equals()** method (thus, **equals()** is also essential for hashing). This aspect of the search is much slower, but if the hash function is good, there will only be a few values in each slot. So instead of searching through the entire list, you quickly jump to a slot where you only compare a few entries to find the value. This is much faster, which is why a **HashMap** is so quick.

Knowing the basics of hashing, you can implement a simple hashed **Map**:

```
// equalshashcode/SimpleHashMap.java
// A demonstration hashed Map
import java.util.*;
```

```
import onjava.*;
public
class SimpleHashMap<K, V> extends AbstractMap<K, V> {
// Choose a prime number for the hash table
// size, to achieve a uniform distribution:
static final int SIZE = 997;
// You can't have a physical array of generics,
// but you can upcast to one:
@SuppressWarnings("unchecked")
LinkedList<MapEntry<K, V>>[] buckets =
new LinkedList[SIZE];
@Override
public V put(K key, V value) {
V oldValue = null;
int index = Math.abs(key.hashCode()) % SIZE;
if(buckets[index] == null)
buckets[index] = new LinkedList<>();
LinkedList<MapEntry<K, V>> bucket = buckets[index];
MapEntry<K, V> pair = new MapEntry<>(key, value);
boolean found = false;
```

```
ListIterator<MapEntry<K, V>> it =
bucket.listIterator();
while(it.hasNext()) {
MapEntry<K, V> iPair = it.next();
if(iPair.getKey().equals(key)) {
oldValue = iPair.getValue();
it.set(pair); // Replace old with new
found = true;
break;
}
}
if(!found)
buckets[index].add(pair);
return oldValue;
}
@Override
public V get(Object key) {
int index = Math.abs(key.hashCode()) % SIZE;
if(buckets[index] == null) return null;
for(MapEntry<K, V> iPair : buckets[index])
```

```
if(iPair.getKey().equals(key))
return iPair.getValue();
return null;
}
@Override
public Set<Map.Entry<K, V>> entrySet() {
Set<Map.Entry<K, V>> set= new HashSet<>();
for(LinkedList<MapEntry<K, V>> bucket : buckets) {
if(bucket == null) continue;
for(MapEntry<K, V> mpair : bucket)
set.add(mpair);
}
return set;
}
public static void main(String[] args) {
SimpleHashMap<String,String> m =
new SimpleHashMap<>();
m.putAll(Countries.capitals(8));
m.forEach((k, v) ->
System.out.println(k + "=" + v));
```

```
System.out.println(m.get("BENIN"));
m.entrySet().forEach(System.out::println);
}
}
/* Output:
CAMEROON=Yaounde
ANGOLA=Luanda
BURKINA FASO=Ouagadougou
BURUNDI=Bujumbura
ALGERIA=Algiers
BENIN=Porto-Novo
CAPE VERDE=Praia
BOTSWANA=Gaberone
Porto-Novo
CAMEROON=Yaounde
ANGOLA=Luanda
BURKINA FASO=Ouagadougou
BURUNDI=Bujumbura
ALGERIA=Algiers
BENIN=Porto-Novo
```

CAPE VERDE=Praia

BOTSWANA=Gaberone

*/

Because the “slots” in a hash table are often called *buckets*, the array that represents the actual table is called **buckets**. To promote even distribution, the number of buckets is typically a prime number.2

Notice it is an array of **LinkedList**, which automatically provides for collisions—each new item is added to the end of the list in a particular bucket. Even though Java will not let you create an array of generics, it is possible to make a *reference* to such an array. Here, it is convenient to upcast to such an array, to prevent extra casting later in the code.

For a **put()**, **hashCode()** is called for the key and the result is forced to a positive number. To fit the resulting number into the **buckets** array, the modulus operator is used with the size of that array. If that location is **null**, it means there are no elements that hash to that location, so a new **LinkedList** holds the object that did

just hash to that location. However, the normal process is to look through the list to see if there are duplicates, and if there are, the old value is put into **oldValue** and the new value replaces the old. The **found** flag keeps track of whether an old key-value pair was found and, if not, the new pair is appended to the end of the list.

get() calculates the index into the **buckets** array in the same fashion as **put()** (this is important to guarantee that you end up in the same spot). If a **LinkedList** exists, it is searched for a match.

This particular implementation is not meant to be tuned for performance; it is only intended to show the operations performed by a hash map. If you look at the source code for **java.util.HashMap**, you'll see a tuned implementation. Also, for simplicity, **SimpleHashMap** uses the same approach to **entrySet()** as did **SlowMap**, which is oversimplified and will not work for a general-purpose **Map**.

Overriding hashCode()

Now you understand how hashing works, writing a proper **hashCode()** method will make more sense.

First of all, you don't control the creation of the actual value that's used to index into the array of buckets. That is dependent on the

capacity of the particular **HashMap** object, and that capacity changes depending on how full the collection is, along with the *load factor* (this term is described later). Thus, the value produced by your **hashCode()** is further processed to create the bucket index (in **SimpleHashMap**, the calculation is just a modulo by the size of the bucket array).

The most important factor in creating a **hashCode()** is that, regardless of when **hashCode()** is called, it produces the same value for a particular object every time. If you end up with an object that produces one **hashCode()** value when it is **put()** into a **HashMap** and another during a **get()**, you can't retrieve the objects. So if your **hashCode()** depends on mutable data in the object, the user must be made aware that changing the data produces a different key because it generates a different **hashCode()**.

In addition, you probably *won't* want to generate a **hashCode()** based on unique object information—in particular, the value of **this** makes a bad **hashCode()** because then you can't generate a new key identical to the one used to **put()** the original key-value pair. This was the problem that occurred in **SpringDetector.java**, because the default implementation of **hashCode()** *does* use the object

address. So use information in the object that identifies the object in a

meaningful way.

One example can be seen in the **String** class. **String**s have the

special characteristic that if a program has several **String** objects that contain identical character sequences, those **String** objects all

map to the same memory. So it makes sense that the **hashCode()**

produced by two separate instances of the **String "hello"** should

be identical, as demonstrated here:

```
// equalshashcode/StringHashCode.java
public class StringHashCode {
public static void main(String[] args) {
String[] hellos = "Hello Hello".split(" ");
System.out.println(hellos[0].hashCode());
System.out.println(hellos[1].hashCode());
}
}
/* Output:
69609650
69609650
*/
```

The **hashCode()** for **String** is clearly based on the contents of the

String.

So, for a **hashCode()** to be effective, it must be both fast and meaningful; that is, it must generate a value based on the contents of the object. Remember this value doesn't have to be unique—you should lean toward speed rather than uniqueness—but between **hashCode()** and **equals()**, the identity of the object must be completely resolved.

Because the **hashCode()** is further processed before the bucket index is produced, the range of values is not important; it must only generate an **int**.

There's one other factor: A good **hashCode()** should result in an even distribution of values. If the values tend to cluster, then the **HashMap** or **HashSet** is more heavily loaded in some areas and is not as fast as it can be with an evenly distributed hashing function.

In *Effective Java Programming Language Guide* (Addison-Wesley, 2001), Joshua Bloch gives a basic recipe for generating a decent **hashCode()**:

1. Store some constant nonzero value, say 17, in an **int** variable called **result**.

2. For each significant field **f** in your object (that is, each field taken into account by the **equals()** method), calculate an **int** hash

code **c** for the field:

Field type

Calculation

boolean

c = (f ? 0 : 1)

byte, **char**,

c = (int)f

short, or **int**

long

c = (int)(f ^ (f>>>32))

c =

float

Float.floatToIntBits(f);

long l =

double

Double.doubleToLongBits(f);

c = (int)(l ^ (l >>> 32))

Object, where

equals() calls

c = f.hashCode()

equals() for this

field

Array

Apply above rules to each element

3. Combine the hash code(s) computed above: **result = 37 ***

result + c;

4. Return **result**.

5. Look at the resulting **hashCode()** and make sure that equal

instances have equal hash codes.

Here’s an example that follows these guidelines. Note that you

shouldn’t actually write code like this—instead, use

Objects.hash() for hashing together multiple fields (as in this

case) and **Objects.hashCode()** for hashing a single field.

```
// equalshashcode/CountedString.java
// Creating a good hashCode()
import java.util.*;
public class CountedString {
private static List<String> created =
new ArrayList<>();
private String s;
```

```
private int id = 0;
public CountedString(String str) {
s = str;
created.add(s);
// id is the total number of instances
// of this String used by CountedString:
for(String s2 : created)
if(s2.equals(s))
id++;
}
@Override
public String toString() {
return "String: " + s + " id: " + id +
" hashCode(): " + hashCode();
}
@Override
public int hashCode() {
// The very simple approach:
// return s.hashCode() * id;
// Using Joshua Bloch's recipe:
```

```
int result = 17;
result = 37 * result + s.hashCode();
result = 37 * result + id;
return result;
}
@Override
public boolean equals(Object o) {
return o instanceof CountedString &&
Objects.equals(s, ((CountedString)o).s) &&
Objects.equals(id, ((CountedString)o).id);
}
public static void main(String[] args) {
Map<CountedString,Integer> map = new HashMap<>();
CountedString[] cs = new CountedString[5];
for(int i = 0; i < cs.length; i++) {
cs[i] = new CountedString("hi");
map.put(cs[i], i); // Autobox int to Integer
}
System.out.println(map);
for(CountedString cstring : cs) {
```

```
System.out.println("Looking up " + cstring);
System.out.println(map.get(cstring));
}
}
}
/* Output:
{String: hi id: 4 hashCode(): 146450=3, String: hi id:
5 hashCode(): 146451=4, String: hi id: 2 hashCode():
146448=1, String: hi id: 3 hashCode(): 146449=2,
String: hi id: 1 hashCode(): 146447=0}
Looking up String: hi id: 1 hashCode(): 146447
0
Looking up String: hi id: 2 hashCode(): 146448
1
Looking up String: hi id: 3 hashCode(): 146449
2
Looking up String: hi id: 4 hashCode(): 146450
3
Looking up String: hi id: 5 hashCode(): 146451
4
```

*/

CountedString includes a **String** and an **id** that represents the number of **CountedString** objects containing an identical **String**. The counting is accomplished in the constructor by iterating through the **static ArrayList** where all the **String**s are stored.

Both **hashCode()** and **equals()** produce results based on both fields; if they were just based on the **String** alone or the **id** alone, there would be duplicate matches for distinct values.

In **main()**, several **CountedString** objects are created using the same **String**, to show that the duplicates create unique values because of the count **id**. The **HashMap** is displayed so you see how it is stored internally (no discernible orders). Each key is looked up individually to demonstrate that the lookup mechanism is working properly.

As a second example, consider the **Individual** class that was used as the base class for the **typeinfo.pet** library defined in the Type Information chapter. The **Individual** class was used in that chapter but the definition is delayed until this appendix so you can properly understand the implementation.

Here, instead of calculating the **hashCode()** by hand, we'll use the proper approach with **Objects.hash()**:

```
// typeinfo/pets/Individual.java
package typeinfo.pets;
import java.util.*;
public class
Individual implements Comparable<Individual> {
private static long counter = 0;
private final long id = counter++;
private String name;
public Individual(String name) { this.name = name; }
// 'name' is optional:
public Individual() {}
@Override
public String toString() {
return getClass().getSimpleName() +
(name == null ? "" : " " + name);
}
public long id() { return id; }
@Override
```

```
public boolean equals(Object o) {
return o instanceof Individual &&
Objects.equals(id, ((Individual)o).id);
}
@Override
public int hashCode() {
return Objects.hash(name, id);
}
@Override
public int compareTo(Individual arg) {
// Compare by class name first:
String first = getClass().getSimpleName();
String argFirst = arg.getClass().getSimpleName();
int firstCompare = first.compareTo(argFirst);
if(firstCompare != 0)
return firstCompare;
if(name != null && arg.name != null) {
int secondCompare = name.compareTo(arg.name);
if(secondCompare != 0)
return secondCompare;
```

}

return (arg.id < id ? -1 : (arg.id == id ? 0 : 1));

}

}

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{ 0xFF6347, "Tomato" },

{ 0x40E0D0, "Turquoise" },

{ 0xEE82EE, "Violet" },

{ 0xF5DEB3, "Wheat" },

{ 0xFFFFFF, "White" },

{ 0xF5F5F5, "WhiteSmoke" },

{ 0xFFFF00, "Yellow" },

{ 0x9ACD32, "YellowGreen" },

};

public static final Map<Integer,String> MAP =

Arrays.stream(ARRAY)

.collect(Collectors.toMap(

element -> (Integer)element[0],

element -> (String)element[1],

(v1, v2) -> { *// Merge function*

throw new IllegalStateException();

```
},
LinkedHashMap::new
));
// Inversion only works if values are unique:
public static <V, K> Map<V, K>
invert(Map<K, V> map) {
return map.entrySet().stream()
.collect(Collectors.toMap(
Map.Entry::getValue,
Map.Entry::getKey,
(v1, v2) -> {
throw new IllegalStateException();
},
LinkedHashMap::new
));
}
public static final Map<String,Integer>
INVMAP = invert(MAP);
// Look up RGB value given a name:
public static Integer rgb(String colorName) {
```

```
return INVMAP.get(colorName);
}
public static final List<String> LIST =
Arrays.stream(ARRAY)
.map(item -> (String)item[1])
.collect(Collectors.toList());
public static final List<Integer> RGBLIST =
Arrays.stream(ARRAY)
.map(item -> (Integer)item[0])
.collect(Collectors.toList());
public static
void show(Map.Entry<Integer,String> e) {
System.out.format(
"0x%06X: %s%n", e.getKey(), e.getValue());
}
public static void
show(Map<Integer,String> m, int count) {
m.entrySet().stream()
.limit(count)
.forEach(e -> show(e));
```

```
}
public static void show(Map<Integer,String> m) {
show(m, m.size());
}
public static
void show(Collection<String> lst, int count) {
lst.stream()
.limit(count)
.forEach(System.out::println);
}
public static void show(Collection<String> lst) {
show(lst, lst.size());
}
public static
void showrgb(Collection<Integer> lst, int count) {
lst.stream()
.limit(count)
.forEach(n -> System.out.format("0x%06X%n", n));
}
public static void showrgb(Collection<Integer> lst) {
```

```
showrgb(lst, lst.size());
}
public static
void showInv(Map<String,Integer> m, int count) {
m.entrySet().stream()
.limit(count)
.forEach(e ->
System.out.format(
"%-20s 0x%06X%n", e.getKey(), e.getValue()));
}
public static void showInv(Map<String,Integer> m) {
showInv(m, m.size());
}
public static void border() {
System.out.println(
"********************************");
}
}
```

MAP is created using Streams. The two-dimensional **ARRAY** is streamed into a **Map**, but notice we are not just using the simple

version of **Collectors.toMap()**. That version produces a

HashMap, which scrambles the order of the keys using a hashing function. In order to preserve the order, we must place the key-value pairs directly into a **TreeMap**, which means we use the more complex version of **Collectors.toMap()**. This takes two functions that extract the key and value from each streamed element, just like the simple **Collectors.toMap()**. Then it requires a *merge function*, which resolves collisions between two values associated with the same key. Our data is pre-vetted so this should never happen and we throw an exception if it does. Finally we pass the function that produces an empty map of our desired type, which is then filled by the stream.

The **rgb()** method is a convenience function that takes a color name **String** and produces its numerical RGB value. To achieve this, we need an *inverted* version of **COLORS** which takes a **String** key and looks up an RGB **Integer** value. This is achieved through the **invert()** method, which throws an exception if any of the **COLORS** values are not unique.

We also create **LIST**, containing all the names, and **RGBLIST**, containing the RGB values in hex notation.

The first **show()** method takes a single **Map.Entry** and displays the key in hex notation to enable easy double-checking against the original

ARRAY. Each of the methods with names that start with **show** are overloaded with one version taking a **count** argument to indicate how many elements you want to display, and the second version displaying all the elements in the sequence.

Here's a basic test:

```
// collectiontopics/HTMLColorTest.java
import static onjava.HTMLColors.*;
public class HTMLColorTest {
static final int DISPLAY_SIZE = 20;
public static void main(String[] args) {
show(MAP, DISPLAY_SIZE);
border();
showInv(INVMAP, DISPLAY_SIZE);
border();
show(LIST, DISPLAY_SIZE);
border();
showrgb(RGBLIST, DISPLAY_SIZE);
}
}
/* Output:
```

0xF0F8FF: AliceBlue

0xFAEBD7: AntiqueWhite

0x7FFFD4: Aquamarine

0xF0FFFF: Azure

0xF5F5DC: Beige

0xFFE4C4: Bisque

0x000000: Black

0xFFEBCD: BlanchedAlmond

0x0000FF: Blue

0x8A2BE2: BlueViolet

0xA52A2A: Brown

0xDEB887: BurlyWood

0x5F9EA0: CadetBlue

0x7FFF00: Chartreuse

0xD2691E: Chocolate

0xFF7F50: Coral

0x6495ED: CornflowerBlue

0xFFF8DC: Cornsilk

0xDC143C: Crimson

0x00FFFF: Cyan

****

AliceBlue 0xF0F8FF

AntiqueWhite 0xFAEBD7

Aquamarine 0x7FFFD4

Azure 0xF0FFFF

Beige 0xF5F5DC

Bisque 0xFFE4C4

Black 0x000000

BlanchedAlmond 0xFFEBCD

Blue 0x0000FF

BlueViolet 0x8A2BE2

Brown 0xA52A2A

BurlyWood 0xDEB887

CadetBlue 0x5F9EA0

Chartreuse 0x7FFF00

Chocolate 0xD2691E

Coral 0xFF7F50

CornflowerBlue 0x6495ED

Cornsilk 0xFFF8DC

Crimson 0xDC143C

Cyan 0x00FFFF

****

AliceBlue

AntiqueWhite

Aquamarine

Azure

Beige

Bisque

Black

BlanchedAlmond

Blue

BlueViolet

Brown

BurlyWood

CadetBlue

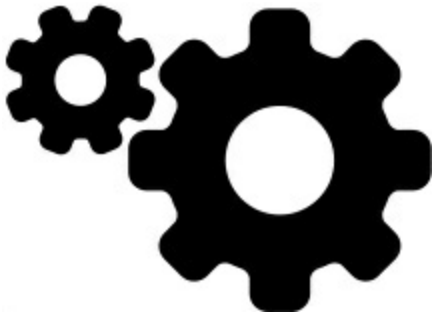
Chartreuse

Chocolate

Coral

CornflowerBlue

Cornsilk



Crimson

Cyan

****

0xF0F8FF

0xFAEBD7

0x7FFFD4

0xF0FFFF

0xF5F5DC

0xFFE4C4

0x000000

0xFFEBCD

0x0000FF

0x8A2BE2

0xA52A2A

0xDEB887

0x5F9EA0

0x7FFF00

0xD2691E

0xFF7F50

0x6495ED

0xFFF8DC

0xDC143C

0x00FFFF

/

Using a **LinkedHashMap**, we are indeed able to preserve the order of **HTMLColors.ARRAY**.

List Behavior

Lists are the most fundamental way to store and retrieve objects (after arrays). Basic List operations include:

add() to insert elements

get() for random-access selection of elements

iterator() to get an **Iterator** over the sequence

stream() to produce a **Stream** of elements

List constructors always preserve the order the elements are added.

The methods in the following example each cover a different group of activities: things that every **List** can do (**basicTest()**), moving

around with an **Iterator** (**iterMotion()**) versus changing things with an **Iterator** (**iterManipulation()**), seeing the effects of **List** manipulation (**testVisual()**), and operations available only to **LinkedList**s:

```
// collectiontopics/ListOps.java
// Things you can do with Lists
import java.util.*;
import onjava.HTMLColors;
public class ListOps {
// Create a short list for testing:
static final List<String> LIST =
HTMLColors.LIST.subList(0, 10);
private static boolean b;
private static String s;
private static int i;
private static Iterator<String> it;
private static ListIterator<String> lit;
public static void basicTest(List<String> a) {
a.add(1, "x"); // Add at location 1
a.add("x"); // Add at end
```

```
// Add a collection:
a.addAll(LIST);
// Add a collection starting at location 3:
a.addAll(3, LIST);
b = a.contains("1"); // Is it in there?
// Is the entire collection in there?
b = a.containsAll(LIST);
// Lists allow random access, which is cheap
// for ArrayList, expensive for LinkedList:
s = a.get(1); // Get (typed) object at location 1
i = a.indexOf("1"); // Tell index of object
b = a.isEmpty(); // Any elements inside?
it = a.iterator(); // Ordinary Iterator
lit = a.listIterator(); // ListIterator
lit = a.listIterator(3); // Start at location 3
i = a.lastIndexOf("1"); // Last match
a.remove(1); // Remove location 1
a.remove("3"); // Remove this object
a.set(1, "y"); // Set location 1 to "y"
// Keep everything that's in the argument
```

```
// (the intersection of the two sets):
a.retainAll(LIST);
// Remove everything that's in the argument:
a.removeAll(LIST);
i = a.size(); // How big is it?
a.clear(); // Remove all elements
}
public static void iterMotion(List<String> a) {
ListIterator<String> it = a.listIterator();
b = it.hasNext();
b = it.hasPrevious();
s = it.next();
i = it.nextIndex();
s = it.previous();
i = it.previousIndex();
}
public static void iterManipulation(List<String> a) {
ListIterator<String> it = a.listIterator();
it.add("47");
// Must move to an element after add():
```

```
it.next();
// Remove the element after the new one:
it.remove();
// Must move to an element after remove():
it.next();
// Change the element after the deleted one:
it.set("47");
}
public static void testVisual(List<String> a) {
System.out.println(a);
List<String> b = LIST;
System.out.println("b = " + b);
a.addAll(b);
a.addAll(b);
System.out.println(a);
// Insert, remove, and replace elements
// using a ListIterator:
ListIterator<String> x =
a.listIterator(a.size()/2);
x.add("one");
```

```
System.out.println(a);
System.out.println(x.next());
x.remove();
System.out.println(x.next());
x.set("47");
System.out.println(a);
// Traverse the list backwards:
x = a.listIterator(a.size());
while(x.hasPrevious())
System.out.print(x.previous() + " ");
System.out.println();
System.out.println("testVisual finished");
}
// There are some things that only LinkedLists can do:
public static void testLinkedList() {
LinkedList<String> ll = new LinkedList<>();
ll.addAll(LIST);
System.out.println(ll);
// Treat it like a stack, pushing:
ll.addFirst("one");
```

```
ll.addFirst("two");
System.out.println(ll);
// Like "peeking" at the top of a stack:
System.out.println(ll.getFirst());
// Like popping a stack:
System.out.println(ll.removeFirst());
System.out.println(ll.removeFirst());
// Treat it like a queue, pulling elements
// off the tail end:
System.out.println(ll.removeLast());
System.out.println(ll);
}
public static void main(String[] args) {
// Make and fill a new list each time:
basicTest(new LinkedList<>(LIST));
basicTest(new ArrayList<>(LIST));
iterMotion(new LinkedList<>(LIST));
iterMotion(new ArrayList<>(LIST));
iterManipulation(new LinkedList<>(LIST));
iterManipulation(new ArrayList<>(LIST));
```

```
testVisual(new LinkedList<>(LIST));
testLinkedList();
}
}
/* Output:
[AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige,
Bisque, Black, BlanchedAlmond, Blue, BlueViolet]
b = [AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige,
Bisque, Black, BlanchedAlmond, Blue, BlueViolet]
[AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige,
Bisque, Black, BlanchedAlmond, Blue, BlueViolet,
AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige,
Bisque, Black, BlanchedAlmond, Blue, BlueViolet,
AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige,
Bisque, Black, BlanchedAlmond, Blue, BlueViolet]
[AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige,
Bisque, Black, BlanchedAlmond, Blue, BlueViolet,
AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige, one,
Bisque, Black, BlanchedAlmond, Blue, BlueViolet,
AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige,
```

Bisque, Black, BlanchedAlmond, Blue, BlueViolet]

Bisque

Black

[AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige,

Bisque, Black, BlanchedAlmond, Blue, BlueViolet,

AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige, one,

47, BlanchedAlmond, Blue, BlueViolet, AliceBlue,

AntiqueWhite, Aquamarine, Azure, Beige, Bisque, Black,

BlanchedAlmond, Blue, BlueViolet]

BlueViolet Blue BlanchedAlmond Black Bisque Beige Azure

Aquamarine AntiqueWhite AliceBlue BlueViolet Blue

BlanchedAlmond 47 one Beige Azure Aquamarine

AntiqueWhite AliceBlue BlueViolet Blue BlanchedAlmond

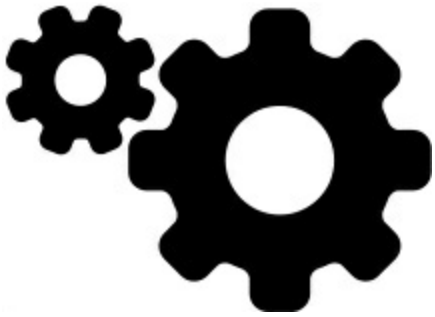
Black Bisque Beige Azure Aquamarine AntiqueWhite

AliceBlue

testVisual finished

[AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige,

Bisque, Black, BlanchedAlmond, Blue, BlueViolet]



[two, one, AliceBlue, AntiqueWhite, Aquamarine, Azure,

Beige, Bisque, Black, BlanchedAlmond, Blue, BlueViolet]

two

two

one

BlueViolet

[AliceBlue, AntiqueWhite, Aquamarine, Azure, Beige,

Bisque, Black, BlanchedAlmond, Blue]

**/*

In **basicTest()** and **iterMotion()** the calls are made to show the proper syntax, and although the return value is captured, it is not used. In some cases, the return value isn't captured at all. Look up the full usage of each of these methods in the JDK documentation before you use them.

Set Behavior

The point of a **Set** is to test for membership, although you can also

use it as a tool to remove duplicate elements. If you don’t care about element order or concurrency, **HashSet** is always your best bet because it is designed for the fastest possible lookup (using the *hashing function* we explored in the Appendix: Understanding **equals()** and **hashCode()**).

Additional **Set** implementations produce different ordering behavior:

```
// collectiontopics/SetOrder.java
import java.util.*;
import onjava.HTMLColors;
public class SetOrder {
static String[] sets = {
"java.util.HashSet",
"java.util.TreeSet",
"java.util.concurrent.ConcurrentSkipListSet",
"java.util.LinkedHashSet",
"java.util.concurrent.CopyOnWriteArraySet",
};
static final List<String> RLIST =
new ArrayList<>(HTMLColors.LIST);
static {
```

```
Collections.reverse(RLIST);
}
public static void
main(String[] args) throws Exception {
for(String type: sets) {
System.out.format("[-> %s <-]%n",
type.substring(type.lastIndexOf('.') + 1));
@SuppressWarnings("unchecked")
Set<String> set = (Set<String>)
Class.forName(type).newInstance();
set.addAll(RLIST);
set.stream()
.limit(10)
.forEach(System.out::println);
}
}
}
/* Output:
[-> HashSet <-]
MediumOrchid
```

PaleGoldenRod

Sienna

LightSlateGray

DarkSeaGreen

Black

Gainsboro

Orange

LightCoral

DodgerBlue

[-> TreeSet <-]

AliceBlue

AntiqueWhite

Aquamarine

Azure

Beige

Bisque

Black

BlanchedAlmond

Blue

BlueViolet

[-> ConcurrentSkipListSet <-]

AliceBlue

AntiqueWhite

Aquamarine

Azure

Beige

Bisque

Black

BlanchedAlmond

Blue

BlueViolet

[-> LinkedHashSet <-]

YellowGreen

Yellow

WhiteSmoke

White

Wheat

Violet

Turquoise

Tomato

Thistle

Teal

[-> CopyOnWriteArraySet <-]

YellowGreen

Yellow

WhiteSmoke

White

Wheat

Violet

Turquoise

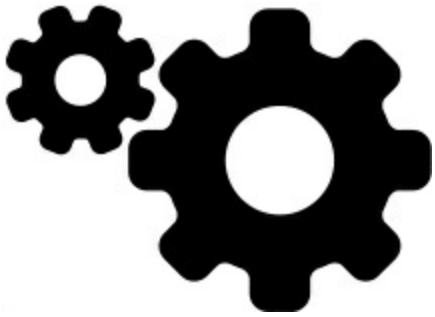
Tomato

Thistle

Teal

**/*

We need **@SuppressWarnings("unchecked")** here because we pass a **String**, which could be anything, to **Class.forName(type).newInstance()**. The compiler can’t



guarantee this is a successful operation.

RLIST is a reversed version of **HTMLColors.LIST**. Because **Collections.reverse()** performs the reverse by modifying the argument (instead of returning a new **List** containing reversed elements), that call is performed inside a **static** clause. **RLIST** prevents us from accidentally thinking that a **Set** sorts its results. The **HashSet** output appears to have no discernible order (because it's based on the hash function). Both **TreeSet** and **ConcurrentSkipListSet** have sorted their elements, and they implement the **SortedSet** interface to indicate this; that interface also has further operations available because the **Set** is in sorted order. **LinkedHashSet** and **CopyOnWriteArraySet** preserve the order of the elements as they are added, although there is no interface to indicate this.

ConcurrentSkipListSet and **CopyOnWriteArraySet** are thread safe.

At the end of the appendix we'll find out the performance cost of the additional ordering imposed on non-**HashSet** implementations, along with the cost of any other functionality in the different implementations.

Using Functional Operations with any Map

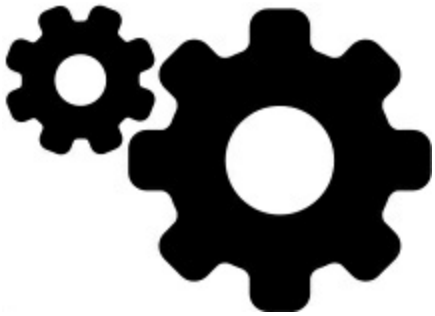
Just as with the **Collection** interface, **forEach()** is built into the **Map** interface. But what if you want to perform any of the other basic functional operations: **map()**, **flatMap()**, **reduce()** or **filter()**? When you look at the **Map** interface, there's no hint of these.

You connect to these methods through **entrySet()**, which produces a **Set** of **Map.Entry** objects. This **Set**, in turn, contains **stream()** and **parallelStream()** methods. The only thing you must remember is that you're working with **Map.Entry** objects:

```
// collectiontopics/FunctionalMap.java
// Functional operations on a Map
import java.util.*;
import java.util.stream.*;
import java.util.concurrent.*;
```

```
import static onjava.HTMLColors.*;
public class FunctionalMap {
public static void main(String[] args) {
MAP.entrySet().stream()
.map(Map.Entry::getValue)
.filter(v -> v.startsWith("Dark"))
.map(v -> v.replaceFirst("Dark", "Hot"))
.forEach(System.out::println);
}
}
/* Output:
HotBlue
HotCyan
HotGoldenRod
HotGray
HotGreen
HotKhaki
HotMagenta
HotOliveGreen
HotOrange
```

HotOrchid



HotRed

HotSalmon

HotSeaGreen

HotSlateBlue

HotSlateGray

HotTurquoise

HotViolet

*/

Once you produce a **Stream**, all the basic functional methods (and more) become available.

Selecting Parts of a Map

The **NavigableMap** interface, implemented by **TreeMap** and **ConcurrentSkipListMap**, solves problems that require selecting portions of a **Map**. Here's an example utilizing **HTMLColors**:

// collectiontopics/NavMap.java

```
// NavigableMap produces pieces of a Map
import java.util.*;
import java.util.concurrent.*;
import static onjava.HTMLColors.*;
public class NavMap {
public static final
NavigableMap<Integer,String> COLORS =
new ConcurrentSkipListMap<>(MAP);
public static void main(String[] args) {
show(COLORS.firstEntry());
border();
show(COLORS.lastEntry());
border();
NavigableMap<Integer, String> toLime =
COLORS.headMap(rgb("Lime"), true);
show(toLime);
border();
show(COLORS.ceilingEntry(rgb("DeepSkyBlue") - 1));
border();
show(COLORS.floorEntry(rgb("DeepSkyBlue") - 1));
```

```
border();
show(toLime.descendingMap());
border();
show(COLORS.tailMap(rgb("MistyRose"), true));
border();
show(COLORS.subMap(
rgb("Orchid"), true,
rgb("DarkSalmon"), false));
}
}
/* Output:
0x000000: Black
*******************************
0xFFFFFF: White
*******************************
0x000000: Black
0x000080: Navy
0x00008B: DarkBlue
0x0000CD: MediumBlue
0x0000FF: Blue
```

0x006400: DarkGreen

0x008000: Green

0x008080: Teal

0x008B8B: DarkCyan

0x00BFFF: DeepSkyBlue

0x00CED1: DarkTurquoise

0x00FA9A: MediumSpringGreen

0x00FF00: Lime

****

0x00BFFF: DeepSkyBlue

****

0x008B8B: DarkCyan

****

0x00FF00: Lime

0x00FA9A: MediumSpringGreen

0x00CED1: DarkTurquoise

0x00BFFF: DeepSkyBlue

0x008B8B: DarkCyan

0x008080: Teal

0x008000: Green

0x006400: DarkGreen

0x0000FF: Blue

0x0000CD: MediumBlue

0x00008B: DarkBlue

0x000080: Navy

0x000000: Black

****

0xFFE4E1: MistyRose

0xFFEBCD: BlanchedAlmond

0xFFEFD5: PapayaWhip

0xFFF0F5: LavenderBlush

0xFFF5EE: SeaShell

0xFFF8DC: Cornsilk

0xFFFACD: LemonChiffon

0xFFFAF0: FloralWhite

0xFFFAFA: Snow

0xFFFF00: Yellow

0xFFFFE0: LightYellow

0xFFFFF0: Ivory

0xFFFFFF: White

****

0xDA70D6: Orchid

0xDAA520: GoldenRod

0xDB7093: PaleVioletRed

0xDC143C: Crimson

0xDCDCDC: Gainsboro

0xDDA0DD: Plum

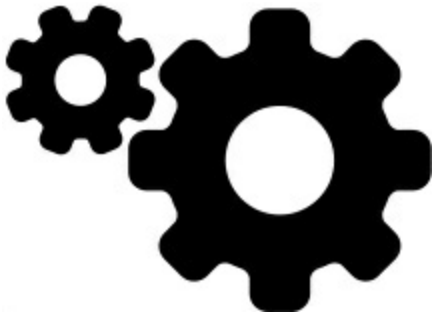
0xDEB887: BurlyWood

0xE0FFFF: LightCyan

0xE6E6FA: Lavender

*/

In **main()**, you see various features of a **NavigableMap**. Because a **NavigableMap** has a key order, it enables the concept of a **firstEntry()** and **lastEntry()**. Calling **headMap()** produces a **NavigableMap** containing the elements starting from the beginning of the **Map** up to the argument to **headMap()**, with the **boolean** value indicating whether to include the argument. Calling **tailMap()** performs a similar operation, but at the end of the **Map**.



subMap() allows you to produce a section of the **Map** from the middle.

ceilingEntry() searches upward from the key value to the next entry, and **floorEntry()** searches downward.

descendingMap() reverses the order of the **NavigableMap**.

If the problem you're solving is simplified by slicing up a **Map**, **NavigableMap** does the trick. Other collection implementations have similar features that can also help your problem-solving process.

Filling Collections

Just as with **Arrays**, there is a companion class called **Collections** containing **static** utility methods, including one called **fill()**. **fill()** just duplicates a single object reference throughout the collection. In addition, it only works for **List** objects, but the resulting list can be passed to a constructor or to an **addAll()** method:

// collectiontopics/FillingLists.java

```
// Collections.fill() & Collections.nCopies()
import java.util.*;
class StringAddress {
private String s;
StringAddress(String s) { this.s = s; }
@Override
public String toString() {
return super.toString() + " " + s;
}
}
```

```
public class FillingLists {
public static void main(String[] args) {
List<StringAddress> list = new ArrayList<>(
Collections.nCopies(4,
new StringAddress("Hello")));
System.out.println(list);
Collections.fill(list,
```

```
new StringAddress("World!"));
System.out.println(list);
}
}
/* Output:
[StringAddress@15db9742 Hello, StringAddress@15db9742
Hello, StringAddress@15db9742 Hello,
StringAddress@15db9742 Hello]
[StringAddress@6d06d69c World!, StringAddress@6d06d69c
World!, StringAddress@6d06d69c World!,
StringAddress@6d06d69c World!]
*/
```

This example shows two ways to fill a **Collection** with references to a single object. The first, **Collections.nCopies()**, creates a **List** which is passed to the constructor; this fills the **ArrayList**. The **toString()** method in **StringAddress** calls **Object.toString()**, which produces the class name followed by the unsigned hexadecimal representation of the hash code of the object (generated by the **hashCode()** method). The output shows that all references are set to the same object, and this is also true after

calling the second method, **Collections.fill()**. The **fill()**

method is made even less useful by the fact it can only replace

elements already in the **List**, and will not add new elements.

Using Suppliers to Fill a

Collection

The **onjava.Suppliers** class introduced in the Generics chapter provides a universal solution for filling **Collections**. Here's an

example that initializes several different types of **Collection** using

Suppliers:

```
// collectiontopics/SuppliersCollectionTest.java

import java.util.*;

import java.util.function.*;

import java.util.stream.*;

import onjava.*;

class Government implements Supplier<String> {

static String[] foundation = (

"strange women lying in ponds " +

"distributing swords is no basis " +

"for a system of government").split(" ");

private int index;

@Override
```

```
public String get() {
return foundation[index++];
}
}
public class SuppliersCollectionTest {
public static void main(String[] args) {
// Suppliers class from the Generics chapter:
Set<String> set = Suppliers.create(
LinkedHashSet::new, new Government(), 15);
System.out.println(set);
List<String> list = Suppliers.create(
LinkedList::new, new Government(), 15);
System.out.println(list);
list = new ArrayList<>();
Suppliers.fill(list, new Government(), 15);
System.out.println(list);
// Or we can use Streams:
set = Arrays.stream(Government.foundation)
.collect(Collectors.toSet());
System.out.println(set);
```

```
list = Arrays.stream(Government.foundation)
.collect(Collectors.toList());
System.out.println(list);
list = Arrays.stream(Government.foundation)
.collect(Collectors
.toCollection(LinkedList::new));
System.out.println(list);
set = Arrays.stream(Government.foundation)
.collect(Collectors
.toCollection(LinkedHashSet::new));
System.out.println(set);
}
}
/* Output:
[strange, women, lying, in, ponds, distributing,
swords, is, no, basis, for, a, system, of, government]
[strange, women, lying, in, ponds, distributing,
swords, is, no, basis, for, a, system, of, government]
[strange, women, lying, in, ponds, distributing,
swords, is, no, basis, for, a, system, of, government]
```

[ponds, no, a, in, swords, for, is, basis, strange,

system, government, distributing, of, women, lying]

[strange, women, lying, in, ponds, distributing,

swords, is, no, basis, for, a, system, of, government]

[strange, women, lying, in, ponds, distributing,

swords, is, no, basis, for, a, system, of, government]

[strange, women, lying, in, ponds, distributing,

swords, is, no, basis, for, a, system, of, government]

**/*

The elements of the **LinkedHashSet** are in insertion order because it maintains a linked list to hold that order.

Notice, however, the second part of the example: much of the time you can just use **Stream**s to create and fill a **Collection**. And here, the **Stream** version doesn't require us to state the number of elements we want created as the **Supplier** version does; it just absorbs all the **Stream** elements.

The **Stream** solution is preferred whenever possible.

Map Suppliers

Populating a **Map** with data using a **Supplier** requires a **Pair** class since a pair of objects (one key and one value) must be produced by each call to a **Supplier**s **get()**:

```
// onjava/Pair.java
package onjava;
public class Pair<K, V> {
public final K key;
public final V value;
public Pair(K k, V v) {
key = k;
value = v;
}
public K key() { return key; }
public V value() { return value; }
public static <K,V> Pair<K, V> make(K k, V v) {
return new Pair<K,V>(k, v);
}
}
```

Pair is a read-only *Data Transfer Object* or *Messenger*. This is

basically the same as **Tuple2** from the Generics chapter, but the name is more appropriate for **Map** initialization. I've also added the

static make() method to provide a simpler shorthand for

creating **Pair** objects.

Java 8 **Stream**s provide convenient ways to produce filled **Map**s:

```
// collectiontopics/StreamFillMaps.java

import java.util.*;

import java.util.function.*;

import java.util.stream.*;

import onjava.*;

class Letters

implements Supplier<Pair<Integer,String>> {

private int number = 1;

private char letter = 'A';

@Override

public Pair<Integer,String> get() {

return new Pair<>(number++, "" + letter++);

}

}

public class StreamFillMaps {

public static void main(String[] args) {
```

```
Map<Integer,String> m =
Stream.generate(new Letters())
.limit(11)
.collect(Collectors
.toMap(Pair::key, Pair::value));
System.out.println(m);
// Two separate Suppliers:
Rand.String rs = new Rand.String(3);
Count.Character cc = new Count.Character();
Map<Character,String> mcs = Stream.generate(
() -> Pair.make(cc.get(), rs.get()))
.limit(8)
.collect(Collectors
.toMap(Pair::key, Pair::value));
System.out.println(mcs);
// A key Supplier and a single value:
Map<Character,String> mcs2 = Stream.generate(
() -> Pair.make(cc.get(), "Val"))
.limit(8)
.collect(Collectors
```

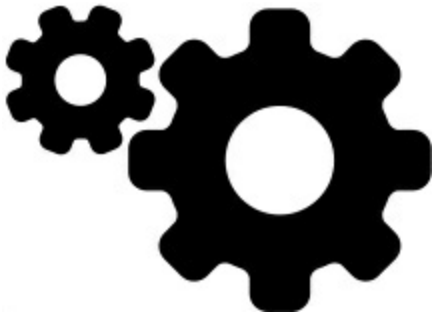
```
.toMap(Pair::key, Pair::value));
System.out.println(mcs2);
}
}
/* Output:
{1=A, 2=B, 3=C, 4=D, 5=E, 6=F, 7=G, 8=H, 9=I, 10=J,
11=K}
{b=btp, c=enp, d=ccu, e=xsz, f=gvg, g=mei, h=nne,
i=elo}
{p=Val, q=Val, j=Val, k=Val, l=Val, m=Val, n=Val,
o=Val}
*/
```

A pattern emerges in the above example, which we can use to create a tool that automatically creates and fills **Map**s:

```
// onjava/FillMap.java
package onjava;
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
public class FillMap {
```

```
public static <K, V> Map<K,V>
basic(Supplier<Pair<K,V>> pairGen, int size) {
return Stream.generate(pairGen)
.limit(size)
.collect(Collectors
.toMap(Pair::key, Pair::value));
}
public static <K, V> Map<K,V>
basic(Supplier<K> keyGen,
Supplier<V> valueGen, int size) {
return Stream.generate(
() -> Pair.make(keyGen.get(), valueGen.get()))
.limit(size)
.collect(Collectors
.toMap(Pair::key, Pair::value));
}
public static <K, V, M extends Map<K,V>>
M create(Supplier<K> keyGen,
Supplier<V> valueGen,
Supplier<M> mapSupplier, int size) {
```

```
return Stream.generate( () ->
Pair.make(keyGen.get(), valueGen.get()))
.limit(size)
.collect(Collectors
.toMap(Pair::key, Pair::value,
(k, v) -> k, mapSupplier));
}
```



```
}
```

The **basic()** method produces a default **Map**, while **create()** allows you to specify an exact type of map, and it returns that exact type.

Here's a test:

```
// collectiontopics/FillMapTest.java
import java.util.*;
import java.util.function.*;
import java.util.stream.*;
```

```
import onjava.*;
public class FillMapTest {
public static void main(String[] args) {
Map<String,Integer> mcs = FillMap.basic(
new Rand.String(4), new Count.Integer(), 7);
System.out.println(mcs);
HashMap<String,Integer> hashm =
FillMap.create(new Rand.String(4),
new Count.Integer(), HashMap::new, 7);
System.out.println(hashm);
LinkedHashMap<String,Integer> linkm =
FillMap.create(new Rand.String(4),
new Count.Integer(), LinkedHashMap::new, 7);
System.out.println(linkm);
}
}
/* Output:
{npcc=1, ztdv=6, gvgm=3, btpe=0, einn=4, eelo=5,
uxsz=2}
{npcc=1, ztdv=6, gvgm=3, btpe=0, einn=4, eelo=5,
```

uxsz=2}

{btpe=0, npcc=1, uxsz=2, gvgm=3, einn=4, eelo=5,

ztdv=6}

**/*

Custom Collection and

Map using *Flyweight*

This section shows how to create custom **Collection** and **Map** implementations. Each **java.util** collection has its own **Abstract** class providing a partial implementation of that collection, so you need only implement the necessary methods to produce the desired collection. You'll see how relatively simple it is to create a custom **Map** and **Collection** by inheriting from the **java.util.Abstract** classes. For example, to create a read-only **Set**, you inherit from **AbstractSet** and implement **iterator()** and **size()**. The last example is an alternate way to produce test data. The resulting collection is typically read-only, and the number of methods you provide is minimized.

This solution also demonstrates the *Flyweight* design pattern. You use a flyweight when the ordinary solution requires too many objects, or when producing normal objects takes up too much space. The

Flyweight pattern externalizes part of the object. Instead of everything in the object being contained within the object, some or all of the object is looked up in a more efficient external table (or produced through some other calculation that saves space).

Here is a **List** that can be any size, and is (effectively) pre-initialized with **Integer** data. To create a read-only **List** from an **AbstractList**, you must implement **get()** and **size()**:

```
// onjava/CountingIntegerList.java
// List of any length, containing sample data
// {java onjava.CountingIntegerList}
package onjava;
import java.util.*;
public class CountingIntegerList
extends AbstractList<Integer> {
private int size;
public CountingIntegerList() { size = 0; }
public CountingIntegerList(int size) {
this.size = size < 0 ? 0 : size;
}
@Override
```

```
public Integer get(int index) {
return index;
}
@Override
public int size() { return size; }
public static void main(String[] args) {
List<Integer> cil =
new CountingIntegerList(30);
System.out.println(cil);
System.out.println(cil.get(500));
}
}
/* Output:
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15,
16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29]
500
*/
```

The value of **size** is only important if you want to “limit the length” of the **List**, as we do in **main()**. Even in that case, **get()** will produce any value.

This class is a clear example of flyweight. **get()** “calculates” the value when you ask for it, so there’s no actual underlying **List** structure that requires storage and initialization.

The storage saved here would never make a difference in most programs. However, it allows you to call **List.get()** using a very large **index** without requiring a **List** populated with all those values. Also, you can use a very large number of **CountingIntegerList**s in your program without worrying about storage. Indeed, one of the benefits of flyweight is it allows you to use nicer abstractions without concern for resources.

We can use flyweight to implement other “initialized” custom collections with a data set of any size. Here is a **Map** that produces a unique value for every **Integer** key:

```
// onjava/CountMap.java
// Unlimited-length Map containing sample data
// {java onjava.CountMap}
package onjava;
import java.util.*;
import java.util.stream.*;
public class CountMap
extends AbstractMap<Integer,String> {
```

```
private int size;
private static char[] chars =
"ABCDEFGHIJKLMNOPQRSTUVWXYZ".toCharArray();
private static String value(int key) {
return
chars[key % chars.length] +
Integer.toString(key / chars.length);
}
public CountMap(int size) {
this.size = size < 0 ? 0 : size;
}
@Override
public String get(Object key) {
return value((Integer)key);
}
private static class Entry
implements Map.Entry<Integer,String> {
int index;
Entry(int index) { this.index = index; }
@Override
```

```
public boolean equals(Object o) {
return o instanceof Entry &&
Objects.equals(index, ((Entry)o).index);
}
@Override
public Integer getKey() { return index; }
@Override
public String getValue() {
return value(index);
}
@Override
public String setValue(String value) {
throw new UnsupportedOperationException();
}
@Override
public int hashCode() {
return Objects.hashCode(index);
}
}
@Override
```

```
public Set<Map.Entry<Integer,String>> entrySet() {
// LinkedHashSet retains initialization order:
return IntStream.range(0, size)
.mapToObj(Entry::new)
.collect(Collectors
.toCollection(LinkedHashSet::new));
}
public static void main(String[] args) {
final int size = 6;
CountMap cm = new CountMap(60);
System.out.println(cm);
System.out.println(cm.get(500));
cm.values().stream()
.limit(size)
.forEach(System.out::println);
System.out.println();
new Random(47).ints(size, 0, 1000)
.mapToObj(cm::get)
.forEach(System.out::println);
}
```

}

/ Output:*

{0=A0, 1=B0, 2=C0, 3=D0, 4=E0, 5=F0, 6=G0, 7=H0, 8=I0,

9=J0, 10=K0, 11=L0, 12=M0, 13=N0, 14=O0, 15=P0, 16=Q0,

17=R0, 18=S0, 19=T0, 20=U0, 21=V0, 22=W0, 23=X0, 24=Y0,

25=Z0, 26=A1, 27=B1, 28=C1, 29=D1, 30=E1, 31=F1, 32=G1,

33=H1, 34=I1, 35=J1, 36=K1, 37=L1, 38=M1, 39=N1, 40=O1,

41=P1, 42=Q1, 43=R1, 44=S1, 45=T1, 46=U1, 47=V1, 48=W1,

49=X1, 50=Y1, 51=Z1, 52=A2, 53=B2, 54=C2, 55=D2, 56=E2,

57=F2, 58=G2, 59=H2}

G19

A0

B0

C0

D0

E0

F0

Y9

J21

R26

D33

Z36

N16

/

To create a read-only **Map**, you inherit from **AbstractMap** and implement **entrySet()**. The **private value()** method performs the calculation of the value for any key, and is used within **get()** and **Entry.getValue()**. The size of a **CountMap** is negligible.

A **LinkedHashSet** is used instead of creating a custom **Set** class, so the flyweight is not fully implemented. This object is only produced if you call **entrySet()**.

Now we'll create a more complex flyweight. The data set in this example is a **Map** of the countries of the world and their capitals. The **capitals()** method produces a **Map** of countries and capitals. The **names()** method produces a **List** of the country names. Both methods provide a partial listing when given an **int** argument indicating the desired size:

// onjava/Countries.java

// "Flyweight" Maps and Lists of sample data

```
// {java onjava.Countries}
package onjava;
import java.util.*;
public class Countries {
public static final String[][] DATA = {
// Africa
{"ALGERIA","Algiers"},
{"ANGOLA","Luanda"},
{"BENIN","Porto-Novo"},
{"BOTSWANA","Gaberone"},
{"BURKINA FASO","Ouagadougou"},
{"BURUNDI","Bujumbura"},
{"CAMEROON","Yaounde"},
{"CAPE VERDE","Praia"},
{"CENTRAL AFRICAN REPUBLIC","Bangui"},
{"CHAD","N'djamena"},
{"COMOROS","Moroni"},
{"CONGO","Brazzaville"},
{"DJIBOUTI","Dijibouti"},
{"EGYPT","Cairo"},
```

{"EQUATORIAL GUINEA","Malabo"},

{"ERITREA","Asmara"},

{"ETHIOPIA","Addis Ababa"},

{"GABON","Libreville"},

{"THE GAMBIA","Banjul"},

{"GHANA","Accra"},

{"GUINEA","Conakry"},

{"BISSAU","Bissau"},

{"COTE D'IVOIR (IVORY COAST)","Yamoussoukro"},

{"KENYA","Nairobi"},

{"LESOTHO","Maseru"},

{"LIBERIA","Monrovia"},

{"LIBYA","Tripoli"},

{"MADAGASCAR","Antananarivo"},

{"MALAWI","Lilongwe"},

{"MALI","Bamako"},

{"MAURITANIA","Nouakchott"},

{"MAURITIUS","Port Louis"},

{"MOROCCO","Rabat"},

{"MOZAMBIQUE","Maputo"},

{"NAMIBIA","Windhoek"},

{"NIGER","Niamey"},

{"NIGERIA","Abuja"},

{"RWANDA","Kigali"},

{"SAO TOME E PRINCIPE","Sao Tome"},

{"SENEGAL","Dakar"},

{"SEYCHELLES","Victoria"},

{"SIERRA LEONE","Freetown"},

{"SOMALIA","Mogadishu"},

{"SOUTH AFRICA","Pretoria/Cape Town"},

{"SUDAN","Khartoum"},

{"SWAZILAND","Mbabane"},

{"TANZANIA","Dodoma"},

{"TOGO","Lome"},

{"TUNISIA","Tunis"},

{"UGANDA","Kampala"},

{"DEMOCRATIC REPUBLIC OF THE CONGO (ZAIRE)",

"Kinshasa"},

{"ZAMBIA","Lusaka"},

{"ZIMBABWE","Harare"},

// Asia

{"AFGHANISTAN","Kabul"},

{"BAHRAIN","Manama"},

{"BANGLADESH","Dhaka"},

{"BHUTAN","Thimphu"},

{"BRUNEI","Bandar Seri Begawan"},

{"CAMBODIA","Phnom Penh"},

{"CHINA","Beijing"},

{"CYPRUS","Nicosia"},

{"INDIA","New Delhi"},

{"INDONESIA","Jakarta"},

{"IRAN","Tehran"},

{"IRAQ","Baghdad"},

{"ISRAEL","Jerusalem"},

{"JAPAN","Tokyo"},

{"JORDAN","Amman"},

{"KUWAIT","Kuwait City"},

{"LAOS","Vientiane"},

{"LEBANON","Beirut"},

{"MALAYSIA","Kuala Lumpur"},

{"THE MALDIVES","Male"},

{"MONGOLIA","Ulan Bator"},

{"MYANMAR (BURMA)","Rangoon"},

{"NEPAL","Katmandu"},

{"NORTH KOREA","P'yongyang"},

{"OMAN","Muscat"},

{"PAKISTAN","Islamabad"},

{"PHILIPPINES","Manila"},

{"QATAR","Doha"},

{"SAUDI ARABIA","Riyadh"},

{"SINGAPORE","Singapore"},

{"SOUTH KOREA","Seoul"},

{"SRI LANKA","Colombo"},

{"SYRIA","Damascus"},

{"TAIWAN (REPUBLIC OF CHINA)","Taipei"},

{"THAILAND","Bangkok"},

{"TURKEY","Ankara"},

{"UNITED ARAB EMIRATES","Abu Dhabi"},

{"VIETNAM","Hanoi"},

{"YEMEN","Sana'a"},

// Australia and Oceania

{"AUSTRALIA","Canberra"},

{"FIJI","Suva"},

{"KIRIBATI","Bairiki"},

{"MARSHALL ISLANDS","Dalap-Uliga-Darrit"},

{"MICRONESIA","Palikir"},

{"NAURU","Yaren"},

{"NEW ZEALAND","Wellington"},

{"PALAU","Koror"},

{"PAPUA NEW GUINEA","Port Moresby"},

{"SOLOMON ISLANDS","Honaira"},

{"TONGA","Nuku'alofa"},

{"TUVALU","Fongafale"},

{"VANUATU","Port Vila"},

{"WESTERN SAMOA","Apia"},

// Eastern Europe and former USSR

{"ARMENIA","Yerevan"},

{"AZERBAIJAN","Baku"},

{"BELARUS (BYELORUSSIA)","Minsk"},

{"BULGARIA","Sofia"},

{"GEORGIA","Tbilisi"},

{"KAZAKSTAN","Almaty"},

{"KYRGYZSTAN","Alma-Ata"},

{"MOLDOVA","Chisinau"},

{"RUSSIA","Moscow"},

{"TAJIKISTAN","Dushanbe"},

{"TURKMENISTAN","Ashkabad"},

{"UKRAINE","Kyiv"},

{"UZBEKISTAN","Tashkent"},

// Europe

{"ALBANIA","Tirana"},

{"ANDORRA","Andorra la Vella"},

{"AUSTRIA","Vienna"},

{"BELGIUM","Brussels"},

{"BOSNIA-HERZEGOVINA","Sarajevo"},

{"CROATIA","Zagreb"},

{"CZECH REPUBLIC","Prague"},

{"DENMARK","Copenhagen"},

{"ESTONIA","Tallinn"},

{"FINLAND","Helsinki"},

{"FRANCE","Paris"},

{"GERMANY","Berlin"},

{"GREECE","Athens"},

{"HUNGARY","Budapest"},

{"ICELAND","Reykjavik"},

{"IRELAND","Dublin"},

{"ITALY","Rome"},

{"LATVIA","Riga"},

{"LIECHTENSTEIN","Vaduz"},

{"LITHUANIA","Vilnius"},

{"LUXEMBOURG","Luxembourg"},

{"MACEDONIA","Skopje"},

{"MALTA","Valletta"},

{"MONACO","Monaco"},

{"MONTENEGRO","Podgorica"},

{"THE NETHERLANDS","Amsterdam"},

{"NORWAY","Oslo"},

{"POLAND","Warsaw"},

{"PORTUGAL","Lisbon"},

{"ROMANIA","Bucharest"},

{"SAN MARINO","San Marino"},

{"SERBIA","Belgrade"},

{"SLOVAKIA","Bratislava"},

{"SLOVENIA","Ljuijana"},

{"SPAIN","Madrid"},

{"SWEDEN","Stockholm"},

{"SWITZERLAND","Berne"},

{"UNITED KINGDOM","London"},

{"VATICAN CITY","Vatican City"},

// North and Central America

{"ANTIGUA AND BARBUDA","Saint John's"},

{"BAHAMAS","Nassau"},

{"BARBADOS","Bridgetown"},

{"BELIZE","Belmopan"},

{"CANADA","Ottawa"},

{"COSTA RICA","San Jose"},

{"CUBA","Havana"},

{"DOMINICA","Roseau"},

{"DOMINICAN REPUBLIC","Santo Domingo"},

{"EL SALVADOR","San Salvador"},

{"GRENADA","Saint George's"},

{"GUATEMALA","Guatemala City"},

{"HAITI","Port-au-Prince"},

{"HONDURAS","Tegucigalpa"},

{"JAMAICA","Kingston"},

{"MEXICO","Mexico City"},

{"NICARAGUA","Managua"},

{"PANAMA","Panama City"},

{"ST. KITTS AND NEVIS","Basseterre"},

{"ST. LUCIA","Castries"},

{"ST. VINCENT AND THE GRENADINES","Kingstown"},

{"UNITED STATES OF AMERICA","Washington, D.C."},

// South America

{"ARGENTINA","Buenos Aires"},

{"BOLIVIA","Sucre (legal)/La Paz(administrative)"},

{"BRAZIL","Brasilia"},

{"CHILE","Santiago"},

{"COLOMBIA","Bogota"},

{"ECUADOR","Quito"},

{"GUYANA","Georgetown"},

```
{"PARAGUAY","Asuncion"},
{"PERU","Lima"},
{"SURINAME","Paramaribo"},
{"TRINIDAD AND TOBAGO","Port of Spain"},
{"URUGUAY","Montevideo"},
{"VENEZUELA","Caracas"},
};
// Use AbstractMap by implementing entrySet()
private static class FlyweightMap
extends AbstractMap<String,String> {
private static class Entry
implements Map.Entry<String,String> {
int index;
Entry(int index) { this.index = index; }
@Override
public boolean equals(Object o) {
return o instanceof FlyweightMap &&
Objects.equals(DATA[index][0], o);
}
@Override
```

```
public int hashCode() {
return Objects.hashCode(DATA[index][0]);
}
@Override
public String getKey() { return DATA[index][0]; }
@Override
public String getValue() {
return DATA[index][1];
}
@Override
public String setValue(String value) {
throw new UnsupportedOperationException();
}
}
// Implement size() & iterator() for AbstractSet:
static class EntrySet
extends AbstractSet<Map.Entry<String,String>> {
private int size;
EntrySet(int size) {
if(size < 0)
```

```
this.size = 0;
// Can't be any bigger than the array:
else if(size > DATA.length)
this.size = DATA.length;
else
this.size = size;
}
@Override
public int size() { return size; }
private class Iter
implements Iterator<Map.Entry<String,String>> {
// Only one Entry object per Iterator:
private Entry entry = new Entry(-1);
@Override
public boolean hasNext() {
return entry.index < size - 1;
}
@Override
public Map.Entry<String,String> next() {
entry.index++;
```

```
return entry;
}
@Override
public void remove() {
throw new UnsupportedOperationException();
}
}
@Override
public
Iterator<Map.Entry<String,String>> iterator() {
return new Iter();
}
}
private static
Set<Map.Entry<String,String>> entries =
new EntrySet(DATA.length);
@Override
public Set<Map.Entry<String,String>> entrySet() {
return entries;
}
```

```
}
// Create a partial map of 'size' countries:
static Map<String,String> select(final int size) {
return new FlyweightMap() {
@Override
public Set<Map.Entry<String,String>> entrySet() {
return new EntrySet(size);
```

```
}
};
}
static Map<String,String> map = new FlyweightMap();
public static Map<String,String> capitals() {
return map; // The entire map
}
public static Map<String,String> capitals(int size) {
return select(size); // A partial map
}
static List<String> names =
new ArrayList<>(map.keySet());
// All the names:
public static List<String> names() { return names; }
// A partial list:
public static List<String> names(int size) {
return new ArrayList<>(select(size).keySet());
}
public static void main(String[] args) {
System.out.println(capitals(10));
```

```
System.out.println(names(10));
System.out.println(new HashMap<>(capitals(3)));
System.out.println(
new LinkedHashMap<>(capitals(3)));
System.out.println(new TreeMap<>(capitals(3)));
System.out.println(new Hashtable<>(capitals(3)));
System.out.println(new HashSet<>(names(6)));
System.out.println(new LinkedHashSet<>(names(6)));
System.out.println(new TreeSet<>(names(6)));
System.out.println(new ArrayList<>(names(6)));
System.out.println(new LinkedList<>(names(6)));
System.out.println(capitals().get("BRAZIL"));
}
}
/* Output:
{ALGERIA=Algiers, ANGOLA=Luanda, BENIN=Porto-Novo,
BOTSWANA=Gaberone, BURKINA FASO=Ouagadougou,
BURUNDI=Bujumbura, CAMEROON=Yaounde, CAPE VERDE=Praia,
CENTRAL AFRICAN REPUBLIC=Bangui, CHAD=N'djamena}
[ALGERIA, ANGOLA, BENIN, BOTSWANA, BURKINA FASO,
```

BURUNDI, CAMEROON, CAPE VERDE, CENTRAL AFRICAN REPUBLIC, CHAD]

{BENIN=Porto-Novo, ANGOLA=Luanda, ALGERIA=Algiers}

{ALGERIA=Algiers, ANGOLA=Luanda, BENIN=Porto-Novo}

{ALGERIA=Algiers, ANGOLA=Luanda, BENIN=Porto-Novo}

{ALGERIA=Algiers, ANGOLA=Luanda, BENIN=Porto-Novo}

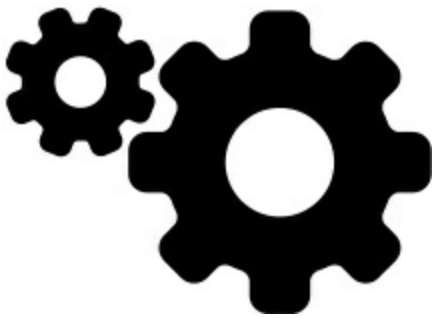
[BENIN, BOTSWANA, ANGOLA, BURKINA FASO, ALGERIA, BURUNDI]

[ALGERIA, ANGOLA, BENIN, BOTSWANA, BURKINA FASO, BURUNDI]

[ALGERIA, ANGOLA, BENIN, BOTSWANA, BURKINA FASO, BURUNDI]

[ALGERIA, ANGOLA, BENIN, BOTSWANA, BURKINA FASO, BURUNDI]

[ALGERIA, ANGOLA, BENIN, BOTSWANA, BURKINA FASO, BURUNDI]



Brasilia

*/

The **String DATA** two-dimensional array is **public** so it can be used elsewhere. **FlyweightMap** must implement the **entrySet()** method, which requires both a custom **Set** implementation and a custom **Map.Entry** class. Here's another way to implement a flyweight: each **Map.Entry** object stores its index, rather than the actual key and value. When you call **getKey()** or **getValue()**, it uses the index to return the appropriate **DATA** element. The **EntrySet** ensures its **size** is no bigger than **DATA**.

The other part of the flyweight is implemented in **EntrySet.Iterator**. Instead of creating a **Map.Entry** object for each data pair in **DATA**, there's only one **Map.Entry** object *per iterator*. The **Entry** object is used as a window into the data; it only contains an **index** into the static array of **String**s. Every time you call **next()** for the iterator, the **index** in the **Entry** is incremented so it points to the next element pair, then that **Iterator**s single **Entry** object is returned from **next()**. 1

The **select()** method produces a **FlyweightMap** containing an **EntrySet** of the desired size, and this is used in the overloaded

capitals() and **names()** methods you see demonstrated in **main()**.

Collection Functionality

The following table shows everything you can do with a **Collection** (not including the methods that automatically come through with **Object**), and thus, everything you can do with a **List**, **Set**, **Queue** or **Deque** (These interfaces may also provide also has additional functionality). **Map**s are not inherited from **Collection** and are treated separately.

boolean add(T)	Ensures that the collection holds the argument of generic type **T**. Returns **false** if it doesn't add the argument. (This is an "optional" method, described in the next section.)
boolean addAll(Collection<?	Adds all the elements in the argument. Returns **true** if

any elements were added.

extends T>)

(“Optional.”)

Removes all the elements in

void clear()

the collection. (“Optional.”)

true if the collection holds

boolean contains(T)

the argument of generic type

T.

Boolean

true if the collection holds

containsAll(Collection<? all the elements in the

>)

argument.

boolean isEmpty()

true if the collection has no

elements.

Returns an iterator to move

Iterator<T> iterator()

through the elements in the

Spliterator<T>

collection. **Spliterators**

spliterator()

are much more complex, and

used for concurrency.

If the argument is in the

collection, one instance of

Boolean remove(Object)

that element is removed.

Returns **true** if a removal

occurred. (“Optional.”)

Removes all the elements

contained in the argument.

boolean

Returns **true** if any

removeAll(Collection<?>) removals occurred.

(“Optional.”)

Retains only elements

contained in the argument

Boolean

(an “intersection,” from set

retainAll(Collection<?>) theory). Returns **true** if any

changes occurred.

(“Optional.”)

boolean

Removes every element in

removeIf(Predicate<?

this collection that satisfies

the given predicate.

super E>)

Stream<E> stream()

Returns a **Stream** of the

Stream<E>

elements in this

parallelStream()

Collection

Returns the number of

int size()

elements in the collection.

Returns an array containing

Object[] toArray()

all the elements in the

collection.

Returns an array containing

all the elements in the

collection. The runtime type

<T> T[] toArray(T[] a)

of the result is that of the

argument array a rather than

plain **Object**.

There’s no **get()** method for random-access element selection because **Collection** also includes **Set**, which maintains its own internal ordering (and thus makes random-access lookup meaningless). Thus, to examine the elements of a **Collection**, you must use an iterator.

This demonstrates all **Collection** methods. **ArrayList** is used as a “least-common denominator” **Collection**:

// collectiontopics/CollectionMethods.java

// Things you can do with all Collections

```
import java.util.*;
import static onjava.HTMLColors.*;
public class CollectionMethods {
public static void main(String[] args) {
Collection<String> c =
new ArrayList<>(LIST.subList(0, 4));
c.add("ten");
c.add("eleven");
show(c);
border();
// Make an array from the List:
Object[] array = c.toArray();
// Make a String array from the List:
String[] str = c.toArray(new String[0]);
// Find max and min elements; this means
// different things depending on the way
// the Comparable interface is implemented:
System.out.println(
"Collections.max(c) = " + Collections.max(c));
System.out.println(
```

```
"Collections.min(c) = " + Collections.min(c));
border();
// Add a Collection to another Collection
Collection<String> c2 =
new ArrayList<>(LIST.subList(10, 14));
c.addAll(c2);
show(c);
border();
c.remove(LIST.get(0));
show(c);
border();
// Remove all components that are
// in the argument collection:
c.removeAll(c2);
show(c);
border();
c.addAll(c2);
show(c);
border();
// Is an element in this Collection?
```

```
String val = LIST.get(3);
System.out.println(
"c.contains(" + val + ") = " + c.contains(val));
// Is a Collection in this Collection?
System.out.println(
"c.containsAll(c2) = " + c.containsAll(c2));
Collection<String> c3 =
((List<String>)c).subList(3, 5);
// Keep all the elements that are in both
// c2 and c3 (an intersection of sets):
c2.retainAll(c3);
show(c2);
// Throw away all the elements
// in c2 that also appear in c3:
c2.removeAll(c3);
System.out.println(
"c2.isEmpty() = " + c2.isEmpty());
border();
// Functional operation:
c = new ArrayList<>(LIST);
```

```
c.removeIf(s -> !s.startsWith("P"));
c.removeIf(s -> s.startsWith("Pale"));
// Stream operation:
c.stream().forEach(System.out::println);
c.clear(); // Remove all elements
System.out.println("after c.clear():" + c);
}
}
/* Output:
AliceBlue
AntiqueWhite
Aquamarine
Azure
ten
eleven
*********************************
Collections.max(c) = ten
Collections.min(c) = AliceBlue
*********************************
AliceBlue
```

AntiqueWhite

Aquamarine

Azure

ten

eleven

Brown

BurlyWood

CadetBlue

Chartreuse

****

AntiqueWhite

Aquamarine

Azure

ten

eleven

Brown

BurlyWood

CadetBlue

Chartreuse

****

AntiqueWhite

Aquamarine

Azure

ten

eleven

****

AntiqueWhite

Aquamarine

Azure

ten

eleven

Brown

BurlyWood

CadetBlue

Chartreuse

****

c.contains(Azure) = true

c.containsAll(c2) = true

c2.isEmpty() = true

****

PapayaWhip

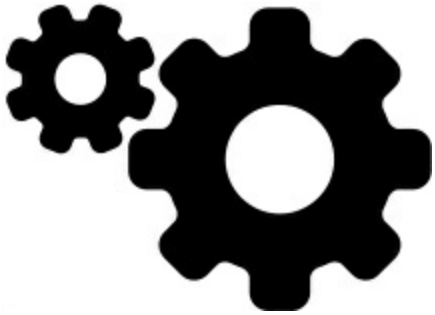
PeachPuff

Peru

Pink

Plum

PowderBlue



Purple

after c.clear():[]

/

To demonstrate that nothing other than the **Collection** interface is used, **ArrayList**s are created containing different sets of data and upcast to **Collection** objects.

Optional Operations

The methods in the **Collection** interface that perform various kinds of addition and removal are *optional operations*. This means the implementing class is not required to provide functioning definitions

for these methods.

This is a very unusual way to define an interface. As you've seen, an interface is a contract. It says, "No matter how you choose to implement this interface, I guarantee you can send these messages to this object" (I use the term "interface" here to describe both the formal **interface** keyword and the more general meaning of "the methods supported by any class or subclass"). But an "optional" operation violates this very fundamental principle; it says that calling some methods will *not* perform meaningful behavior. Instead, they will throw exceptions! It appears that compile-time type safety is discarded.

It's not that bad. If an operation is optional, the compiler still restricts you to calling only the methods in that interface. It's not like a dynamic language, where you can call any method for any object, and find out at run time whether a particular call will work. 2 In addition, most methods that take a **Collection** as an argument only *read* from that **Collection**, and all the "read" methods of **Collection** are *not* optional.

Why would you define methods as "optional?" Doing so prevents an explosion of interfaces in the design. Other designs for collection libraries tend to produce a confusing plethora of interfaces to describe

each of the variations on the main theme. It's not even possible to capture all special cases in interfaces, because someone can always invent a new interface. The "unsupported operation" approach achieves an important goal of the Java collections library: The collections are simple to learn and use. Unsupported operations are a special case that can be delayed until necessary. For this approach to work, however:

1. The **UnsupportedOperationException** must be a rare event. That is, for most classes, all operations should work, and only in special cases should an operation be unsupported. This is true in the Java collections library, since the classes you'll use 99 percent of the time—**ArrayList**, **LinkedList**, **HashSet**, and **HashMap**, as well as the other concrete implementations—support all operations. The design does provide a "back door" to create a new **Collection** without providing meaningful definitions for all the methods in the **Collection** interface, that still fits into the existing library.
2. When an operation *is* unsupported, it should be reasonably likely that an **UnsupportedOperationException** will appear at implementation time, rather than after you've shipped the

product to the customer. After all, it indicates a programming error: You've used an implementation incorrectly.

It's worth noting that unsupported operations are only detectable at run time, and therefore represent dynamic type checking. If you're coming from a statically typed language like C++, Java might appear to be just another statically typed language. Java certainly *has* static type checking, but it also has a significant amount of dynamic typing, so it's hard to say it's exactly one type of language or another. Once you begin to notice this, you'll start to see other examples of dynamic

type checking in Java.

Unsupported Operations

A common source of unsupported operations are collections backed by fixed-sized data structures. You get such a collection when you turn an array into a **List** with the **Arrays.asList()** method. You can also *choose* to make any collection (including a **Map**) throw **UnsupportedOperationException**s by using the "unmodifiable" methods in the **Collections** class. This example

shows both cases:

```
// collectiontopics/Unsupported.java
// Unsupported operations in Java collections
import java.util.*;
public class Unsupported {
static void
check(String description, Runnable tst) {
try {
tst.run();
} catch(Exception e) {
System.out.println(description + "(): " + e);
}
}
static void test(String msg, List<String> list) {
System.out.println("--- " + msg + " ---");
Collection<String> c = list;
Collection<String> subList = list.subList(1,8);
// Copy of the sublist:
Collection<String> c2 = new ArrayList<>(subList);
check("retainAll", () -> c.retainAll(c2));
```

```
check("removeAll", () -> c.removeAll(c2));
check("clear", () -> c.clear());
check("add", () -> c.add("X"));
check("addAll", () -> c.addAll(c2));
check("remove", () -> c.remove("C"));
// The List.set() method modifies the value but
// doesn't change the size of the data structure:
check("List.set", () -> list.set(0, "X"));
}
public static void main(String[] args) {
List<String> list = Arrays.asList(
"A B C D E F G H I J K L".split(" "));
test("Modifiable Copy", new ArrayList<>(list));
test("Arrays.asList()", list);
test("unmodifiableList()",
Collections.unmodifiableList(
new ArrayList<>(list)));
}
}
/* Output:
```

--- Modifiable Copy ---

--- Arrays.asList() ---

retainAll(): java.lang.UnsupportedOperationException

removeAll(): java.lang.UnsupportedOperationException

clear(): java.lang.UnsupportedOperationException

add(): java.lang.UnsupportedOperationException

addAll(): java.lang.UnsupportedOperationException

remove(): java.lang.UnsupportedOperationException

--- unmodifiableList() ---

retainAll(): java.lang.UnsupportedOperationException

removeAll(): java.lang.UnsupportedOperationException

clear(): java.lang.UnsupportedOperationException

add(): java.lang.UnsupportedOperationException

addAll(): java.lang.UnsupportedOperationException

remove(): java.lang.UnsupportedOperationException

List.set(): java.lang.UnsupportedOperationException

**/*

Because **Arrays.asList()** produces a **List** that is backed by a fixed-size array, it makes sense that the only supported operations are the ones that don't change the *size* of the array. Any method that

would cause a change to the size of the underlying data structure produces an **UnsupportedOperationException**, to indicate a call to an unsupported method (a programming error).

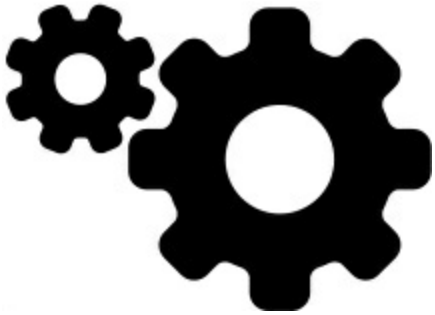
Note you can always pass the result of **Arrays.asList()** as a constructor argument to any **Collection** (or use the **addAll()** method, or the **static Collections.addAll()** method) to create a regular collection that allows all the methods—this is shown in the first call to **test()** in **main()**. Such a call produces a new resizable underlying data structure.

The "unmodifiable" methods in the **Collections** class wrap the collection in a proxy that produces an **UnsupportedOperationException** if you perform any operation that modifies the collection in any way. The goal of using these methods is to produce a "constant" collection object. The full list of "unmodifiable" **Collections** methods is described later.

The last **check()** in **test()** examines the **set()** method that's part of **List**. Here, the granularity of the "unsupported operation" technique comes in handy—the resulting "interface" can vary by one method between the object returned by **Arrays.asList()** and that returned by **Collections.unmodifiableList()**.

Arrays.asList() returns a fixed-sized **List**, whereas **Collections.unmodifiableList()** produces a list that cannot be changed. As seen in the output, it's OK to *modify* the elements in the **List** returned by **Arrays.asList()**, because this would not violate the "fixed-sized" nature of that **List**. But clearly, the result of **unmodifiableList()** should not be modifiable in any way. If interfaces were used, this would require two additional interfaces, one with a working **set()** method and one without. Additional interfaces would be required for various unmodifiable subtypes of **Collection**.

The documentation for a method that takes a collection as an argument should specify which of the optional methods must be implemented.



Sets and Storage Order

The **Set** examples in the Collections chapter provide a good introduction to the operations on basic **Set**s. However, those

examples conveniently use predefined Java types such as **Integer** and **String**, which were designed to be usable inside collections. When creating your own types, be aware that a **Set** (and also a **Map**, which we'll look at shortly) needs a way to maintain storage order, which varies from one implementation of **Set** to another. Thus, different **Set** implementations not only have different behaviors, they have different requirements for the type of object you can put into a particular **Set**:

Each element you add to the **Set** must be unique; otherwise, the **Set** doesn't add the duplicate element. Elements added to a **Set** must at least define **equals()** to establish object uniqueness. **Set** has exactly the same interface as **Collection**. The **Set** interface does not guarantee it will maintain its elements in any particular order.

Set (**interface**)

For **Set**s where fast lookup time is

HashSet*

important. Elements must define

hashCode() and **equals()**.

An ordered **Set** backed by a tree.

This way, you can extract an

TreeSet

ordered sequence from a **Set**.

Elements must also implement the

Comparable interface.

Has the lookup speed of a

HashSet, but internally

maintains the order you add the

elements (the insertion order)

LinkedHashSet

using a linked list. Thus, when you

iterate through the **Set**, the

results appear in insertion order.

Elements must define

hashCode() and **equals()**.

The asterisk on **HashSet** indicates that, in the absence of other constraints, this should be your default choice because it is optimized for speed.

Defining **hashCode()** is described in the Appendix: Understanding **equals()** and **hashCode()**. You must create an **equals()** for both hashed and tree storage, but the **hashCode()** is necessary only if the class is placed in a **HashSet** (this is likely, since that should generally be your first choice as a **Set** implementation) or **LinkedHashSet**. However, for good programming style, always override **hashCode()** when you override **equals()**.

This example demonstrates the methods required to successfully use a type with a particular **Set** implementation:

```
// collectiontopics/TypesForSets.java
// Methods necessary to put your own type in a Set
import java.util.*;
import java.util.function.*;
import java.util.Objects;
class SetType {
protected int i;
SetType(int n) { i = n; }
```

```
@Override
public boolean equals(Object o) {
return o instanceof SetType &&
Objects.equals(i, ((SetType)o).i);
}
@Override
public String toString() {
return Integer.toString(i);
}
}
class HashType extends SetType {
HashType(int n) { super(n); }
@Override
public int hashCode() {
return Objects.hashCode(i);
}
}
class TreeType extends SetType
implements Comparable<TreeType> {
TreeType(int n) { super(n); }
```

```
@Override
public int compareTo(TreeType arg) {
return Integer.compare(arg.i, i);
// Equivalent to:
// return arg.i < i ? -1 : (arg.i == i ? 0 : 1);
}
}
public class TypesForSets {
static <T> void
fill(Set<T> set, Function<Integer, T> type) {
for(int i = 10; i >= 5; i--) // Descending
set.add(type.apply(i));
for(int i = 0; i < 5; i++) // Ascending
set.add(type.apply(i));
}
static <T> void
test(Set<T> set, Function<Integer, T> type) {
fill(set, type);
fill(set, type); // Try to add duplicates
fill(set, type);
```

```
System.out.println(set);
}
public static void main(String[] args) {
test(new HashSet<>(), HashType::new);
test(new LinkedHashSet<>(), HashType::new);
test(new TreeSet<>(), TreeType::new);
// Things that don't work:
test(new HashSet<>(), SetType::new);
test(new HashSet<>(), TreeType::new);
test(new LinkedHashSet<>(), SetType::new);
test(new LinkedHashSet<>(), TreeType::new);
try {
test(new TreeSet<>(), SetType::new);
} catch(Exception e) {
System.out.println(e.getMessage());
}
try {
test(new TreeSet<>(), HashType::new);
} catch(Exception e) {
System.out.println(e.getMessage());
```

```
}
}
}
/* Output:
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
[10, 9, 8, 7, 6, 5, 0, 1, 2, 3, 4]
[10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0]
[1, 6, 8, 6, 2, 7, 8, 9, 4, 10, 7, 5, 1, 3, 4, 9, 9,
10, 5, 3, 2, 0, 4, 1, 2, 0, 8, 3, 0, 10, 6, 5, 7]
[3, 1, 4, 8, 7, 6, 9, 5, 3, 0, 10, 5, 5, 10, 7, 8, 8,
9, 1, 4, 10, 2, 6, 9, 1, 6, 0, 3, 2, 0, 7, 2, 4]
[10, 9, 8, 7, 6, 5, 0, 1, 2, 3, 4, 10, 9, 8, 7, 6, 5,
0, 1, 2, 3, 4, 10, 9, 8, 7, 6, 5, 0, 1, 2, 3, 4]
[10, 9, 8, 7, 6, 5, 0, 1, 2, 3, 4, 10, 9, 8, 7, 6, 5,
0, 1, 2, 3, 4, 10, 9, 8, 7, 6, 5, 0, 1, 2, 3, 4]
SetType cannot be cast to java.lang.Comparable
HashType cannot be cast to java.lang.Comparable
*/
```

To prove which methods are necessary for a particular **Set** and at the same time to avoid code duplication, three classes are created. The

base class, **SetType**, stores an **int**, and produces it via **toString()**. Since all classes stored in **Set**s must have an **equals()**, that method is also placed in the base class. Equality is based on the value of the **int i**.

HashType inherits from **SetType** and adds the **hashCode()** method necessary for an object to be placed in a hashed implementation of a **Set**.

The **Comparable** interface, implemented by **TreeType**, is necessary to use an object in any kind of sorted collection, such as a **SortedSet** (of which **TreeSet** is the only implementation). In **compareTo()**, note I did *not* use the "simple and obvious" form **return i-i2**. Although this is a common programming error, it would only work properly if **i** and **i2** were "unsigned" **int**s (if Java *had* an "unsigned" keyword, which it does not). It breaks for Java's signed **int**, which is not big enough to represent the difference of two signed **int**s. If **i** is a large positive integer and **j** is a large negative integer, **i-j** will overflow and return a negative value, which will not work.

You'll usually want the **compareTo()** method to produce a natural ordering consistent with the **equals()** method. If **equals()** produces **true** for a particular comparison, **compareTo()** should produce a

zero result for that comparison, and if **equals()** produces **false** for a comparison then **compareTo()** should produce a nonzero result for that comparison.

In **TypesForSets**, both **fill()** and **test()** are defined using generics, to prevent code duplication. To verify the behavior of a **Set**, **test()** calls **fill()** on the test **set** three times, attempting to introduce duplicate objects. The **fill()** method takes a **Set** of any type, and a **Function** object that produces that type. Because all the objects used in this example have a constructor that takes a single **int** argument, you can pass the constructor as this **Function** and it will supply the objects to fill the **Set**.

Note that the **fill()** method adds its first elements in descending order, and the last in ascending order, to point out the resulting storage order. The output shows that the **HashSet** keeps the elements in ascending order—however, in the Appendix: Understanding **equals()** and **hashCode()** you'll see that this is incidental, because hashing creates its own storage order. Only because our value is a simple **int** is it ascending in this case. The **LinkedHashSet** keeps the elements in the order they were inserted, and the **TreeSet** maintains the elements in sorted order (descending order in this example, because of the way **compareTo()** is

implemented).

If we try to use types that don’t properly support the necessary operations with **Set**s that require those operations, things go very wrong. Placing a **SetType** or **TreeType** object, which doesn’t include a redefined **hashCode()** method, into any hashed

implementations results in duplicate values, so the primary contract of the **Set** is violated. This is rather disturbing because there’s not even a runtime error. However, the default **hashCode()** is legitimate and so this is legal behavior, even if it’s incorrect. The only reliable way to ensure the correctness of such a program is to incorporate unit tests into your build system.

If you try to use a type that doesn’t implement **Comparable** in a **TreeSet**, you get a more definitive result: An exception is thrown when the **TreeSet** attempts to use the object as a **Comparable**.

SortedSet

The elements in a **SortedSet** are guaranteed to be in sorted order, yielding additional functionality from the following methods in the

SortedSet interface:

Comparator comparator(): Produces the **Comparator**

used for this **Set**, or **null** for natural ordering.

Object first(): Produces the lowest element.

Object last(): Produces the highest element.

SortedSet subSet(fromElement, toElement):

Produces a view of this **Set** with elements from **fromElement**,

inclusive, to **toElement**, exclusive.

SortedSet headSet(toElement): Produces a view of this

Set with elements less than **toElement**.

SortedSet tailSet(fromElement): Produces a view of

this **Set** with elements greater than or equal to **fromElement**.

Here's a simple demonstration:

// collectiontopics/SortedSetDemo.java

import java.util.*;

import static java.util.stream.Collectors.*;

public class SortedSetDemo {

public static void main(String[] args) {

SortedSet<String> sortedSet =

Arrays.stream(

```
"one two three four five six seven eight"
.split(" "))
.collect(toCollection(TreeSet::new));
System.out.println(sortedSet);
String low = sortedSet.first();
String high = sortedSet.last();
System.out.println(low);
System.out.println(high);
Iterator<String> it = sortedSet.iterator();
for(int i = 0; i <= 6; i++) {
if(i == 3) low = it.next();
if(i == 6) high = it.next();
else it.next();
}
System.out.println(low);
System.out.println(high);
System.out.println(sortedSet.subSet(low, high));
System.out.println(sortedSet.headSet(high));
System.out.println(sortedSet.tailSet(low));
}
```

}

/ Output:*

[eight, five, four, one, seven, six, three, two]

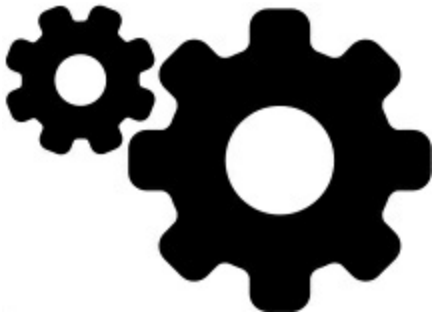
eight

two

one

two

[one, seven, six, three]



[eight, five, four, one, seven, six, three]

[one, seven, six, three, two]

**/*

Note that **SortedSet** means “sorted according to the comparison function of the object,” not “insertion order.” Insertion order can be preserved using a **LinkedHashSet**.

Queues

There are many **Queue** implementations, most of which are designed

for concurrency applications Many are differentiated by ordering behavior rather than performance. Here’s a basic example that involves most of the **Queue** implementations, including the concurrency-based **Queue**s. You place elements in one end and extract them from the other:

```
// collectiontopics/QueueBehavior.java
// Compares basic behavior
import java.util.*;
import java.util.stream.*;
import java.util.concurrent.*;
public class QueueBehavior {
static Stream<String> strings() {
return Arrays.stream(
("one two three four five six seven " +
"eight nine ten").split(" "));
}
static void test(int id, Queue<String> queue) {
System.out.print(id + ": ");
strings().map(queue::offer).count();
while(queue.peek() != null)
```

```
System.out.print(queue.remove() + " ");
System.out.println();
}
public static void main(String[] args) {
```

```
int count = 10;
test(1, new LinkedList<>());
test(2, new PriorityQueue<>());
test(3, new ArrayBlockingQueue<>(count));
test(4, new ConcurrentLinkedQueue<>());
test(5, new LinkedBlockingQueue<>());
test(6, new PriorityBlockingQueue<>());
test(7, new ArrayDeque<>());
test(8, new ConcurrentLinkedDeque<>());
test(9, new LinkedBlockingDeque<>());
test(10, new LinkedTransferQueue<>());
test(11, new SynchronousQueue<>());
}
```

}

/ *Output:*

1: one two three four five six seven eight nine ten

2: eight five four nine one seven six ten three two

3: one two three four five six seven eight nine ten

4: one two three four five six seven eight nine ten

5: one two three four five six seven eight nine ten

6: eight five four nine one seven six ten three two

7: one two three four five six seven eight nine ten

8: one two three four five six seven eight nine ten

9: one two three four five six seven eight nine ten

10: one two three four five six seven eight nine ten

11:

**/*

The **Deque** interface also inherits from **Queue**. With the exception of the priority queues, a **Queue** produces elements in the same order as they are placed in the **Queue**. In this example, **SynchronousQueue** doesn’t produce any results because it is a blocking queue where each insert operation must wait for a corresponding remove operation by another thread, and vice versa.

Priority Queues

Consider a to-do list, where each object contains a **String** and a primary and secondary priority value. The ordering of this list is controlled by implementing **Comparable**:

```
// collectiontopics/ToDoList.java
// A more complex use of PriorityQueue
import java.util.*;
class ToDoItem implements Comparable<ToDoItem> {
private char primary;
private int secondary;
private String item;
ToDoItem(String td, char pri, int sec) {
primary = pri;
secondary = sec;
item = td;
}
@Override
public int compareTo(ToDoItem arg) {
if(primary > arg.primary)
return +1;
```

```
if(primary == arg.primary)
if(secondary > arg.secondary)
return +1;
else if(secondary == arg.secondary)
return 0;
return -1;
}
@Override
public String toString() {
return Character.toString(primary) +
secondary + ": " + item;
}
}
class ToDoList {
public static void main(String[] args) {
PriorityQueue<ToDoItem> toDo =
new PriorityQueue<>();
toDo.add(new ToDoItem("Empty trash", 'C', 4));
toDo.add(new ToDoItem("Feed dog", 'A', 2));
toDo.add(new ToDoItem("Feed bird", 'B', 7));
```

```
toDo.add(new ToDoItem("Mow lawn", 'C', 3));
```

```
toDo.add(new ToDoItem("Water lawn", 'A', 1));
toDo.add(new ToDoItem("Feed cat", 'B', 1));
while(!toDo.isEmpty())
System.out.println(toDo.remove());
}
}
/* Output:
A1: Water lawn
A2: Feed dog
B1: Feed cat
B7: Feed bird
C3: Mow lawn
C4: Empty trash
*/
```

This shows the automatic ordering of the items via the priority queue.

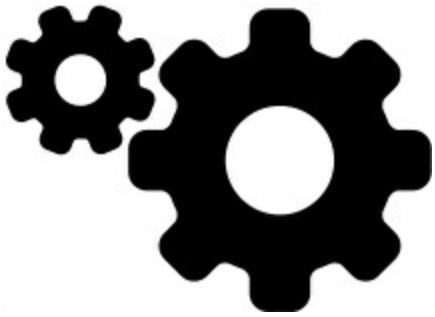
Deque

A **Deque** (double-ended queue) is like a queue, but you can add and remove elements from either end. Java 6 added an explicit interface for **Deque**. Here is a test of the most fundamental **Deque** methods for the classes that implement **Deque**:

```
// collectiontopics/SimpleDeques.java
// Very basic test of Deques
import java.util.*;
import java.util.concurrent.*;
import java.util.function.*;
class CountString implements Supplier<String> {
private int n = 0;
CountString() {}
CountString(int start) { n = start; }
@Override
public String get() {
return Integer.toString(n++);
}
}
public class SimpleDeques {
static void test(Deque<String> deque) {
```

```
CountString s1 = new CountString(),
s2 = new CountString(20);
for(int n = 0; n < 8; n++) {
deque.offerFirst(s1.get());
deque.offerLast(s2.get()); // Same as offer()
}
System.out.println(deque);
String result = "";
while(deque.size() > 0) {
System.out.print(deque.peekFirst() + " ");
result += deque.pollFirst() + " ";
System.out.print(deque.peekLast() + " ");
result += deque.pollLast() + " ";
}
System.out.println("\n" + result);
}
public static void main(String[] args) {
int count = 10;
System.out.println("LinkedList");
test(new LinkedList<>());
```

```
System.out.println("ArrayDeque");
test(new ArrayDeque<>());
System.out.println("LinkedBlockingDeque");
test(new LinkedBlockingDeque<>(count));
System.out.println("ConcurrentLinkedDeque");
test(new ConcurrentLinkedDeque<>());
}
}
/* Output:
LinkedList
[7, 6, 5, 4, 3, 2, 1, 0, 20, 21, 22, 23, 24, 25, 26,
27]
7 27 6 26 5 25 4 24 3 23 2 22 1 21 0 20
7 27 6 26 5 25 4 24 3 23 2 22 1 21 0 20
ArrayDeque
[7, 6, 5, 4, 3, 2, 1, 0, 20, 21, 22, 23, 24, 25, 26,
27]
7 27 6 26 5 25 4 24 3 23 2 22 1 21 0 20
7 27 6 26 5 25 4 24 3 23 2 22 1 21 0 20
```



LinkedBlockingDeque

[4, 3, 2, 1, 0, 20, 21, 22, 23, 24]

4 24 3 23 2 22 1 21 0 20

4 24 3 23 2 22 1 21 0 20

ConcurrentLinkedDeque

[7, 6, 5, 4, 3, 2, 1, 0, 20, 21, 22, 23, 24, 25, 26,

27]

7 27 6 26 5 25 4 24 3 23 2 22 1 21 0 20

7 27 6 26 5 25 4 24 3 23 2 22 1 21 0 20

**/*

I've only used the "offer" and "poll" versions of the **Deque** methods because they don't throw exceptions when the **LinkedBlockingDeque** has a limited size. Notice that **LinkedBlockingDeque** only fills to its limit, then ignores further offers.

Understanding Maps

As you learned in the Collections chapter, a **Map** (also called an *associative array*) maintains key-value associations (pairs) so you can look up a value using a key. The standard Java library contains different basic implementations of **Map**s, such as **HashMap**, **TreeMap**, **LinkedHashMap**, **WeakHashMap**, **ConcurrentHashMap**, and **IdentityHashMap**. They all have the same basic **Map** interface, but they differ in behaviors including efficiency, the order the pairs are held and presented, how long the objects are held by the map, how the map works in multithreaded programs, and how key equality is determined. The number of implementations of the **Map** interface should tell you something about the importance of this tool.

To gain a deeper understanding of **Map**s, it is helpful to learn how to construct an associative array. Here is an extremely simple implementation:

```
// collectiontopics/AssociativeArray.java
// Associates keys with values
public class AssociativeArray<K, V> {
private Object[][] pairs;
private int index;
public AssociativeArray(int length) {
```

```
pairs = new Object[length][2];
}
public void put(K key, V value) {
if(index >= pairs.length)
throw new ArrayIndexOutOfBoundsException();
pairs[index++] = new Object[]{ key, value };
}
@SuppressWarnings("unchecked")
public V get(K key) {
for(int i = 0; i < index; i++)
if(key.equals(pairs[i][0]))
return (V)pairs[i][1];
return null; // Did not find key
}
@Override
public String toString() {
StringBuilder result = new StringBuilder();
for(int i = 0; i < index; i++) {
result.append(pairs[i][0].toString());
result.append(" : ");
```

```
result.append(pairs[i][1].toString());
if(i < index - 1)
result.append("\n");
}
return result.toString();
}
public static void main(String[] args) {
AssociativeArray<String,String> map =
new AssociativeArray<>(6);
map.put("sky", "blue");
map.put("grass", "green");
map.put("ocean", "dancing");
map.put("tree", "tall");
map.put("earth", "brown");
map.put("sun", "warm");
try {
map.put("extra", "object"); // Past the end
} catch(ArrayIndexOutOfBoundsException e) {
System.out.println("Too many objects!");
}
```

```
System.out.println(map);
System.out.println(map.get("ocean"));
}
}
/* Output:
Too many objects!
sky : blue
grass : green
ocean : dancing
tree : tall
earth : brown
sun : warm
dancing
*/
```

The essential methods in an associative array are **put()** and **get()**, but for easy display, **toString()** is overridden to print the key-value pairs. To show it works, **main()** loads an **AssociativeArray** with pairs of **String**s and prints the resulting map, followed by a **get()** of one of the values.

To use the **get()** method, you pass in the **key** you want it to look up,

and it produces the associated value as the result or returns **null** if it can't be found. The **get()** method is using what is possibly the least efficient approach imaginable to locate the value: starting at the top of the array and using **equals()** to compare keys. But the point here is simplicity, not efficiency.

This version is instructive, but it isn't very efficient and it has a fixed

size, which is inflexible. Fortunately, the **Map**s in **java.util** do not have these problems.

Performance

Performance is a fundamental issue for maps, and it's very slow to use a linear search in **get()** when hunting for a key. This is where **HashMap** speeds things up. Instead of a slow search for the key, it uses a special value called a *hash code*. The hash code is a way to take some information from the object in question and turn it into a "relatively unique" **int** for that object. **hashCode()** is a method in the root class **Object**, so all Java objects can produce a hash code. A **HashMap** takes the **hashCode()** of the object and uses it to quickly

hunt for the key. This results in dramatic performance improvements.3

Here are the basic **Map** implementations. The asterisk on **HashMap** indicates that, in the absence of other constraints, this should be your default choice because it is optimized for speed. The other implementations emphasize other characteristics, and are thus not as fast as **HashMap**.

Implementation based on a hash table. (Use this class instead of **Hashtable**.)	
Provides constant-time performance for inserting and	**HashMap***
locating pairs. Performance can be adjusted via constructors that allow you to set the *capacity* and *load factor* of the hash table.	
Like a **HashMap**, but when you iterate through, you get the	

pairs in insertion order, or in least-recently-used (LRU)

LinkedHashMap

order. Only slightly slower than **HashMap**, except when iterating, where it is faster due to the linked list used to maintain the internal ordering. Implementation based on a red-black tree. When you view the keys or the pairs, they are in sorted order (determined by **Comparable** or

TreeMap

Comparator). The point of a **TreeMap** is that you get the results in sorted order. **TreeMap** is the only **Map** with the **subMap()** method, which returns a portion of the tree.

A **Map** of *weak keys* that allow objects referred to by the map to be released; designed to solve certain types of problems.

WeakHashMap

If no references to a particular key are held outside the map, that key can be garbage collected.

A thread-safe **Map** that does not use synchronization

ConcurrentHashMap

locking. This is discussed in the Concurrent Programming chapter.

A hash map that uses == instead of **equals()** to

IdentityHashMap

compare keys. Only for solving special types of problems; not

for general use.

Hashing is the most commonly used way to store elements in a map.

The requirements for the keys used in a **Map** are the same as for the elements in a **Set**. You saw these demonstrated in **TypesForSets.java**. Any key must have an **equals()** method.

If the key is used in a hashed **Map**, it must also have a proper **hashCode()**. If the key is used in a **TreeMap**, it must implement **Comparable**.

The following example shows the operations available through the **Map** interface, using the previously defined **CountMap** test data set:

```
// collectiontopics/MapOps.java
// Things you can do with Maps
import java.util.concurrent.*;
import java.util.*;
import onjava.*;
public class MapOps {
public static
void printKeys(Map<Integer,String> map) {
System.out.print("Size = " + map.size() + ", ");
System.out.print("Keys: ");
```

```
// Produce a Set of the keys:
System.out.println(map.keySet());
}
public static
void test(Map<Integer,String> map) {
System.out.println(
map.getClass().getSimpleName());
map.putAll(new CountMap(25));
// Map has 'Set' behavior for keys:
map.putAll(new CountMap(25));
printKeys(map);
// Producing a Collection of the values:
System.out.print("Values: ");
System.out.println(map.values());
System.out.println(map);
System.out.println("map.containsKey(11): " +
map.containsKey(11));
System.out.println(
"map.get(11): " + map.get(11));
System.out.println("map.containsValue(\"F0\"): "
```

```
+ map.containsValue("F0"));
Integer key = map.keySet().iterator().next();
System.out.println("First key in map: " + key);
map.remove(key);
printKeys(map);
map.clear();
System.out.println(
"map.isEmpty(): " + map.isEmpty());
map.putAll(new CountMap(25));
// Operations on the Set change the Map:
map.keySet().removeAll(map.keySet());
System.out.println(
"map.isEmpty(): " + map.isEmpty());
}
public static void main(String[] args) {
test(new HashMap<>());
test(new TreeMap<>());
test(new LinkedHashMap<>());
test(new IdentityHashMap<>());
test(new ConcurrentHashMap<>());
```

```
test(new WeakHashMap<>());
}
}
/* Output: (First 11 Lines)
HashMap
Size = 25, Keys: [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11,
12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24]
Values: [A0, B0, C0, D0, E0, F0, G0, H0, I0, J0, K0,
L0, M0, N0, O0, P0, Q0, R0, S0, T0, U0, V0, W0, X0, Y0]
{0=A0, 1=B0, 2=C0, 3=D0, 4=E0, 5=F0, 6=G0, 7=H0, 8=I0,
9=J0, 10=K0, 11=L0, 12=M0, 13=N0, 14=O0, 15=P0, 16=Q0,
17=R0, 18=S0, 19=T0, 20=U0, 21=V0, 22=W0, 23=X0, 24=Y0}
map.containsKey(11): true
map.get(11): L0
map.containsValue("F0"): true
First key in map: 0
Size = 24, Keys: [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11,
12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24]
map.isEmpty(): true
map.isEmpty(): true
```

...

*/

The **printKeys()** method demonstrates how to produce a **Collection** view of a **Map**. The **keySet()** method produces a **Set** backed by the keys in the **Map**. Printing the result of the **values()** method produces a **Collection** containing all the values in the **Map**. (Note that keys must be unique, but values can contain duplicates.) Since these **Collection**s are backed by the **Map**, any changes in a **Collection** are reflected in the associated **Map**.

The rest of the program provides simple examples of each **Map** operation and tests each basic type of **Map**.

SortedMap

With a **SortedMap** (implemented by **TreeMap** or **ConcurrentSkipListMap**), the keys are guaranteed to be in sorted order, which allows additional functionality to be provided with these methods in the **SortedMap** interface:

Comparator comparator(): Produces the

comparator used for this Map, ornull for natural

ordering.

`T firstKey(): Produces the lowest key.

`T lastKey(): Produces the highest key.

SortedMap subMap(fromKey, toKey): Produces a

view of this Map with keysfrom fromKey, inclusive, to

toKey, exclusive.

SortedMap headMap(toKey): Produces a view of

this Map with keys less thantoKey.

SortedMap tailMap(fromKey): Produces a view of this

Map with keys greater than or equal to **fromKey**.

Here's an example that's similar to **SortedSetDemo.java** and

shows this additional behavior of **TreeMap**s:

```
// collectiontopics/SortedMapDemo.java
// What you can do with a TreeMap
import java.util.*;
import onjava.*;
```

```
public class SortedMapDemo {
public static void main(String[] args) {
TreeMap<Integer,String> sortedMap =
new TreeMap<>(new CountMap(10));
System.out.println(sortedMap);
Integer low = sortedMap.firstKey();
Integer high = sortedMap.lastKey();
System.out.println(low);
System.out.println(high);
Iterator<Integer> it =
sortedMap.keySet().iterator();
for(int i = 0; i <= 6; i++) {
if(i == 3) low = it.next();
if(i == 6) high = it.next();
else it.next();
}
System.out.println(low);
```

```
System.out.println(high);
System.out.println(sortedMap.subMap(low, high));
System.out.println(sortedMap.headMap(high));
System.out.println(sortedMap.tailMap(low));
}
}
/* Output:
{0=A0, 1=B0, 2=C0, 3=D0, 4=E0, 5=F0, 6=G0, 7=H0, 8=I0,
9=J0}
0
9
3
7
{3=D0, 4=E0, 5=F0, 6=G0}
{0=A0, 1=B0, 2=C0, 3=D0, 4=E0, 5=F0, 6=G0}
{3=D0, 4=E0, 5=F0, 6=G0, 7=H0, 8=I0, 9=J0}
*/
```

Here, the pairs are stored by key-sorted order. Because there is a sense of order in the **TreeMap**, the concept of “location” makes sense, so you can have first and last elements and submaps.

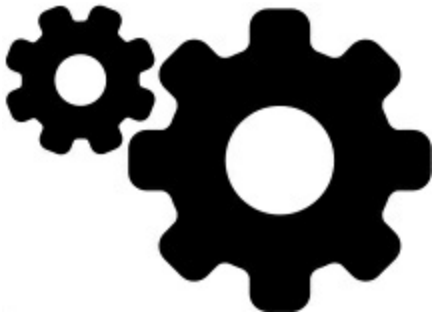
LinkedHashMap

The **LinkedHashMap** hashes everything for speed, but also produces the pairs in insertion order during a traversal (**System.out.println()** iterates through the map, so you see the results of traversal). In addition, a **LinkedHashMap** can be configured in the constructor to use a *least-recently-used* (LRU) algorithm based on accesses, so elements that haven't been accessed (and thus are candidates for removal) appear at the front of the list. This allows easy creation of programs that do periodic cleanup to save space. Here's a simple example showing both features:

```
// collectiontopics/LinkedHashMapDemo.java
// What you can do with a LinkedHashMap
import java.util.*;
import onjava.*;
public class LinkedHashMapDemo {
public static void main(String[] args) {
LinkedHashMap<Integer,String> linkedMap =
new LinkedHashMap<>(new CountMap(9));
System.out.println(linkedMap);
// Least-recently-used order:
```

```
linkedMap =
new LinkedHashMap<>(16, 0.75f, true);
linkedMap.putAll(new CountMap(9));
System.out.println(linkedMap);
for(int i = 0; i < 6; i++)
linkedMap.get(i);
System.out.println(linkedMap);
linkedMap.get(0);
System.out.println(linkedMap);
}
}
/* Output:
{0=A0, 1=B0, 2=C0, 3=D0, 4=E0, 5=F0, 6=G0, 7=H0, 8=I0}
{0=A0, 1=B0, 2=C0, 3=D0, 4=E0, 5=F0, 6=G0, 7=H0, 8=I0}
{6=G0, 7=H0, 8=I0, 0=A0, 1=B0, 2=C0, 3=D0, 4=E0, 5=F0}
{6=G0, 7=H0, 8=I0, 1=B0, 2=C0, 3=D0, 4=E0, 5=F0, 0=A0}
*/
```

The pairs are indeed traversed in insertion order, even for the LRU



version. However, after the first six items (only) are accessed in the LRU version, the last three items move to the front of the list. Then, when "**0**" is accessed again, it moves to the back of the list.

Utilities

There are a number of standalone utilities for collections, expressed as **static** methods in **java.util.Collections**. You've already seen some of these, such as **addAll()**, **reverseOrder()** and **binarySearch()**. Here are the others (the **synchronized** and **unmodifiable** utilities are covered in sections that follow). In this table, generics are used when they are relevant:

checkedCollection(Collection<T>, Class<T> type)

Produces a *dynamically* type-

checkedList(List<T>, Class<T> type)

safe view of a

Collection, or a

checkedMap(Map<K, V>, Class<K>

specific subtype of

keyType

Collection. Use

, **Class<V> valueType)**

this when it’s not

possible to use the

checkedSet(Set<T>, Class<T>

statically checked

type)

version.

checkedSortedMap(SortedMap<K,

These were shown

in the Generics

V>, Class<K> keyType, Class<V>

chapter under the

valueType)

heading “Dynamic

type safety.”

checkedSortedSet(SortedSet<T>,

Class<T> type)

Produces the

maximum or

minimum element

max(Collection)

in the argument

using the natural

min(Collection)

comparison method

of the objects in the

Collection.

Produces the

maximum or

max(Collection, Comparator)

minimum element

in the

min(Collection, Comparator)

Collection

using the

Comparator.

Produces starting

index of the *first*

indexOfSubList(List source, List

place where

target)

target appears

inside **source**, or

-1 if none occurs.

Produces starting

index of the *last*

lastIndexOfSubList(List source,

place where

target appears

List target)

inside **source**, or

-1 if none occurs.

Replaces all

replaceAll(List<T>, T oldVal, T

oldVal with

newVal)

newVal.

Reverses all the

reverse(List)

elements in place.

Returns a

Comparator that

reverses the natural

ordering of a

collection of objects

reverseOrder()

that implement

reverseOrder(Comparator<T>)

Comparable<T> .

The second version

reverses the order of

the supplied

Comparator.

Moves all elements

forward by

rotate(List, int distance)

distance, taking

the ones off the end

and placing them at

the beginning.

Randomly permutes

the specified list.

shuffle(List)

The first form

provides its own

randomization

shuffle(List, Random)

source, or you can

provide your own

with the second

form.

Sorts the **List<T>**

sort(List<T>)

using its natural

ordering. The

sort(List<T>, Comparator<? super

second form takes a

T> c)

Comparator for

sorting.

copy(List<? super T> dest,

Copies elements

List<? extends T> src)

from **src** to **dest**.

Swaps elements at

locations **i** and **j** in

swap(List, int i, int j)

the **List**. Probably

faster than what

you’d write by hand.

Replaces all the

fill(List<? super T>, T x)

elements of the

List with **x**.

Returns an

immutable

nCopies(int n, T x)

List<T> of size **n**

whose references all

point to **x**.

Returns **true** if the

disjoint(Collection, Collection) two **Collection**s

have no elements in

common.

Returns the number

of elements in the

frequency(Collection, Object x)

Collection

equal to **x**.

Returns an

immutable empty

emptyList()

List, **Map**, or **Set**

These are generic,

emptyMap()

so the resulting

Collection

emptySet()

is

parameterized to

the desired type.

Produces an

immutable

singleton(T x)

Set<T> ,

singletonList(T x)

List<T> , or

Map<K, V>

singletonMap(K key, V value)

containing a single

entry based on the

given argument(s).

Produces an

ArrayList<T>

containing the
elements in the
order in which they
are returned by the
list(Enumeration<T> e)
(old-style)
Enumeration
(predecessor to the
Iterator). For
converting from
legacy code.
Produces an old-
style
enumeration(Collection<T>)
Enumeration<T>
for the argument.
Note that **min()** and **max()** work with **Collection** objects, not with **List**s, so you don't worry if the **Collection** should be sorted or not. (As mentioned earlier, you *do* **sort()** a **List** or an array before performing a **binarySearch()**.)

Here’s an example showing the basic use of most of the utilities in the above table:

```
// collectiontopics/Utilities.java
// Simple demonstrations of the Collections utilities
import java.util.*;
public class Utilities {
static List<String> list = Arrays.asList(
"one Two three Four five six one".split(" "));
public static void main(String[] args) {
System.out.println(list);
System.out.println("'list' disjoint (Four)?: " +
Collections.disjoint(list,
Collections.singletonList("Four")));
System.out.println(
"max: " + Collections.max(list));
System.out.println(
"min: " + Collections.min(list));
System.out.println(
"max w/ comparator: " + Collections.max(list,
String.CASE_INSENSITIVE_ORDER));
```

```
System.out.println(
"min w/ comparator: " + Collections.min(list,
String.CASE_INSENSITIVE_ORDER));
List<String> sublist =
Arrays.asList("Four five six".split(" "));
System.out.println("indexOfSubList: " +
Collections.indexOfSubList(list, sublist));
System.out.println("lastIndexOfSubList: " +
Collections.lastIndexOfSubList(list, sublist));
Collections.replaceAll(list, "one", "Yo");
System.out.println("replaceAll: " + list);
Collections.reverse(list);
System.out.println("reverse: " + list);
Collections.rotate(list, 3);
System.out.println("rotate: " + list);
List<String> source =
Arrays.asList("in the matrix".split(" "));
Collections.copy(list, source);
System.out.println("copy: " + list);
Collections.swap(list, 0, list.size() - 1);
```

```
System.out.println("swap: " + list);
Collections.shuffle(list, new Random(47));
System.out.println("shuffled: " + list);
Collections.fill(list, "pop");
System.out.println("fill: " + list);
System.out.println("frequency of 'pop': " +
Collections.frequency(list, "pop"));
List<String> dups =
Collections.nCopies(3, "snap");
System.out.println("dups: " + dups);
System.out.println("'list' disjoint 'dups'?: " +
Collections.disjoint(list, dups));
// Getting an old-style Enumeration:
Enumeration<String> e =
Collections.enumeration(dups);
Vector<String> v = new Vector<>();
while(e.hasMoreElements())
v.addElement(e.nextElement());
// Converting an old-style Vector
// to a List via an Enumeration:
```

```
ArrayList<String> arrayList =
Collections.list(v.elements());
System.out.println("arrayList: " + arrayList);
}
}
/* Output:
[one, Two, three, Four, five, six, one]
'list' disjoint (Four)?: false
max: three
min: Four
max w/ comparator: Two
min w/ comparator: five
indexOfSubList: 3
lastIndexOfSubList: 3
replaceAll: [Yo, Two, three, Four, five, six, Yo]
reverse: [Yo, six, five, Four, three, Two, Yo]
rotate: [three, Two, Yo, Yo, six, five, Four]
copy: [in, the, matrix, Yo, six, five, Four]
swap: [Four, the, matrix, Yo, six, five, in]
shuffled: [six, matrix, the, Four, Yo, five, in]
```

fill: [pop, pop, pop, pop, pop, pop, pop]

frequency of 'pop': 7

dups: [snap, snap, snap]

'list' disjoint 'dups'?: true

arrayList: [snap, snap, snap]

**/*

The output explains the behavior of each utility method. Note the

difference in **min()** and **max()** with the **String.CASE_INSENSITIVE_ORDER Comparator** because of capitalization.

Sorting and Searching Lists

Utilities to perform sorting and searching for **List**s have the same names and signatures as those for sorting arrays of objects, but are **static** methods of **Collections** instead of **Arrays**. Here's an example that uses the **list** data from **Utilities.java**:

// collectiontopics/ListSortSearch.java

// Sorting/searching Lists with Collections utilities

```
import java.util.*;
public class ListSortSearch {
public static void main(String[] args) {
List<String> list =
new ArrayList<>(Utilities.list);
list.addAll(Utilities.list);
System.out.println(list);
Collections.shuffle(list, new Random(47));
System.out.println("Shuffled: " + list);
// Use ListIterator to trim off last elements:
ListIterator<String> it = list.listIterator(10);
while(it.hasNext()) {
it.next();
it.remove();
}
System.out.println("Trimmed: " + list);
Collections.sort(list);
System.out.println("Sorted: " + list);
String key = list.get(7);
int index = Collections.binarySearch(list, key);
```

```
System.out.println(
"Location of " + key + " is " + index +
", list.get(" + index + ") = " +
list.get(index));
Collections.sort(list,
String.CASE_INSENSITIVE_ORDER);
System.out.println(
"Case-insensitive sorted: " + list);
key = list.get(7);
index = Collections.binarySearch(list, key,
String.CASE_INSENSITIVE_ORDER);
System.out.println(
"Location of " + key + " is " + index +
", list.get(" + index + ") = " +
list.get(index));
}
}
/* Output:
[one, Two, three, Four, five, six, one, one, Two,
three, Four, five, six, one]
```

Shuffled: [Four, five, one, one, Two, six, six, three,

three, five, Four, Two, one, one]

Trimmed: [Four, five, one, one, Two, six, six, three,

three, five]

Sorted: [Four, Two, five, five, one, one, six, six,

three, three]

Location of six is 7, list.get(7) = six

Case-insensitive sorted: [five, five, Four, one, one,

six, six, three, three, Two]

Location of three is 7, list.get(7) = three

**/*

Just as when searching and sorting with arrays, if you sort using a **Comparator**, you must **binarySearch()** using the same **Comparator**.

This program also demonstrates the **shuffle()** method in **Collections**, which randomizes the order of a **List**. A **ListIterator** is created at a particular location in the shuffled list, and used to remove the elements from that location until the end of the list.

Making a Collection or Map

Unmodifiable

Often it is convenient to create a read-only version of a **Collection** or **Map**. The **Collections** class does this by accepting the original collection into a method that hands back a read-only version. There are a number of variations on this method, for **Collection**s (if you can't treat a **Collection** as a more specific type), **List**s, **Set**s, and **Map**s. This example shows the proper way to build read-only versions of each:

```
// collectiontopics/ReadOnly.java
// Using the Collections.unmodifiable methods
import java.util.*;
import onjava.*;
public class ReadOnly {
static Collection<String> data =
new ArrayList<>(Countries.names(6));
public static void main(String[] args) {
```

```
Collection<String> c =
Collections.unmodifiableCollection(
new ArrayList<>(data));
System.out.println(c); // Reading is OK
//- c.add("one"); // Can't change it
List<String> a = Collections.unmodifiableList(
new ArrayList<>(data));
ListIterator<String> lit = a.listIterator();
System.out.println(lit.next()); // Reading is OK
//- lit.add("one"); // Can't change it
Set<String> s = Collections.unmodifiableSet(
new HashSet<>(data));
System.out.println(s); // Reading is OK
//- s.add("one"); // Can't change it
// For a SortedSet:
Set<String> ss =
Collections.unmodifiableSortedSet(
new TreeSet<>(data));
Map<String,String> m =
Collections.unmodifiableMap(
```

```
new HashMap<>(Countries.capitals(6)));
System.out.println(m); // Reading is OK
//- m.put("Ralph", "Howdy!");
// For a SortedMap:
Map<String,String> sm =
Collections.unmodifiableSortedMap(
new TreeMap<>(Countries.capitals(6)));
}
}
/* Output:
[ALGERIA, ANGOLA, BENIN, BOTSWANA, BURKINA FASO,
BURUNDI]
ALGERIA
[BENIN, BOTSWANA, ANGOLA, BURKINA FASO, ALGERIA,
BURUNDI]
{BENIN=Porto-Novo, BOTSWANA=Gaberone, ANGOLA=Luanda,
BURKINA FASO=Ouagadougou, ALGERIA=Algiers,
BURUNDI=Bujumbura}
*/
```

Calling the “unmodifiable” method for a particular type does not cause

compile-time checking, but once the transformation has occurred, any calls to methods that modify the contents of a particular collection will produce an **UnsupportedOperationException**.

In each case, you must fill the collection with meaningful data *before* you make it read-only. Once it is loaded, the best approach is to replace the existing reference with the reference that is produced by the "unmodifiable" call. That way, you don't run the risk of accidentally trying to change the contents once you've made it unmodifiable. On the other hand, this tool also lets you keep a modifiable collection as **private** within a class and to return a read-

only reference to that collection from a method call. So, you can change it from within the class, but everyone else can only read it.

Synchronizing a Collection or Map

The **synchronized** keyword is an important part of the subject of *multithreading*, a more complicated topic introduced in the Concurrent Programming chapter. Here, I shall note only that the **Collections**

class contains a way to automatically synchronize an

entire collection. The syntax is similar to the “unmodifiable” methods:

```
// collectiontopics/Synchronization.java
// Using the Collections.synchronized methods
import java.util.*;
public class Synchronization {
public static void main(String[] args) {
Collection<String> c =
Collections.synchronizedCollection(
new ArrayList<>());
List<String> list = Collections
.synchronizedList(new ArrayList<>());
Set<String> s = Collections
.synchronizedSet(new HashSet<>());
Set<String> ss = Collections
.synchronizedSortedSet(new TreeSet<>());
Map<String,String> m = Collections
.synchronizedMap(new HashMap<>());
Map<String,String> sm = Collections
.synchronizedSortedMap(new TreeMap<>());
```

}

}

It is best to immediately pass the new collection through the appropriate “synchronized” method, as shown above. That way, there’s no chance of accidentally exposing the unsynchronized version.

Fail Fast

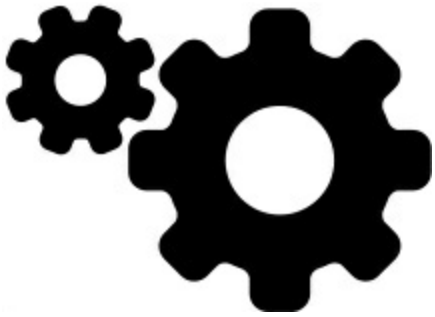
The Java collections also have a mechanism to prevent more than one process from modifying the contents of a collection. The problem occurs if you’re in the middle of iterating through a collection, then some other process steps in and inserts, removes, or changes an object in that collection. Maybe you’ve already passed that element in the collection, maybe it’s ahead of you, maybe the size of the collection shrinks after you call **size()**—there are many scenarios for disaster.

The Java collections library uses a *fail-fast* mechanism that looks for any changes to the collection apart from those caused by your process. If it detects that someone else is modifying the collection, it immediately produces a **ConcurrentModification-Exception**. This is the “fail-fast” aspect—it doesn’t try to detect a problem later on using a more complex algorithm.

It’s easy to see the fail-fast mechanism in operation by creating an

iterator and adding an element to the collection where the iterator points, like this:

```
// collectiontopics/FailFast.java
// Demonstrates the "fail-fast" behavior
import java.util.*;
public class FailFast {
public static void main(String[] args) {
Collection<String> c = new ArrayList<>();
Iterator<String> it = c.iterator();
c.add("An object");
try {
String s = it.next();
} catch(ConcurrentModificationException e) {
System.out.println(e);
}
}
}
/* Output:
java.util.ConcurrentModificationException
```



*/

The exception comes from attempting to place an element in the collection *after* the iterator is acquired from the collection. The possibility that two parts of the program might modify the same collection produces an uncertain state, so the exception notifies you to change your code—in this case, acquire the iterator *after* you have added all the elements to the collection.

The **ConcurrentHashMap**, **CopyOnWriteArrayList**, and **CopyOnWriteArraySet** use techniques that avoid **ConcurrentModificationException**s.

Holding References

The **java.lang.ref** library contains a set of classes that allow greater flexibility in garbage collection. These classes are especially useful when you have large objects that might cause memory exhaustion. There are three classes inherited from the abstract class **Reference**: **SoftReference**, **WeakReference**, and

PhantomReference. Each of these provides a different level of indirection for the garbage collector if the object in question is only reachable through one of these **Reference** objects.

If an object is *reachable*, it means somewhere in your program the object can be found. This could mean you have an ordinary reference on the stack that goes right to the object, but you might also have a reference to an object that has a reference to the object in question; there can be many intermediate links. If an object is reachable, the garbage collector cannot release it because it's still in use by your program. If an object isn't reachable, there's no way for your program to use it, so it's safe to garbage collect that object.

You use **Reference** objects to continue holding a reference to that object—to reach that object—but also to allow the garbage collector to release that object. Thus, you have a way to use the object, but if memory exhaustion is imminent, you allow that object to be released.

You accomplish this by using a **Reference** object as an intermediary (a *proxy*) between you and the ordinary reference. In addition, there must be no ordinary references to the object (ones not wrapped inside **Reference** objects). If the garbage collector discovers that an object is reachable through an ordinary reference, it will not release that

object.

In the order of **SoftReference**, **WeakReference**, and **PhantomReference**, each one is “weaker” than the last and corresponds to a different level of reachability. Soft references are for implementing memory-sensitive caches. Weak references are for implementing “canonicalizing mappings”—where instances of objects can be simultaneously used in multiple places in a program, to save storage—that do not prevent their keys (or values) from being reclaimed. Phantom references are for scheduling pre-mortem cleanup actions in a more flexible way than is possible with the Java finalization mechanism.

With **SoftReference**s and **WeakReference**s, you have a choice about whether to place them on a **ReferenceQueue** (the device used for pre-mortem cleanup actions), but a **PhantomReference** can only be built on a **ReferenceQueue**. Here’s a simple demonstration:

```
// collectiontopics/References.java
// Demonstrates Reference objects
import java.lang.ref.*;
import java.util.*;
```

```
class VeryBig {
private static final int SIZE = 10000;
private long[] la = new long[SIZE];
private String ident;
VeryBig(String id) { ident = id; }
@Override
public String toString() { return ident; }
@Override
protected void finalize() {
System.out.println("Finalizing " + ident);
}
}
public class References {
private static ReferenceQueue<VeryBig> rq =
new ReferenceQueue<>();
public static void checkQueue() {
Reference<? extends VeryBig> inq = rq.poll();
if(inq != null)
System.out.println("In queue: " + inq.get());
}
```

```
public static void main(String[] args) {
int size = 10;
// Or, choose size via the command line:
if(args.length > 0)
size = Integer.valueOf(args[0]);
LinkedList<SoftReference<VeryBig>> sa =
new LinkedList<>();
for(int i = 0; i < size; i++) {
sa.add(new SoftReference<>(
new VeryBig("Soft " + i), rq));
System.out.println(
"Just created: " + sa.getLast());
checkQueue();
}
LinkedList<WeakReference<VeryBig>> wa =
new LinkedList<>();
for(int i = 0; i < size; i++) {
wa.add(new WeakReference<>(
new VeryBig("Weak " + i), rq));
System.out.println(
```

```
"Just created: " + wa.getLast());
checkQueue();
}
SoftReference<VeryBig> s =
new SoftReference<>(new VeryBig("Soft"));
WeakReference<VeryBig> w =
new WeakReference<>(new VeryBig("Weak"));
System.gc();
LinkedList<PhantomReference<VeryBig>> pa =
new LinkedList<>();
for(int i = 0; i < size; i++) {
pa.add(new PhantomReference<>(
new VeryBig("Phantom " + i), rq));
System.out.println(
"Just created: " + pa.getLast());
checkQueue();
}
}
}
/* Output: (First and Last 10 Lines)
```

Just created: java.lang.ref.SoftReference@15db9742

Just created: java.lang.ref.SoftReference@6d06d69c

Just created: java.lang.ref.SoftReference@7852e922

Just created: java.lang.ref.SoftReference@4e25154f

Just created: java.lang.ref.SoftReference@70dea4e

Just created: java.lang.ref.SoftReference@5c647e05

Just created: java.lang.ref.SoftReference@33909752

Just created: java.lang.ref.SoftReference@55f96302

Just created: java.lang.ref.SoftReference@3d4eac69

Just created: java.lang.ref.SoftReference@42a57993

..._____..._____..._____..._____...

Just created: java.lang.ref.PhantomReference@45ee12a7

In queue: null

Just created: java.lang.ref.PhantomReference@330bedb4

In queue: null

Just created: java.lang.ref.PhantomReference@2503dbd3

In queue: null

Just created: java.lang.ref.PhantomReference@4b67cf4d

In queue: null

Just created: java.lang.ref.PhantomReference@7ea987ac

In queue: null

*/

When you run this program (redirect the output into a text file to view the output in pages), you'll see that the objects are garbage collected,

even though you can still access them through the **Reference** object (to get the actual object reference, use **get()**). You'll also see that the **ReferenceQueue** always produces a **Reference** containing a **null** object. To use this, inherit from a particular **Reference** class and add more useful methods to the new class.

The WeakHashMap

The collections library has a special **Map** to hold weak references: the **WeakHashMap**. This class makes it easier to create canonicalized mappings. In such a mapping, you save storage by creating only one instance of a particular value. When the program needs that value, it looks up the existing object in the mapping and uses that (rather than creating one from scratch). The mapping can make the values as part of its initialization, but it's more likely that the values are made on

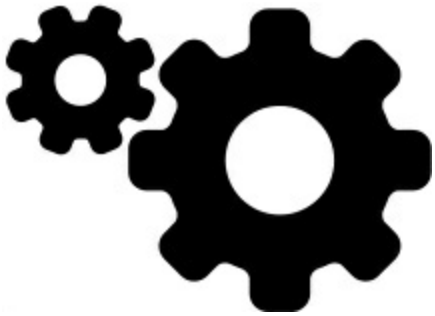
demand.

Since this is a storage-saving technique, it’s very convenient that the **WeakHashMap** allows the garbage collector to automatically clean up the keys and values. You don’t do anything special to the keys and values you place in the **WeakHashMap**; these are automatically wrapped in **WeakReference**s by the map. The trigger to allow cleanup is that the key is no longer in use, as demonstrated here:

```
// collectiontopics/CanonicalMapping.java
// Demonstrates WeakHashMap
import java.util.*;
class Element {
private String ident;
Element(String id) { ident = id; }
@Override
public String toString() { return ident; }
@Override
public int hashCode() {
return Objects.hashCode(ident);
}
@Override
```

```
public boolean equals(Object r) {
return r instanceof Element &&
Objects.equals(ident, ((Element)r).ident);
}
@Override
protected void finalize() {
System.out.println("Finalizing " +
getClass().getSimpleName() + " " + ident);
}
}
class Key extends Element {
Key(String id) { super(id); }
}
class Value extends Element {
Value(String id) { super(id); }
}
public class CanonicalMapping {
public static void main(String[] args) {
int size = 1000;
// Or, choose size via the command line:
```

```
if(args.length > 0)
size = Integer.valueOf(args[0]);
Key[] keys = new Key[size];
WeakHashMap<Key,Value> map =
new WeakHashMap<>();
for(int i = 0; i < size; i++) {
Key k = new Key(Integer.toString(i));
Value v = new Value(Integer.toString(i));
if(i % 3 == 0)
keys[i] = k; // Save as "real" references
map.put(k, v);
}
System.gc();
}
}
```



The **Key** class must have a **hashCode()** and an **equals()** since it is used as a key in a hashed data structure. The subject of **hashCode()** was described in the Appendix: Understanding **equals()** and **hashCode()**.

Run the program and you'll see the garbage collector skip every third key. An ordinary reference to that key has also been placed in the **keys** array, and thus those objects cannot be garbage collected.

Java 1.0/1.1

Collections

Unfortunately, much code was written using the Java 1.0/1.1 collections, and even new code is sometimes written using these classes. Never use the old collections when writing new code. The old collections were limited, so there's not that much to say about them. Since they are anachronistic, I try to refrain from overemphasizing some of their hideous design decisions.

Vector & Enumeration

The only self-expanding sequence in Java 1.0/1.1 was the **Vector**, so

it saw a lot of use. Its flaws are too numerous to describe here (see the 1st edition of *Thinking in Java*, available as a free download from www.OnJava8.com). Basically, you can think of it as an **ArrayList** with long, awkward method names. In the revised Java collection library, **Vector** was adapted so it could work as a **Collection** and a **List**. This turns out to be a bit perverse, as it can confuse some people into thinking that **Vector** has gotten better, when it is actually included only to support older Java code.

The Java 1.0/1.1 version of the iterator chose to invent a new name, "enumeration," instead of using a term that everyone was already familiar with ("iterator"). The **Enumeration** interface is smaller than **Iterator**, with only two methods, and it uses longer method names: **boolean hasMoreElements()** produces **true** if this enumeration contains more elements, and **Object nextElement()** returns the next element of this enumeration if there are any more (otherwise it throws an exception).

Enumeration is only an interface, not an implementation, and even new libraries sometimes still use the old **Enumeration**, which is unfortunate but generally harmless. Always use **Iterator** when you can in your own code, but be prepared for libraries that hand you an **Enumeration**.

In addition, you can produce an **Enumeration** for any **Collection** by using the **Collections.enumeration()** method, as seen in this example:

```
// collectiontopics/Enumerations.java
// Java 1.0/1.1 Vector and Enumeration
import java.util.*;
import onjava.*;
public class Enumerations {
public static void main(String[] args) {
Vector<String> v =
new Vector<>(Countries.names(10));
Enumeration<String> e = v.elements();
while(e.hasMoreElements())
System.out.print(e.nextElement() + ", ");
// Produce an Enumeration from a Collection:
e = Collections.enumeration(new ArrayList<>());
}
```

}

/ *Output:*

ALGERIA, ANGOLA, BENIN, BOTSWANA, BURKINA FASO,

BURUNDI, CAMEROON, CAPE VERDE, CENTRAL AFRICAN

REPUBLIC, CHAD,

**/*

To produce an **Enumeration**, you call **elements()**, then you can use it to perform a forward iteration.

The last line creates an **ArrayList** and uses **enumeration()** to adapt an **Enumeration** from the **ArrayList Iterator**. Thus, if

you have old code that wants an **Enumeration**, you can still use the new collections.

Hashtable

As you've seen in the performance comparison in this appendix, the basic **Hashtable** is very similar to the **HashMap**, even down to the method names. There's no reason to use **Hashtable** instead of **HashMap** in new code.

Stack

The concept of the stack was introduced earlier, with the **LinkedList**. What's rather odd about the Java 1.0/1.1 **Stack** is that instead of using a **Vector** with composition, **Stack** is *inherited* from **Vector**. So it has all characteristics and behaviors of a **Vector** plus some extra **Stack** behaviors. It's difficult to know whether the designers consciously thought this was a helpful way of doing things, or whether it was just naïve; in any event it was clearly not reviewed before it was rushed into distribution, so this bad design is *still* hanging around (but don't use it).

Here's a simple demonstration of **Stack** that pushes each **String** representation of an **enum**. It also shows how you can just as easily use a **LinkedList** as a stack, or the **Stack** class created in the

Collections chapter:

```
// collectiontopics/Stacks.java
// Demonstration of Stack Class
import java.util.*;
enum Month { JANUARY, FEBRUARY, MARCH, APRIL,
MAY, JUNE, JULY, AUGUST, SEPTEMBER,
OCTOBER, NOVEMBER }
public class Stacks {
public static void main(String[] args) {
Stack<String> stack = new Stack<>();
for(Month m : Month.values())
stack.push(m.toString());
System.out.println("stack = " + stack);
// Treating a stack as a Vector:
stack.addElement("The last line");
System.out.println(
"element 5 = " + stack.elementAt(5));
System.out.println("popping elements:");
while(!stack.empty())
System.out.print(stack.pop() + " ");
```

```
// Using a LinkedList as a Stack:
LinkedList<String> lstack = new LinkedList<>();
for(Month m : Month.values())
lstack.addFirst(m.toString());
System.out.println("lstack = " + lstack);
while(!lstack.isEmpty())
System.out.print(lstack.removeFirst() + " ");
// Using the Stack class from
// the Collections Chapter:
onjava.Stack<String> stack2 =
new onjava.Stack<>();
for(Month m : Month.values())
stack2.push(m.toString());
System.out.println("stack2 = " + stack2);
while(!stack2.isEmpty())
System.out.print(stack2.pop() + " ");
}
}
/* Output:
stack = [JANUARY, FEBRUARY, MARCH, APRIL, MAY, JUNE,
```

JULY, AUGUST, SEPTEMBER, OCTOBER, NOVEMBER]

element 5 = JUNE

popping elements:

The last line NOVEMBER OCTOBER SEPTEMBER AUGUST JULY

JUNE MAY APRIL MARCH FEBRUARY JANUARY lstack =

[NOVEMBER, OCTOBER, SEPTEMBER, AUGUST, JULY, JUNE, MAY,

APRIL, MARCH, FEBRUARY, JANUARY]

NOVEMBER OCTOBER SEPTEMBER AUGUST JULY JUNE MAY APRIL

MARCH FEBRUARY JANUARY stack2 = [NOVEMBER, OCTOBER,

SEPTEMBER, AUGUST, JULY, JUNE, MAY, APRIL, MARCH,

FEBRUARY, JANUARY]

NOVEMBER OCTOBER SEPTEMBER AUGUST JULY JUNE MAY APRIL

MARCH FEBRUARY JANUARY

**/*

A **String** representation is generated from the **Month** constants,

inserted into the **Stack** with **push()**, and later fetched from the top

of the stack with a **pop()**. To make a point, **Vector** operations are

also performed on the **Stack** object. This is possible because, by

virtue of inheritance, a **Stack** *is* a **Vector**. Thus, all operations that can be performed on a **Vector** can also be performed on a **Stack**,

such as **elementAt()**.

As mentioned earlier, use a **LinkedList** when you want stack behavior, or the **onjava.Stack** class created from the **LinkedList** class.

BitSet

A **BitSet** is used to efficiently store a lot of on-off information. It's efficient only from the standpoint of size; if you're looking for efficient access, it is slightly slower than using a native array.

In addition, the minimum size of the **BitSet** is that of a **long**: 64 bits. This implies that if you're storing anything smaller, like 8 bits, a **BitSet** is wasteful; you're better off creating your own class, or just an array, to hold your flags if size is an issue. (This will only be the case if you're creating many objects containing lists of on-off information, and should only be decided based on profiling and other metrics. If you make this decision because you just think something is too big, you end up creating needless complexity and wasting a lot of time.)

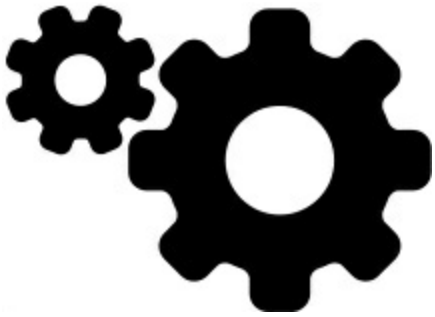
A normal collection expands as you add more elements, and the **BitSet** does this as well. The following example shows how the

BitSet works:

```
// collectiontopics/Bits.java
// Demonstration of BitSet
import java.util.*;
public class Bits {
public static void printBitSet(BitSet b) {
System.out.println("bits: " + b);
StringBuilder bbits = new StringBuilder();
for(int j = 0; j < b.size() ; j++)
bbits.append(b.get(j) ? "1" : "0");
System.out.println("bit pattern: " + bbits);
}
public static void main(String[] args) {
Random rand = new Random(47);
// Take the LSB of nextInt():
byte bt = (byte)rand.nextInt();
BitSet bb = new BitSet();
for(int i = 7; i >= 0; i--)
if(((1 << i) & bt) != 0)
bb.set(i);
```

```
else
bb.clear(i);
System.out.println("byte value: " + bt);
printBitSet(bb);
short st = (short)rand.nextInt();
BitSet bs = new BitSet();
for(int i = 15; i >= 0; i--)
if(((1 << i) & st) != 0)
bs.set(i);
else
bs.clear(i);
System.out.println("short value: " + st);
printBitSet(bs);
int it = rand.nextInt();
BitSet bi = new BitSet();
for(int i = 31; i >= 0; i--)
if(((1 << i) & it) != 0)
bi.set(i);
else
bi.clear(i);
```

```
System.out.println("int value: " + it);
printBitSet(bi);
// Test bitsets >= 64 bits:
BitSet b127 = new BitSet();
b127.set(127);
System.out.println("set bit 127: " + b127);
BitSet b255 = new BitSet(65);
b255.set(255);
System.out.println("set bit 255: " + b255);
BitSet b1023 = new BitSet(512);
b1023.set(1023);
b1023.set(1024);
System.out.println("set bit 1023: " + b1023);
}
}
/* Output:
byte value: -107
bits: {0, 2, 4, 7}
```



bit pattern: 10101001000000000000000000000000000000000

00000000000000000000

short value: 1302

bits: {1, 2, 4, 8, 10}

bit pattern: 01101000101000000000000000000000000000000

00000000000000000000

int value: -2014573909

bits: {0, 1, 3, 5, 7, 9, 11, 18, 19, 21, 22, 23, 24,

25, 26, 31}

bit pattern: 11010101010100000011011111000010000000000

00000000000000000000

set bit 127: {127}

set bit 255: {255}

set bit 1023: {1023, 1024}

**/*

The random number generator is used to create a random **byte**,

short, and **int**, and each one is transformed into a corresponding bit pattern in a **BitSet**. This works fine because a **BitSet** is 64 bits, so none of these cause it to increase in size. Then larger **BitSet**s are created. Notice that the **BitSet** is expanded as necessary.

An **EnumSet** (see the Enumerations chapter) is usually a better choice than a **BitSet** for a fixed set of flags that you can name, because the **EnumSet** lets you manipulate the names rather than numerical bit locations, and thus reduces errors. **EnumSet** also prevents you from accidentally adding new flag locations, which could cause some serious, difficult-to-find bugs. The only reasons to use **BitSet** instead of **EnumSet** is if you don't know how many flags you need until run time, or if it is unreasonable to assign names to the flags, or you need one of the special operations in **BitSet** (see the JDK documentation for **BitSet** and **EnumSet**).

Summary

Collections are arguably the most often-used tools in a programming language. Some languages (Python, for example) even include the fundamental collection components (lists, maps and sets) as built-ins.

As you saw in the Collections chapter, it's possible to do a number of very useful things with collections, without much effort. However, at some point you're forced to know more about collections to use them

properly—in particular, you must know enough about hashing operations to write your own **hashCode()** method (and you must know when it is necessary), and you must know enough about various collection implementations to choose the appropriate one for your needs. This appendix covered these concepts and discussed additional useful details about the collection library. You're now reasonably well prepared to use the Java collections in your everyday programming tasks.

The design of a collections library is difficult (this is true of most library design problems). In C++, the collection classes covered the bases with many different classes. This was better than what was available prior to the C++ collection classes (nothing), but it didn't translate well into Java. At the other extreme, I've seen a collections library that consists of a single class, "collection," which acts like both a linear sequence and an associative array at the same time. The Java collection library attempts to strike a balance between power and complexity. The result can seem a bit odd in places. Unlike some of the decisions made in the early Java libraries, these oddities were not accidents, but carefully considered decisions based on trade-offs in complexity.

1. The **Map**s in **java.util** perform bulk copies using **getKey()** and **getValue()** for **Map**s, so this works. If a custom **Map** were to simply copy the entire **Map.Entry** then this approach would cause a problem.↩

2. Although this sounds odd and possibly useless when I describe it this way, you've seen, especially in the Type Information chapter, that this kind of dynamic behavior can be very powerful.↩

3. If these speedups still don't meet your performance needs, you can further accelerate table lookup by writing your own **Map** and customizing it to your particular types to avoid delays due to casting to and from **Object**s. To reach even higher levels of performance, speed enthusiasts can use Donald Knuth's *The Art of Computer Programming, Volume 3: Sorting and Searching, Second Edition*, to replace overflow bucket lists with arrays that have two additional benefits: they can be optimized for disk storage characteristics and they can save most of the time of creating and garbage collecting individual records.↩

Appendix: Low-Level Concurrency

Although it is never advisable to write

low-level Java concurrency code yourself,

it is often helpful to understand

something of how it works.

The Concurrent Programming chapter introduced the concepts of concurrency at a high level, including more recent and safer constructs

(parallel **Stream**s and **CompletableFuture**s) for concurrent Java

programming. This appendix introduces low-level concurrency

concepts in Java, so you have a grasp of such code when you read it.

You will also gain further insight into the general issues of

concurrency.

Low-level concurrency concepts were a big part of concurrent

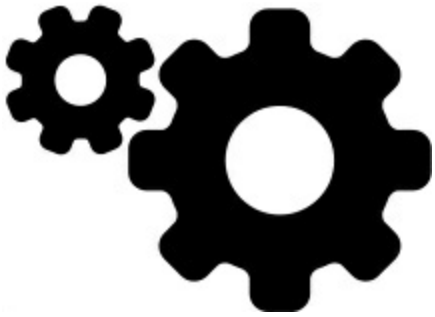
programming in early versions of Java. We'll look at the complexity

around those techniques and why you should avoid them. The

Concurrent Programming chapter demonstrates the improved

techniques afforded by more recent versions of Java (especially Java

8) that make concurrency, if not easy, then much easier.



What is a Thread?

Concurrency partitions a program into separate, independently running tasks. Each task is driven by a *thread of execution*, which we typically shorten to just *thread*. A *thread* is a single sequential flow of control within an operating-system process. A process can thus have multiple concurrently-executing tasks, but you program as if each task has a processor to itself. The threading model is a programming convenience to simplify juggling multiple tasks within a single program. The operating system allocates time from the processor(s) among all of your threads.

The core mechanism of Java concurrency is the **Thread** class. In initial versions of the language, **Thread**s were intended to be created and managed directly by the programmer. As the language evolved and people discovered better approaches, intermediate mechanisms—in particular the **Executor**—were added to remove the mental overhead (and mistakes) of managing threads yourself. Eventually,

even better mechanisms than **Executor** were developed, as shown in the Concurrent Programming chapter.

A **Thread** is a software construct that connects a task to a processor. Although creating and using **Thread**s seems similar to any other class, under the covers they are very different. When you create a **Thread**, the JVM allocates a significant chunk of memory in a special area reserved just for **Thread**s, to provide everything necessary to run a task:

A program counter indicating the next JVM bytecode instruction to execute.

A stack to support the execution of Java code, containing information about the methods this thread has called to reach the

current point of execution. It also contains all local variables for each method being executed (including primitives and references to heap objects). This stack is typically between 64K and 1M *per thread*.1

A second stack for native code.

Storage for *thread-local variables*.

Housekeeping state variables to control the thread.

All code including **main()** runs inside some thread. Whenever a method is called, the current program counter is pushed onto that thread's stack, then the stack pointer is moved down enough to create a *stack frame* with all the storage for that method's local variables, arguments, and the return value. All local primitives go directly on the stack. While any *references* to objects created in the method (or used by the method) live in the stack frame, the objects themselves go on the heap. There's only one heap, shared between all threads in the program.

On top of all this, the **Thread** must be registered with the operating system (OS), so it can actually be connected to a processor at some point. This is managed for you as part of the **Thread** construction process. Java uses the mechanisms in the underlying OS to manage the execution of threads.

The Optimal Number of

Threads

If you look at the examples in Concurrent Programming that use *CachedThreadPool*, you'll see that the **ExecutorService** allocates a thread for each task we submit. However, the parallel **Stream** in

CountingStream.java only allocated 8 threads (*worker* s 1-7 and a thread for **main()**, which it cleverly used for an additional parallel

stream). If you try increasing the upper bound of the **range()**, you'll

see no additional threads are created. Why is this?

We can discover the number of processors on the current machine:

```
// lowlevel/NumberOfProcessors.java
public class NumberOfProcessors {
public static void main(String[] args) {
System.out.println(
Runtime.getRuntime().availableProcessors());
}
}
/* Output:
8
*/
```

On *my* machine (using an Intel Core i7), I have four cores, each

presenting two *hyperthreads* (a hardware trick to produce very rapid

context switching on a single processor, which can in some situations

make it look like two hardware threads). Although this is a common

configuration on "recent" machines (at the time of this writing), you

might see a different result—along with an equivalent number of

default threads in **CountingStream.java**.

Your operating system might have a way to discover more information about your processor. For example, on Windows 10, press the “Start” button, type “Task Manager” and the “Enter” key. Click “More Details.” Choose the “Performance” tab, and you’ll see all kinds of information about your hardware, including “Cores” and “Logical Processors.”

It turns out that the “generic” optimal number of threads is the number of processors available (this might not be true for specific problems). This comes from the cost of *context switching* between Java threads: storing the current state of the thread being suspended

and retrieving the other thread’s current state to continue execution from where it entered suspension. For eight processors and eight (compute-intensive) Java threads, the JVM never has to switch contexts when running those eight tasks. For fewer tasks than the number of processors, it doesn’t help to allocate more threads.

Intel hyperthreading, which defines the number of “logical

processors," does not increase computational capacity—the feature maintains extra thread *contexts* at a hardware level, which speeds context switches, and this helps in the responsiveness of user interfaces, for example. For compute-intensive tasks, consider matching the number of threads to the number of physical cores (not hyperthreads). Although Java considers each hyperthread to be a processor, this appears to be a mistake influenced by Intel's over-marketing of hyperthreads. Despite this, for programming simplicity I'll just allow the JVM to decide the default number of threads. You will want to experiment with your production applications. This doesn't mean that matching the number of threads to the number of processors is appropriate for all problems; on the contrary it's primarily used only for compute-intensive solutions.

How Many Threads Can I Create?

The largest part of a **Thread** object is the Java stack for executing methods. Discovering the size of a **Thread** object varies between operating systems. This program tests it by creating **Thread** objects until the JVM runs out of memory:

// lowlevel/ThreadSize.java

```
// {ExcludeFromGradle} Takes a long time or hangs
import java.util.concurrent.*;
import onjava.Nap;
public class ThreadSize {
static class Dummy extends Thread {
@Override
public void run() { new Nap(1); }
}
public static void main(String[] args) {
ExecutorService exec =
Executors.newCachedThreadPool();
int count = 0;
try {
while(true) {
exec.execute(new Dummy());
count++;
}
} catch(Error e) {
System.out.println(
e.getClass().getSimpleName() + ": " + count);
```

```
System.exit(0);
} finally {
exec.shutdown();
}
}
}
```

A *CachedThreadPool* continues creating **Thread**s as long as you keep passing it tasks. Passing a **Dummy** object to **execute()** starts the task, allocating a new **Thread** if one isn't available. The **pause()** size must be large enough that tasks don't start finishing (thus freeing up existing **Thread**s for new tasks). As long as tasks keep coming in and not finishing, a *CachedThreadPool* will eventually run out of memory.

I wasn't always able to cause out-of-memory errors on every machine I tried. On one machine, I see this result:

```
>java ThreadSize
OutOfMemoryError: 2816
```

We can reduce each **Thread**s stack size using the **-Xss** flag. The minimum stack size allowed is 64k:

```
>java -Xss64K ThreadSize
```

OutOfMemoryError: 4952

If we increase the stack size to 2 Megabytes, we can allocate far fewer threads:

>java -Xss2M ThreadSize

OutOfMemoryError: 722

The default Windows stack size is 320K, which we can verify by noting it gives us about the same number as when we don't set the stack size at all:

>java -Xss320K ThreadSize

OutOfMemoryError: 2816

You can also increase the JVM's maximum memory allocation using the **-Xmx** flag:

>java -Xss64K -Xmx5M ThreadSize

OutOfMemoryError: 5703

Notice that the operating system may also apply limits to the number of threads allowed.

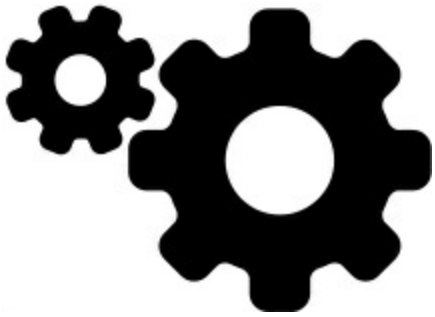
So the answer to the question "how many threads can I have" is "a few thousand." If you find yourself allocating thousands of threads, however, you might want to rethink your approach; the appropriate question is "how many threads do I *need*?"

The WorkStealingPool

This is an **ExecutorService** that automatically creates a thread pool using all available processors (as reported by the JVM).

```
// lowlevel/WorkStealingPool.java
import java.util.stream.*;
import java.util.concurrent.*;
class ShowThread implements Runnable {
@Override
public void run() {
System.out.println(
Thread.currentThread().getName());
}
}
public class WorkStealingPool {
public static void main(String[] args)
throws InterruptedException {
System.out.println(
Runtime.getRuntime().availableProcessors());
ExecutorService exec =
Executors.newWorkStealingPool();
```

```
IntStream.range(0, 10)
.mapToObj(n -> new ShowThread())
.forEach(exec::execute);
exec.awaitTermination(1, TimeUnit.SECONDS);
}
}
/* Output:
8
ForkJoinPool-1-worker-2
ForkJoinPool-1-worker-1
ForkJoinPool-1-worker-2
ForkJoinPool-1-worker-3
ForkJoinPool-1-worker-2
ForkJoinPool-1-worker-1
ForkJoinPool-1-worker-3
ForkJoinPool-1-worker-1
ForkJoinPool-1-worker-4
ForkJoinPool-1-worker-2
*/
```



The Work Stealing algorithm allows threads that have run out of work items in their input queue to “steal” work items from other queues.

The goal is to distribute work items among processors, thus making

maximal use of all available processors for compute-intensive tasks. It

is also used in Java’s fork/join framework.

Catching Exceptions

This might surprise you:

// lowlevel/SwallowedException.java

import java.util.concurrent.*;

public class SwallowedException {

public static void main(String[] args)

throws InterruptedException {

ExecutorService exec =

Executors.newSingleThreadExecutor();

exec.submit(() -> {

throw new RuntimeException();

});

exec.shutdown();

}

}

This program outputs … nothing (if, however, you replace **submit()** with **execute()**, you *will* see the exception). This points out that exceptions thrown inside threads are tricky, and require special attention.

You can't catch an exception that has escaped from a thread. Once an exception gets outside of a task's **run()** method, it will propagate out to the console unless you take special steps to capture such errant exceptions.

Here's a task that throws an exception which propagates outside of its **run()** method, and a **main()** that shows what happens when you run it:

```
// lowlevel/ExceptionThread.java
// {ThrowsException}
import java.util.concurrent.*;
public class ExceptionThread implements Runnable {
@Override
public void run() {
```

```
throw new RuntimeException();
}
public static void main(String[] args) {
ExecutorService es =
Executors.newCachedThreadPool();
es.execute(new ExceptionThread());
es.shutdown();
}
}
/* Output:
___[ Error Output ]___
Exception in thread "pool-1-thread-1"
java.lang.RuntimeException
at ExceptionThread.run(ExceptionThread.java:8)
at java.util.concurrent.ThreadPoolExecutor.runW
orker(ThreadPoolExecutor.java:1142)
at java.util.concurrent.ThreadPoolExecutor$Work
er.run(ThreadPoolExecutor.java:617)
at java.lang.Thread.run(Thread.java:745)
*/
```

The output is (after trimming some qualifiers to fit):

Exception in thread "pool-1-thread-1" RuntimeException

at ExceptionThread.run(ExceptionThread.java:9)

at ThreadPoolExecutor.runWorker(...)

at ThreadPoolExecutor$Worker.run(...)

at java.lang.Thread.run(Thread.java:745)

Encompassing the body of main within a **try-catch** block is unsuccessful:

```
// lowlevel/NaiveExceptionHandling.java
// {ThrowsException}
import java.util.concurrent.*;
public class NaiveExceptionHandling {
public static void main(String[] args) {
ExecutorService es =
Executors.newCachedThreadPool();
try {
es.execute(new ExceptionThread());
} catch(RuntimeException ue) {
// This statement will NOT execute!
System.out.println("Exception was handled!");
```

} **finally** {

es.shutdown();

}

}

}

/ *Output:*

___[Error Output]___

Exception in thread "pool-1-thread-1"

java.lang.RuntimeException

at ExceptionThread.run(ExceptionThread.java:8)

at java.util.concurrent.ThreadPoolExecutor.runW

orker(ThreadPoolExecutor.java:1142)

at java.util.concurrent.ThreadPoolExecutor$Work

er.run(ThreadPoolExecutor.java:617)

at java.lang.Thread.run(Thread.java:745)

**/*

This produces the same result as the previous example: an uncaught exception.

To solve the problem, change the way the **Executor** produces threads. **Thread.UncaughtExceptionHandler** is an interface

for attaching an exception handler to each **Thread** object.

Thread.UncaughtExceptionHandler.uncaughtException()

is automatically called when that thread is about to die from an uncaught exception. To use it, we create a new type of

ThreadFactory which attaches a new

Thread.UncaughtExceptionHandler to each new **Thread**

object it creates. We pass that factory to the **Executors** method that creates a new **ExecutorService**:

```
// lowlevel/CaptureUncaughtException.java
import java.util.concurrent.*;
class ExceptionThread2 implements Runnable {
@Override
public void run() {
Thread t = Thread.currentThread();
System.out.println("run() by " + t.getName());
System.out.println(
"eh = " + t.getUncaughtExceptionHandler());
throw new RuntimeException();
}
}
```

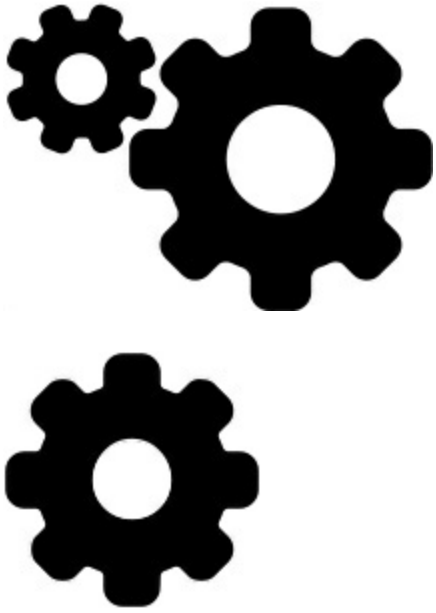
```
class MyUncaughtExceptionHandler implements
Thread.UncaughtExceptionHandler {
@Override
public void uncaughtException(Thread t, Throwable e) {
System.out.println("caught " + e);
}
}
class HandlerThreadFactory implements ThreadFactory {
@Override
public Thread newThread(Runnable r) {
System.out.println(this + " creating new Thread");
Thread t = new Thread(r);
System.out.println("created " + t);
t.setUncaughtExceptionHandler(
new MyUncaughtExceptionHandler());
System.out.println(
"eh = " + t.getUncaughtExceptionHandler());
return t;
}
}
```

```
public class CaptureUncaughtException {
public static void main(String[] args) {
ExecutorService exec =
Executors.newCachedThreadPool(
new HandlerThreadFactory());
exec.execute(new ExceptionThread2());
exec.shutdown();
}
}
/* Output:
HandlerThreadFactory@4e25154f creating new Thread
created Thread[Thread-0,5,main]
eh = MyUncaughtExceptionHandler@70dea4e
run() by Thread-0
eh = MyUncaughtExceptionHandler@70dea4e
caught java.lang.RuntimeException
*/
```

Additional tracing verifies that the threads created by the factory get the new **UncaughtExceptionHandler**. The uncaught exceptions are now captured by **uncaughtException**.

The above example sets the handler on a case-by-case basis. If you know that you’re going to use the same exception handler everywhere, an even simpler approach is to set the *default* uncaught exception handler, which sets a **static** field inside the **Thread** class:

```
// lowlevel/SettingDefaultHandler.java
import java.util.concurrent.*;
public class SettingDefaultHandler {
public static void main(String[] args) {
Thread.setDefaultUncaughtExceptionHandler(
new MyUncaughtExceptionHandler());
ExecutorService es =
Executors.newCachedThreadPool();
es.execute(new ExceptionThread());
```



```
es.shutdown();
}
}
/* Output:
caught java.lang.RuntimeException
*/
```

This handler is only called if there is no per-thread uncaught exception handler. The system checks for a per-thread version, and if it doesn't find one it checks to see if the thread group specializes its **uncaughtException()** method; if not, it calls the **defaultUncaughtExceptionHandler**.

Compare this with the improved approach seen with **CompletableFuture**s.

Sharing Resources

You can think of a single-threaded program as one lonely entity moving around through your problem space and doing one thing at a time. Because there's only one entity, you never think about the problem of two entities trying to use the same resource at the same time: problems such as two people trying to park in the same space, walk through a door at the same time, or even talk at the same time.

With concurrency, things aren’t lonely anymore, but now two or more tasks might interfere with each other. If you don’t prevent such a collision, you’ll have two tasks trying to access the same bank account at the same time, print to the same printer, adjust the same valve, and so on.

Resource Contention

When you start a task to perform some work, the results of that work can be captured in two different ways: through *side effects* or via a return value.

Programmatically, side effects can seem easier: you just use your results to manipulate something in the environment. For example, your task might perform some calculation, then directly write its results into a collection.

The problem with this approach is that the collection is typically a *shared resource*. When more than one task is running, any task might read or write a shared resource at the same time. This reveals the problem of *resource contention*, one of the main pitfalls when working with tasks.

You don’t think about resource contention in a single-threaded system because you’re never doing more than one thing at a time. When you have multiple tasks, you must always guard against resource

contention.

One approach to the problem is to use a collection that copes with resource contention. If more than one task tries to write to such a collection at the same time, such collections compensate for the problem. You'll find a number of classes in the Java concurrency libraries that attempt to solve resource contention problems; in this appendix you'll see a handful of these but the coverage is not comprehensive.

Consider the following example, where one task generates even numbers and other tasks consume those numbers. Here, the only job of the consumer tasks is to check the validity of the even numbers. We shall define **EvenChecker**, the consumer task, to make it reusable in the subsequent examples. To decouple **EvenChecker** from our various experimental generators, we'll first create an abstract class called **IntGenerator**, which contains the minimum necessary methods that **EvenChecker** must know about: it has a **next()** method and it can be canceled.

```
// lowlevel/IntGenerator.java
import java.util.concurrent.atomic.AtomicBoolean;
public abstract class IntGenerator {
```

```
private AtomicBoolean canceled =
new AtomicBoolean();
public abstract int next();
public void cancel() { canceled.set(true); }
public boolean isCanceled() {
return canceled.get();
}
}
```

cancel() changes the state of the **AtomicBoolean canceled** flag and **isCanceled()** tells whether the flag is set. Because the **canceled** flag is **AtomicBoolean**, it is *atomic*, which means simple operations like assignment and value return happen without the possibility of interruption, so you can't see the field in an intermediate state in the midst of those simple operations. You'll learn more about atomicity and the **Atomic** classes later in this appendix.

Any **IntGenerator** can be tested with the following **EvenChecker** class:

```
// lowlevel/EvenChecker.java
import java.util.*;
import java.util.stream.*;
```

```
import java.util.concurrent.*;
import onjava.TimedAbort;
public class EvenChecker implements Runnable {
private IntGenerator generator;
private final int id;
public EvenChecker(IntGenerator generator, int id) {
this.generator = generator;
this.id = id;
}
@Override
public void run() {
while(!generator.isCanceled()) {
int val = generator.next();
if(val % 2 != 0) {
System.out.println(val + " not even!");
generator.cancel(); // Cancels all EvenCheckers
}
}
}
// Test any IntGenerator:
```

```
public static void test(IntGenerator gp, int count) {
List<CompletableFuture<Void>> checkers =
IntStream.range(0, count)
.mapToObj(i -> new EvenChecker(gp, i))
.map(CompletableFuture::runAsync)
.collect(Collectors.toList());
checkers.forEach(CompletableFuture::join);
}
// Default value for count:
public static void test(IntGenerator gp) {
new TimedAbort(4, "No odd numbers discovered");
test(gp, 10);
}
}
```

The **test()** method starts a number of **EvenChecker**s that access the same **IntGenerator**. **EvenChecker** tasks constantly read and test the values from their associated **IntGenerator**. If the **IntGenerator** causes a failure, **test()** reports it and returns.

All **EvenChecker** tasks that depend on the **IntGenerator** object check it to see whether it’s been canceled. If

generator.isCanceled() is **true**, **run()** returns. Any **EvenChecker** task can call **cancel()** on the **IntGenerator**, which causes all other **EvenChecker**s using that **IntGenerator** to gracefully shut down.

In this design, tasks sharing a common resource (the **IntGenerator**) watch that resource for the signal to terminate. This eliminates the so-called race condition, where two or more tasks race to respond to a condition and thus collide or otherwise produce inconsistent results.

You must carefully think about and protect against all possible ways a concurrent system can fail. For example, a task cannot depend on another task, because task shutdown order is not guaranteed. Here, by making tasks depend on a non-task object, we eliminate the potential race condition.

Normally, we presume that **test()** eventually fails because the **EvenChecker** tasks are able to access the information in **IntGenerator** while it's in an "incorrect" state. However, it might not detect the problem until the **IntGenerator** has completed many cycles, depending on the particulars of your operating system and other implementation details. To ensure that this book's

automated build doesn’t get stuck, we use **TimedAbort**, defined here:

```
// onjava/TimedAbort.java
// Terminate a program after t seconds
package onjava;
import java.util.concurrent.*;
public class TimedAbort {
private volatile boolean restart = true;
public TimedAbort(double t, String msg) {
CompletableFuture.runAsync(() -> {
try {
while(restart) {
restart = false;
TimeUnit.MILLISECONDS
.sleep((int)(1000 * t));
}
} catch(InterruptedException e) {
throw new RuntimeException(e);
}
System.out.println(msg);
```

```
System.exit(0);
});
}
public TimedAbort(double t) {
this(t, "TimedAbort " + t);
}
public void restart() { restart = true; }
}
```

We create a **Runnable** using a lambda expression, which is executed using the **static runAsync()** method of **CompletableFuture**. The value of **runAsync()** is that it returns immediately. As a result, **TimedAbort** doesn't hold any task open that would otherwise complete, but if it takes too long it will still terminate that task (**TimedAbort** is sometimes referred to as a *daemon*).

TimedAbort also allows you to **restart()** it, in order to keep a program open if there is some kind of useful activity going on.

We can see **TimedAbort** in action:

```
// lowlevel/TestAbort.java
import onjava.*;
```

```
public class TestAbort {
public static void main(String[] args) {
new TimedAbort(1);
System.out.println("Napping for 4");
new Nap(4);
}
}
/* Output:
Napping for 4
TimedAbort 1.0
*/
```

If you comment out the **Nap** line, the program exits immediately, showing that **TimedAbort** is not holding the program open.

The first **IntGenerator** we'll look at has a **next()** that produces a series of even values:

```
// lowlevel/EvenProducer.java
// When threads collide
// {VisuallyInspectOutput}
public class EvenProducer extends IntGenerator {
private int currentEvenValue = 0;
```

```
@Override
public int next() {
++currentEvenValue; // [1]
++currentEvenValue;
return currentEvenValue;
}
public static void main(String[] args) {
EvenChecker.test(new EvenProducer());
}
}
/* Output:
419 not even!
425 not even!
423 not even!
421 not even!
417 not even!
*/
```

[1] It's possible for one task to call **next()** after another task has performed the first increment of **currentEvenValue** but not the second. This puts the value into an "incorrect" state.

To prove this can happen, **EvenChecker.test()** creates a group of **EvenChecker** objects to continually read the output of an **EvenProducer** and test to see if each one is even. If not, the error is reported and the program is shut down.

Part of the problem with multithreaded programs is they can appear correct even when there’s a bug, if the probability for failure is very low.

It’s important to note that the increment operation itself requires multiple steps, and the task can be suspended by the threading mechanism in the midst of an increment—that is, increment is not an atomic operation in Java. So even a single increment isn’t safe without protecting the task.

The program doesn’t always terminate the first time a non-even number is produced. All the tasks don’t instantly shut down, which is typical of a concurrent program.

Resolving Resource

Contention

The previous example shows a fundamental problem when you use threads: You never know when a thread might run. Imagine sitting at a table with a fork, about to spear the last piece of food on a platter, and as your fork reaches for it, the food suddenly vanishes … because your thread was suspended and another diner came in and ate the food. That's the problem you're dealing with when writing concurrent programs. For concurrency to work, you need some way to prevent two tasks from accessing the same resource, at least during critical periods.

Preventing this kind of collision is a matter of putting a lock on a resource when one task is using it. The first task that accesses a resource must lock it, then the other tasks cannot access that resource until it is unlocked, at which time another task locks and uses it, and so on. If the front seat of the car is the limited resource, the child who shouts "shotgun!" acquires the lock (for the duration of that trip).

To solve the problem of thread collision, basic concurrency schemes *serialize access to shared resources*. This means only one task at a time is allowed to access the shared resource. This is ordinarily accomplished by putting a clause around a piece of code that only allows one task at a time to pass through that piece of code. Because this clause produces *mutual exclusion*, a common name for such a

mechanism is *mutex*.

Consider the bathroom in your house; multiple people (tasks driven by threads) want exclusive use of the bathroom (the shared resource). To access the bathroom, a person knocks on the door to see if it's available. If so, they enter and lock the door. Any other task that wants to use the bathroom is "blocked" from using it, so those tasks wait at the door until the bathroom is available.

The analogy breaks down a bit when the bathroom is released and it comes time to give access to another task. There isn't actually a line of people, and we don't know for sure who gets the bathroom next, because the thread scheduler isn't deterministic. Instead, it's as if there is a group of blocked tasks milling about in front of the bathroom, and when the task that has locked the bathroom unlocks it and emerges, the thread scheduler decides which task will be the next to go in.

To prevent collisions over resources, Java has built-in support in the form of the **synchronized** keyword. When a task wishes to execute a piece of code guarded by the **synchronized** keyword, the Java compiler generates the code to see if the lock is available. If it is, the task acquires it, executes the code, and releases it.

The shared resource is typically just a piece of memory in the form of an object, but it can also be a file, an I/O port, or something like a printer. To control access to a shared resource, you first put it inside an object. Then any method that uses the resource can be made **synchronized**. If a task is inside a call to one of the **synchronized** methods, all other tasks are blocked from entering *any* of the **synchronized** methods of that object until the first task returns from its call.

You typically make fields **private** and access those fields only through methods. You prevent collisions by declaring methods using the **synchronized** keyword, like this:

synchronized void f() { /* ... */ }

synchronized void g() { /* ... */ }

All objects automatically contain a single lock (also called a *monitor*). When you call any **synchronized** method, that object is locked and no other **synchronized** method of that object can be called until the first one finishes and releases the lock. If **f()** is called for an object by one task, a different task cannot call **f()** *or* **g()** for the same object until **f()** is completed and releases the lock. Thus, there is a single lock shared by all **synchronized** methods of a particular

object, and this lock can prevent object memory from being written by more than one task at a time.

It’s especially important to make fields **private** when working with concurrency; otherwise the **synchronized** keyword cannot prevent another task from accessing a field directly, and thus producing collisions.

One thread can acquire an object’s lock multiple times. This happens if one method calls a second method on the same object, which in turn calls another method on the same object, etc. The JVM keeps track of the number of times the object is locked. If the object is unlocked, it has a count of zero. As a thread acquires the lock for the first time, the count goes to one. Each time the same thread acquires another lock on the same object, the count is incremented. Naturally, multiple lock acquisition is only allowed for the thread that acquired the lock in the first place. Each time the thread leaves a **synchronized** method, the count is decremented, until the count goes to zero, releasing the

lock entirely for use by other threads.

There's also a single lock *per class* (as part of the **Class** object for that class), so **synchronized static** methods can lock each other out from simultaneous access of **static** data on a class-wide basis.

When should you synchronize? Apply *Brian's Rule of Synchronization*:2

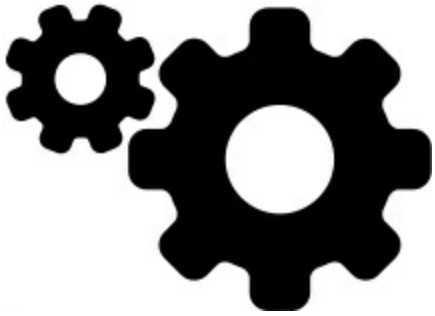
If you are writing a variable that might
next be read by another thread, or
reading a variable that might have last
been written by another thread, you must
use synchronization, and further, both the
reader and the writer must synchronize
using the same monitor lock.

With more than one method in your class dealing with critical data, you must synchronize all relevant methods. If you synchronize only one of the methods, then the others are free to ignore the object lock and can be called with impunity. This is an important point: Every operation that accesses a critical shared resource must be **synchronized** or it won't work right.

Synchronizing the

EvenProducer

By adding **synchronized** to **EvenProducer.java**, we can prevent the undesirable thread access:



```
// lowlevel/SynchronizedEvenProducer.java
// Simplifying mutexes with the synchronized keyword
import onjava.Nap;
public class
SynchronizedEvenProducer extends IntGenerator {
private int currentEvenValue = 0;
@Override
public synchronized int next() {
++currentEvenValue;
new Nap(0.01); // Cause failure faster
++currentEvenValue;
return currentEvenValue;
}
```

```
public static void main(String[] args) {
EvenChecker.test(new SynchronizedEvenProducer());
}
}
/* Output:
No odd numbers discovered
*/
```

A **Nap()** is inserted between the two increments, to raise the likelihood of a context switch while **currentEvenValue** is in an odd state. Because the mutex prevents more than one task at a time in the critical section, this will not produce a failure. The first task that enters **next()** acquires the lock, and any further tasks that try to acquire the lock are blocked from doing so until the first task releases the lock. At that point, the scheduling mechanism selects another task that is waiting on the lock. This way, only one task at a time can pass through the code that is guarded by the mutex.

The volatile Keyword

volatile is perhaps the most subtle and difficult keyword in Java. Fortunately, in modern Java you can virtually always avoid using it,

and if you *do* see it used in code you should be skeptical and suspicious—there's a good chance that either the code is old, or whoever wrote that code doesn't understand the ramifications of **volatile** or concurrency in general (or both).

volatile is used for three reasons.

Word Tearing

Word tearing occurs when your data type is large enough (**long** and **double** in Java, which are both 64 bits) that the process of writing to a variable happens in two steps. The JVM is allowed to perform reads and writes of 64-bit quantities as two separate 32-bit operations,[3] raising the possibility that a context switch happens in the middle of a read or write, so other tasks see incorrect results. This is called *word tearing* because you might see the value after only part of it changes.

Basically, a task can sometimes read the variable after the first step but before the second, resulting in a garbage value (This is not a problem with small variables such as **boolean** or **int**; anything except **long** or **double**).

Defining a **long** or **double** as **volatile**—in the absence of any other protection—prevents word tearing. However, **volatile** is superseded if those variables are guarded using **synchronized** or one of the **java.util.concurrent.atomic** classes. Also, **volatile** doesn't affect the fact that an increment isn't an atomic operation.

Visibility

The second problem falls under the "everything matters" part of Maxim 2 of The Four Maxims of Java Concurrency. You must assume that every task has its own processor, and each processor has its own local memory cache. This cache allows the processor to run faster because it won't always need to fetch data from main memory, which takes significantly longer than using cached values.

The problem arises because Java tries to be as efficient as possible. The whole point of the cache is to avoid reading from main memory. But with concurrency, it sometimes becomes unclear when Java should refresh values from main memory into the local cache—this

issue is called *cache coherence*.

Each thread can store local copies of variables in the processor cache. Defining a field as **volatile** prevents these compiler optimizations so that reads and writes go directly to memory, and are not cached. As soon as a write occurs for that field, all reads across all tasks will see the change. If a **volatile** field happens to be held in a local cache, it is immediately written through to main memory, and any reads of that field will always occur from main memory.

volatile should be applied to a variable when:

1. That variable is simultaneously accessed by multiple tasks.
2. At least one of those accesses is a write.
3. You are trying to avoid synchronization (in modern Java, you can avoid synchronization using higher-level tools).

For example, if you use a variable as a flag to stop a task, that variable must at least be declared **volatile** (although that doesn't necessarily guarantee thread-safety for such a flag). Otherwise, when one task makes changes to the flag, those changes can be stored in the local processor cache and not flushed to main memory. When another task looks at the flag it doesn't see the changes. (I prefer the **AtomicBoolean** approach for flags shown in Concurrent

Programming in the section Terminating Long-Running Tasks).

Any writes that a task makes to its own variables are always visible to that task, so you don't need to make a variable **volatile** if it is only used within a task.

If a single thread writes to a variable and other threads only read it, you can get away with making that variable **volatile**. In general, if you have multiple threads writing to a variable, **volatile** won't solve your problems, and you must use **synchronized** instead to prevent race conditions. There is a special exception to this: It's possible to have multiple threads writing to that variable, *as long as they don't need to read it first and use the value to create the new value to write into the variable.* If those multiple threads use the old value in the result, you have a race condition because one of the other threads could modify the variable while your thread is doing its calculation. Even if you start out doing it right, imagine how easy it is to forget and introduce a breaking change during code modifications or maintenance, or for a different programmer who doesn't understand the issue (This is especially problematic in Java because programmers tend to rely heavily on compile-time checking to tell them if their code is correct).

It’s important to understand that atomicity and volatility are distinct concepts. An atomic operation on a non-**volatile** variable has no guarantees about whether it is flushed to main memory. Synchronization also causes flushing to main memory, so if a variable is completely guarded by **synchronized** methods or blocks (or is one of the **java.util.concurrent.atomic** types), it is not necessary to make it **volatile**.

Reordering and *Happens Before*

Java may optimize performance by reordering instructions, as long as the result produces no changes in program behavior. This reordering, however, can affect the way the local processor cache interacts with main memory, producing subtle program bugs. It wasn’t until Java 5 that this issue was understood and fixed. Now the **volatile** keyword prevents problematic reordering of reading and writing instructions around **volatile** variables. This reordering rule is called the *happens before* guarantee.

Instructions that happen before the read or write of a **volatile** variable are guaranteed to happen before that read or write. Similarly, any instructions that follow a read or write of a **volatile** variable are guaranteed to happen after the read or write. For example:

```
// lowlevel/ReOrdering.java
public class ReOrdering implements Runnable {
int one, two, three, four, five, six;
volatile int volaTile;
@Override
public void run() {
one = 1;
two = 2;
three = 3;
volaTile = 92;
int x = four;
int y = five;
int z = six;
}
}
```

The assignments of **one**, **two** and **three** may be reordered, as long

as they all happen before the **volatile** write. Similarly, the **x**, **y** and

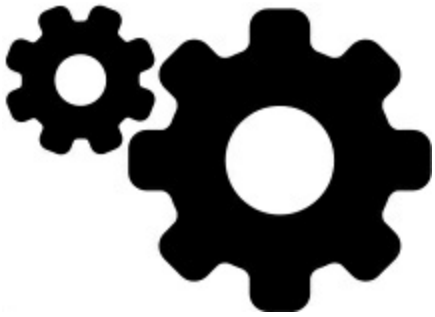
z statements may be reordered as long as the **volatile** write happens before all of them. The **volatile** operation is often called a *memory barrier*. The *happens before* guarantee ensures that read and write instructions of **volatile** variables cannot be reordered across a memory barrier.

The *happens before* guarantee has another effect: When a thread writes to a **volatile** variable, then all other variables—including non-**volatile**s—changed by the thread before writing to the **volatile** variable are also flushed to main memory. When a thread reads a **volatile** variable it also reads all other variables—including non-**volatile**s—that were flushed to main memory together with the **volatile** variable. Although this is an important feature that solves some very devious bugs that appeared in Java before version 5, you shouldn't rely on it to "automatically" make surrounding variables **volatile**. If you intend for a variable to be **volatile**, that should be clear to anyone maintaining your code.

When to use volatile

With earlier versions of Java it wasn't too hard to write an example that demonstrated the need for **volatile**. If you search you can find such examples, but if you try them with Java 8 they don't work (none that I've found). I have struggled to write such an example but to no avail. This might result from improvements in the JVM or the hardware or both. The effect could be beneficial for existing programs with storage that ought to be **volatile** but isn't; for such programs, failures will occur far less often—and the problem will be that much harder to track down.

If you are attempting to use **volatile**, you're probably trying to



make a variable thread-safe without incurring the cost of synchronization. Because **volatile** is so subtle and tricky to use, I suggest not using it at all; instead, use one of the **java.util.concurrent.atomic** classes, described later in this appendix. Those give complete thread-safety at a much lower cost than

synchronization.

If you are trying to debug someone else's concurrency code, first look for uses of **volatile** and replace those with **Atomic** variables.

Unless you know for sure that the programmer has a high level of understanding of concurrency, it's likely they are misusing **volatile**.

Atomicity

An oft-repeated but incorrect piece of lore in Java threading discussions is that "Atomic operations do not need synchronization."

An *atomic operation* is one that cannot be interrupted by the thread scheduler; if the operation begins, it runs to completion before the possibility of a context switch. Relying on *innate* atomicity (atomicity that is part of the nature of a particular data type) is tricky and dangerous—you should only try to use innate atomicity instead of synchronization or a thread-safe data structure if you are a concurrency expert, or you have help from such an expert. If you think you're smart enough to play with this kind of fire, take this test:

The Goetz Test: If you can write a high-performance JVM for a modern microprocessor, then you are qualified to

think about whether you can avoid

synchronizing. [4]

It's useful to *know* about innate atomicity, and to know that, along with other advanced techniques, it was used to implement some of the

more clever **java.util.concurrent** library components. But

strongly resist the urge to rely on it yourself.

Atomicity applies to "simple operations" on primitive types except for

longs and **double**s. Reading and writing primitive variables other

than **long** and **double** is guaranteed to happen as indivisible

(atomic) operations.

Atomic operations are thus not interruptible by the threading

mechanism. Expert programmers can take advantage of this to write

lock-free code, which does not need synchronization. But even this is

an oversimplification. Sometimes, even when it seems like an atomic

operation should be safe, it might not be. Readers of this book will not

typically pass the aforementioned Goetz Test, and will thus not be

qualified to try to replace synchronization with atomic operations.

Trying to remove synchronization is usually a sign of premature

optimization, and will cause you much trouble, probably without

gaining much, or anything.

On multicore systems, *visibility* rather than atomicity is much more of

an issue than on single-processor systems. Changes made by one task, even if they're atomic in the sense of not being interruptible, might not be visible to other tasks (the changes might be temporarily stored in a local processor cache, for example), so different tasks have a different view of the application's state. The synchronization mechanism, on the other hand, forces changes by one task on a multiprocessor system to be visible across the application. Without synchronization, it's indeterminate when changes become visible.

What qualifies as an atomic operation? Assignment and returning the value in a field might be. In C++ even the following *might* be atomic:

```
i++; // Might be atomic in C++
i += 2; // Might be atomic in C++
```

But in C++, this depends on the compiler and processor. You're unable to write cross-platform code in C++ that relies on atomicity, because C++5 didn't have a consistent *memory model*, as Java does.

In Java, the above operations are definitely *not* atomic, as shown by the JVM instructions produced from the following methods:

```
// lowlevel/NotAtomic.java
// {javap -c NotAtomic}
// {VisuallyInspectOutput}
```

```
public class NotAtomic {
int i;
void f1() { i++; }
void f2() { i += 3; }
}
/* Output:
Compiled from "NotAtomic.java"
public class NotAtomic {
int i;
public NotAtomic();
Code:
0: aload_0
1: invokespecial #1 // Method
java/lang/Object."<init>":()V
4: return
void f1();
Code:
0: aload_0
1: dup
2: getfield #2 // Field
```

i:I

5: iconst_1

6: iadd

7: putfield #2 // Field

i:I

10: return

void f2();

Code:

0: aload_0

1: dup

2: getfield #2 // Field

i:I

5: iconst_3

6: iadd

7: putfield #2 // Field

i:I

10: return

}

**/*

Each instruction produces a “get” and a “put,” with instructions in

between. So in between getting and putting, another task could modify the field, and thus the operations are not atomic.

Let’s test this idea of atomicity by defining an abstract class with a method that increments a integer value by even amounts, and a **run()** that constantly calls that method:

```
// lowlevel/IntTestable.java
import java.util.function.*;
public abstract class
IntTestable implements Runnable, IntSupplier {
abstract void evenIncrement();
@Override
public void run() {
while(true)
evenIncrement();
}
}
```

IntSupplier is a functional interface with a **getAsInt()** method.

Now we can create a test that starts **run()** as a separate task and then fetches values to check whether they are even:

```
// lowlevel/Atomicity.java
import java.util.concurrent.*;
import onjava.TimedAbort;
public class Atomicity {
public static void test(IntTestable it) {
new TimedAbort(4, "No failures found");
CompletableFuture.runAsync(it);
while(true) {
int val = it.getAsInt();
if(val % 2 != 0) {
System.out.println("failed with: " + val);
System.exit(0);
}
}
}
}
```

It’s easy to blindly apply the idea of atomicity. Here, **getAsInt()** appears to be safely atomic:

```
// lowlevel/UnsafeReturn.java
import java.util.function.*;
```

```
import java.util.concurrent.*;
public class UnsafeReturn extends IntTestable {
private int i = 0;
public int getAsInt() { return i; }
public synchronized void evenIncrement() {
i++; i++;
}
public static void main(String[] args) {
Atomicity.test(new UnsafeReturn());
}
}
/* Output:
failed with: 79
*/
```

However, **Atomicity.test()** fails with non-even values. Although **return i** is indeed an atomic operation, the lack of synchronization allows the value to be read while the object is in an unstable

intermediate state. On top of this, since **i** isn't **volatile** either, there are visibility problems. Both **getValue()** *and* **evenIncrement()** must be **synchronized** (which also takes care of **i** without making it **volatile**):

```
// lowlevel/SafeReturn.java
import java.util.function.*;
import java.util.concurrent.*;
public class SafeReturn extends IntTestable {
private int i = 0;
public synchronized int getAsInt() { return i; }
public synchronized void evenIncrement() {
i++; i++;
}
public static void main(String[] args) {
Atomicity.test(new SafeReturn());
}
}
/* Output:
No failures found
*/
```

Only concurrency experts are qualified to attempt optimizations in situations like this; again, apply Brian's Rule of Synchronization.

Josh's Serial Numbers

As a second example, consider something even simpler: a class producing serial numbers, inspired by Joshua Bloch's *Effective Java Programming Language Guide* (Addison-Wesley, 2001), p. 190. Each call to **nextSerialNumber()** must return a unique value:

```
// lowlevel/SerialNumbers.java
public class SerialNumbers {
private volatile int serialNumber = 0;
public int nextSerialNumber() {
return serialNumber++; // Not thread-safe
}
}
```

SerialNumbers is about as simple a class as you can imagine, and if you're coming from C++ or some other low-level background, you might expect the increment to be an atomic operation, because a C++ increment can often be implemented as a single microprocessor instruction (although not in any consistent, reliable, cross-platform fashion). As noted before, however, a Java increment is *not* atomic and

involves both a read and a write, so there's room for threading problems even in such a simple operation.

We throw in **volatile** here just to see if it might help. However, the real problem is that **nextSerialNumber()** accesses a shared mutable value without synchronizing.

To test **SerialNumbers**, we'll create a set that doesn't run out of memory, in case it takes a long time to detect a problem. The **CircularSet** shown here reuses the memory that stores **int**s, eventually overwriting old values (duplicates often happen quickly enough that you could probably use a **java.util.Set** instead):

```
// lowlevel/CircularSet.java
// Reuses storage so we don't run out of memory
import java.util.*;
public class CircularSet {
private int[] array;
private int size;
private int index = 0;
public CircularSet(int size) {
this.size = size;
array = new int[size];
```

```
// Initialize to a value not produced
// by SerialNumbers:
Arrays.fill(array, -1);
}
public synchronized void add(int i) {
array[index] = i;
// Wrap index and write over old elements:
index = ++index % size;
}
public synchronized boolean contains(int val) {
for(int i = 0; i < size; i++)
if(array[i] == val) return true;
return false;
}
}
```

The **add()** and **contains()** methods are **synchronized** to prevent thread collisions.

SerialNumberChecker contains a **CircularSet** holding the most recent serial numbers, and a **run()** that fills the **CircularSet** and ensures those serial numbers are unique:

```
// lowlevel/SerialNumberChecker.java
// Test SerialNumbers implementations for thread-safety
import java.util.concurrent.*;
import onjava.Nap;
public class SerialNumberChecker implements Runnable {
private CircularSet serials = new CircularSet(1000);
private SerialNumbers producer;
public SerialNumberChecker(SerialNumbers producer) {
this.producer = producer;
}
@Override
public void run() {
while(true) {
int serial = producer.nextSerialNumber();
if(serials.contains(serial)) {
System.out.println("Duplicate: " + serial);
System.exit(0);
}
serials.add(serial);
}
```

```
}
static void test(SerialNumbers producer) {
for(int i = 0; i < 10; i++)
CompletableFuture.runAsync(
new SerialNumberChecker(producer));
new Nap(4, "No duplicates detected");
}
}
```

test() creates multiple tasks to contend over a single **SerialNumbers** object. The competing **SerialNumberChecker** tasks try to produce a duplicate serial number (this happens more quickly on machines with more cores).

When we test the basic **SerialNumbers** class, it fails:

```
// lowlevel/SerialNumberTest.java
public class SerialNumberTest {
public static void main(String[] args) {
SerialNumberChecker.test(new SerialNumbers());
}
}
/* Output:
```

Duplicate: 148044

/

volatile is no help here. To solve the problem, add the

synchronized keyword to **nextSerialNumber()**:

```
// lowlevel/SynchronizedSerialNumbers.java
public class
SynchronizedSerialNumbers extends SerialNumbers {
private int serialNumber = 0;
public synchronized int nextSerialNumber() {
return serialNumber++;
}
public static void main(String[] args) {
```

```
SerialNumberChecker.test(
new SynchronizedSerialNumbers());
}
}
/* Output:
```

No duplicates detected

*/

volatile is no longer necessary, because the **synchronized** keyword ensures the behavior of **volatile**.

Reading and assigning primitives are supposed to be safe atomic operations. However, as seen in **UnsafeReturn.java**, it's still easy to use an atomic operation that accesses your object while it's in an unstable intermediate state. Making assumptions about this issue is tricky and dangerous. The most sensible thing to do is just to follow Brian's Rule of Synchronization (and if you can, don't share variables in the first place).

Atomic Classes

Java 5 introduced special atomic variable classes such as **AtomicInteger**, **AtomicLong**, **AtomicReference**, etc. that provide atomic updates. These are fast, lock-free operations that take advantage of machine-level atomicity available on modern processors.

We can rewrite **UnsafeReturn.java** using **AtomicInteger**:

// lowlevel/AtomicIntegerTest.java

import java.util.concurrent.*;

import java.util.concurrent.atomic.*;

```
import java.util.*;
import onjava.*;
public class AtomicIntegerTest extends IntTestable {
private AtomicInteger i = new AtomicInteger(0);
public int getAsInt() { return i.get(); }
public void evenIncrement() { i.addAndGet(2); }
public static void main(String[] args) {
Atomicity.test(new AtomicIntegerTest());
}
}
/* Output:
No failures found
*/
```

We've eliminated the **synchronized** keyword by using **AtomicInteger**.

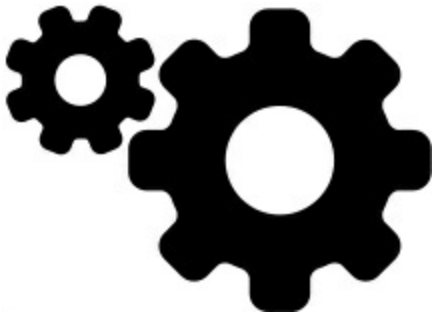
Here is **SynchronizedEvenProducer.java** rewritten to use **AtomicInteger**:

```
// lowlevel/AtomicEvenProducer.java
// Atomic classes: occasionally useful in regular code
import java.util.concurrent.atomic.*;
```

```
public class AtomicEvenProducer extends IntGenerator {
private AtomicInteger currentEvenValue =
new AtomicInteger(0);
@Override
public int next() {
return currentEvenValue.addAndGet(2);
}
public static void main(String[] args) {
EvenChecker.test(new AtomicEvenProducer());
}
}
/* Output:
No odd numbers discovered
*/
```

Again, the need for all other forms of synchronization is eliminated using **AtomicInteger**.

Here is an implementation of **SerialNumbers** using



AtomicInteger:

```
// lowlevel/AtomicSerialNumbers.java

import java.util.concurrent.atomic.*;

public class

AtomicSerialNumbers extends SerialNumbers {

private AtomicInteger serialNumber =

new AtomicInteger();

public synchronized int nextSerialNumber() {

return serialNumber.getAndIncrement();

}

public static void main(String[] args) {

SerialNumberChecker.test(

new AtomicSerialNumbers());

}

}

/* Output:
```

No duplicates detected

*/

These are simple examples with a single field; when you create more complex classes you must determine which fields need protection, and in some cases you might still end up using the **synchronized** keyword on methods.

Critical Sections

Sometimes, you only want to prevent multiple thread access to part of the code inside a method instead of the entire method. The section of code to isolate is called a *critical section* and is created with the same **synchronized** keyword we use to protect an entire method, but using a different syntax. Here, **synchronized** specifies the object whose lock is used to synchronize the enclosed code:

synchronized(syncObject) {

// This code can be accessed

// by only one task at a time

}

This is also called a *synchronized block*. Before it can be entered, the **syncObject** lock must be acquired. If some other task already has this lock, then the critical section cannot be entered until the lock is

released. When this happens, the task trying to acquire that lock is suspended. The scheduler periodically comes back and checks to see if the lock has been released; if so it wakes up the task.

The primary motivation for using a **synchronized** block instead of synchronizing the whole method is performance (and sometimes, clever algorithms—but be especially wary of cleverness where concurrency is concerned). The following example demonstrates that synchronizing a block instead of the whole method can make a method much more accessible to other tasks. The example counts the number of successful accesses to **method()** and launches a number of tasks that compete to try to call **method()**:

```
// lowlevel/SynchronizedComparison.java
// Synchronizing blocks instead of entire methods
// speeds up access.
import java.util.*;
import java.util.stream.*;
import java.util.concurrent.*;
import java.util.concurrent.atomic.*;
import onjava.Nap;
abstract class Guarded {
```

```
AtomicLong callCount = new AtomicLong();
public abstract void method();
@Override
public String toString() {
return getClass().getSimpleName() +
": " + callCount.get();
}
}
class SynchronizedMethod extends Guarded {
public synchronized void method() {
new Nap(0.01);
callCount.incrementAndGet();
}
}
class CriticalSection extends Guarded {
public void method() {
new Nap(0.01);
synchronized(this) {
callCount.incrementAndGet();
}
```

```
}
}
class Caller implements Runnable {
private Guarded g;
Caller(Guarded g) { this.g = g; }
private AtomicLong successfulCalls =
new AtomicLong();
private AtomicBoolean stop =
new AtomicBoolean(false);
@Override
public void run() {
new Timer().schedule(new TimerTask() {
public void run() { stop.set(true); }
}, 2500);
while(!stop.get()) {
g.method();
successfulCalls.getAndIncrement();
}
System.out.println(
"-> " + successfulCalls.get());
```

```
}
}
public class SynchronizedComparison {
static void test(Guarded g) {
List<CompletableFuture<Void>> callers =
Stream.of(
new Caller(g),
new Caller(g),
new Caller(g),
new Caller(g))
.map(CompletableFuture::runAsync)
.collect(Collectors.toList());
callers.forEach(CompletableFuture::join);
System.out.println(g);
}
public static void main(String[] args) {
test(new CriticalSection());
test(new SynchronizedMethod());
}
}
```

/ *Output:*

-> 243

-> 243

-> 243

-> 243

CriticalSection: 972

-> 69

-> 61

-> 83

-> 36

SynchronizedMethod: 249

**/*

The **Guarded** class keeps track of the number of successful calls to **method()** in **callCount**. **SynchronizedMethod** synchronizes the entire **method()**, while **CriticalSection** uses a **synchronized** block to only synchronize part of the method. This way, the time-consuming **Nap** can be excluded from the **synchronized** block. The output shows how much more available **method()** is for **CriticalSection**.

Keep in mind that using a **synchronized** block has risks: it requires

that you know for certain that the un-**synchronized** code outside the block is actually safe.

Caller is a task that tries to call **method()** as many times as

possible in a given period (and reports this number). To establish that period, we use **java.util.Timer** which is a little dated but still works well. It takes a **TimerTask**, which is not a functional interface so we can't use a lambda and must explicitly create the class (in this case, using an anonymous inner class). When it times out, it sets the **AtomicBoolean stop** flag to **true** so the loop will quit.

The **test()** method accepts a **Guarded** and creates four **Caller** tasks, all attached to the same **Guarded** object, so they compete to acquire the lock used by **method()**.

You will typically see variation in output from one run to the next. The results show that that **CriticalSection** allows much more access to its **method()** than **SynchronizedMethod**. This is typically the reason to use a **synchronized** block instead of synchronizing the whole method: To allow other tasks more access (as long as it is safe to

do so).

Synchronizing on Other

Objects

A **synchronized** block must synchronize upon an object. The most sensible object to use is usually just the current object via **synchronized(this)**, which is the approach taken in **CriticalSection** in the previous example. That way, when the lock is acquired for the **synchronized** block, other **synchronized** methods and critical sections in the same object cannot be called. Thus, the effect of the critical section when synchronizing on **this** is to reduce the scope of synchronization. Sometimes you must synchronize on another object, but if you do this you must ensure that all relevant tasks are synchronizing on the same object. The following example demonstrates that two tasks can enter an object when the methods in that object synchronize on different locks:

```
// lowlevel/SyncOnObject.java
// Synchronizing on another object
import java.util.*;
import java.util.stream.*;
```

```
import java.util.concurrent.*;
import onjava.Nap;
class DualSynch {
ConcurrentLinkedQueue<String> trace =
new ConcurrentLinkedQueue<>();
public synchronized void f(boolean nap) {
for(int i = 0; i < 5; i++) {
trace.add(String.format("f() " + i));
if(nap) new Nap(0.01);
}
}
private Object syncObject = new Object();
public void g(boolean nap) {
synchronized(syncObject) {
for(int i = 0; i < 5; i++) {
trace.add(String.format("g() " + i));
if(nap) new Nap(0.01);
}
}
}
```

```
}
public class SyncOnObject {
static void test(boolean fNap, boolean gNap) {
DualSynch ds = new DualSynch();
List<CompletableFuture<Void>> cfs =
Arrays.stream(new Runnable[] {
() -> ds.f(fNap), () -> ds.g(gNap) })
.map(CompletableFuture::runAsync)
.collect(Collectors.toList());
cfs.forEach(CompletableFuture::join);
ds.trace.forEach(System.out::println);
}
public static void main(String[] args) {
test(true, false);
System.out.println("****");
test(false, true);
}
}
/* Output:
f() 0
```

g() 0

g() 1

g() 2

g() 3

g() 4

f() 1

f() 2

f() 3

f() 4

****

f() 0

g() 0

f() 1

f() 2

f() 3

f() 4

g() 1

g() 2

g() 3

g() 4

*/

DualSync.f() synchronizes on **this** (by synchronizing the entire method), and **g()** has a **synchronized** block that synchronizes on **syncObject**. Thus, the two synchronizations are independent. This is demonstrated in **test()** by running two independent task that call **f()** and **g**. The **fNap** and **gNap** flags indicate whether **f()** or **g()**, respectively, should call **Nap()** within its **for** loop. When **f()** naps, for example, it continues to hold its lock, but you can see that this

doesn’t prevent **g()** from being called, and vice-versa.

Using Explicit Lock Objects

The **java.util.concurrent** library contains an explicit mutex mechanism defined in **java.util.concurrent.locks**. The **Lock** object must be explicitly created, locked and unlocked, so it produces less elegant code than the built-in **synchronized** keyword. However, it is more flexible for solving certain types of problems. Here is **SynchronizedEvenProducer.java** rewritten to use explicit **Lock**s:

```
// lowlevel/MutexEvenProducer.java
// Preventing thread collisions with mutexes
import java.util.concurrent.locks.*;
import onjava.Nap;
public class MutexEvenProducer extends IntGenerator {
private int currentEvenValue = 0;
private Lock lock = new ReentrantLock();
@Override
public int next() {
lock.lock();
try {
++currentEvenValue;
new Nap(0.01); // Cause failure faster
++currentEvenValue;
return currentEvenValue;
} finally {
lock.unlock();
}
}
public static void main(String[] args) {
```

```
EvenChecker.test(new MutexEvenProducer());
}
}
/*
No odd numbers discovered
*/
```

MutexEvenProducer adds a mutex called **lock** and uses the **lock()** and **unlock()** methods to create a critical section within **next()**. When you use **Lock** objects, it is important to use the idiom shown here: Right after the call to **lock()**, you must place a **try-finally** statement with **unlock()** in the **finally** clause—this is the only way to guarantee that the lock is always released. Note that the **return** statement must occur inside the **try** clause to ensure that the **unlock()** doesn't happen too early and expose the data to a second task.

Although the **try-finally** requires more code than using the **synchronized** keyword, it also represents one of the advantages of explicit **Lock** objects. If something fails using the **synchronized** keyword, an exception is thrown, but you don't get the chance to do any cleanup to maintain your system in a good state. With explicit

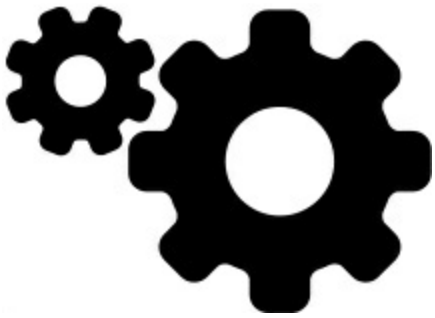
Lock objects, you can maintain proper state in your system using the **finally** clause.

In general, when you use **synchronized**, there is less code to write, and the opportunity for user error is greatly reduced, so you'll usually only use the explicit **Lock** objects when you're solving special problems. For example, with the **synchronized** keyword, you can't try and fail to acquire a lock, or try to acquire a lock for a certain amount of time, then give up—to do this, you must use the **concurrent** library:

```
// lowlevel/AttemptLocking.java
// Locks in the concurrent library allow you
// to give up on trying to acquire a lock
import java.util.concurrent.*;
import java.util.concurrent.locks.*;
import onjava.Nap;
public class AttemptLocking {
private ReentrantLock lock = new ReentrantLock();
public void untimed() {
boolean captured = lock.tryLock();
try {
```

```
System.out.println("tryLock(): " + captured);
} finally {
if(captured)
lock.unlock();
}
}
public void timed() {
boolean captured = false;
try {
captured = lock.tryLock(2, TimeUnit.SECONDS);
} catch(InterruptedException e) {
throw new RuntimeException(e);
}
try {
System.out.println(
"tryLock(2, TimeUnit.SECONDS): " + captured);
} finally {
if(captured)
lock.unlock();
}
```

```
}
public static void main(String[] args) {
final AttemptLocking al = new AttemptLocking();
al.untimed(); // True -- lock is available
al.timed(); // True -- lock is available
// Now create a second task to grab the lock:
CompletableFuture.runAsync( () -> {
al.lock.lock();
System.out.println("acquired");
});
new Nap(0.1); // Give the second task a chance
al.untimed(); // False -- lock grabbed by task
al.timed(); // False -- lock grabbed by task
}
```



```
}
/* Output:
```

tryLock(): true

tryLock(2, TimeUnit.SECONDS): true

acquired

tryLock(): false

tryLock(2, TimeUnit.SECONDS): false

/

A **ReentrantLock** can try and fail to acquire the lock, so if someone else already has the lock, you can decide to go off and do something else rather than waiting until it is free, as in the **untimed()** method. In **timed()**, an attempt is made to acquire the lock which can fail after 2 seconds (note the **TimeUnit** class to specify units). In **main()**, a separate **Thread** is created as an anonymous class, and it acquires the lock so the **untimed()** and **timed()** methods have something to contend with.

The explicit **Lock** object provides finer-grained control over locking and unlocking than does the built-in **synchronized** lock. This is useful for implementing specialized synchronization structures, such as *hand-over-hand locking* (also called *lock coupling*), used for traversing the nodes of a linked list—the traversal code must capture the lock of the next node before it releases the current node's lock.

Library Components

The **java.util.concurrent** library provides a significant number of classes designed to solve concurrency problems, and can help you produce simpler and more robust concurrent programs. Note, however, that these tools are lower-level mechanisms than parallel streams or **CompletableFuture**s.

In this section we'll look at a couple of examples using different components, then talk a little about how *lock-free* library components work.

DelayQueue

This is an unbounded **BlockingQueue** of objects that implement the **Delayed** interface. An object can only be taken from the queue when its delay has expired. The queue is sorted so the object at the head has a delay that has expired for the longest time. If no delay has expired, then there is no head element and **poll()** will return **null** (because of this, you cannot place **null** elements in the queue).

Here's an example where the **Delayed** objects are themselves tasks,

and the **DelayedTaskConsumer** takes the most “urgent” task (the one that expired for the longest time) off the queue and runs it. Note that **DelayQueue** is thus a variation of a priority queue.

```
// lowlevel/DelayQueueDemo.java
import java.util.*;
import java.util.stream.*;
import java.util.concurrent.*;
import static java.util.concurrent.TimeUnit.*;
class DelayedTask implements Runnable, Delayed {
private static int counter = 0;
private final int id = counter++;
private final int delta;
private final long trigger;
protected static List<DelayedTask> sequence =
new ArrayList<>();
DelayedTask(int delayInMilliseconds) {
delta = delayInMilliseconds;
trigger = System.nanoTime() +
NANOSECONDS.convert(delta, MILLISECONDS);
sequence.add(this);
```

```
}
@Override
public long getDelay(TimeUnit unit) {
return unit.convert(
trigger - System.nanoTime(), NANOSECONDS);
}
@Override
public int compareTo(Delayed arg) {
DelayedTask that = (DelayedTask)arg;
if(trigger < that.trigger) return -1;
if(trigger > that.trigger) return 1;
return 0;
}
@Override
public void run() {
System.out.print(this + " ");
}
@Override
public String toString() {
return
```

```
String.format("[%d] Task %d", delta, id);
}
public String summary() {
return String.format("(%d:%d)", id, delta);
}
public static class EndTask extends DelayedTask {
EndTask(int delay) { super(delay); }
@Override
public void run() {
sequence.forEach(dt ->
System.out.println(dt.summary()));
}
}
}
public class DelayQueueDemo {
public static void
main(String[] args) throws Exception {
DelayQueue<DelayedTask> tasks =
Stream.concat( // Random delays:
new Random(47).ints(20, 0, 4000)
```

```
.mapToObj(DelayedTask::new),
// Add the summarizing task:
Stream.of(new DelayedTask.EndTask(4000)))
.collect(Collectors
.toCollection(DelayQueue::new));
while(tasks.size() > 0)
tasks.take().run();
}
}
/* Output:
[128] Task 12 [429] Task 6 [551] Task 13 [555] Task 2
[693] Task 3 [809] Task 15 [961] Task 5 [1258] Task 1
[1258] Task 20 [1520] Task 19 [1861] Task 4 [1998] Task
17 [2200] Task 8 [2207] Task 10 [2288] Task 11 [2522]
Task 9 [2589] Task 14 [2861] Task 18 [2868] Task 7
[3278] Task 16 (0:4000)
(1:1258)
(2:555)
(3:693)
(4:1861)
```

(5:961)

(6:429)

(7:2868)

(8:2200)

(9:2522)

(10:2207)

(11:2288)

(12:128)

(13:551)

(14:2589)

(15:809)

(16:3278)

(17:1998)

(18:2861)

(19:1520)

(20:1258)

**/*

DelayedTask contains a **List<DelayedTask>** called **sequence** that preserves the order of task creation so we can see that sorting does in fact take place.

The **Delayed** interface has one method, **getDelay()**, which says how long until the delay time expires or how long ago the delay time has expired. This method forces us to use the **TimeUnit** class because that's the argument type. This turns out to be a convenient class because you can convert units without doing any calculations. For example, the value of **delta** is stored in milliseconds, but **System.nanoTime()** produces time in nanoseconds. You can convert the value of **delta** by giving the units it is in and the units you want it to be in, like this:

NANOSECONDS.convert(delta, MILLISECONDS);

In **getDelay()**, the desired units are passed as the **unit** argument, and you use this to convert the time difference from the trigger time into the units requested by the caller, without even knowing what those units are (this is a simple example of the *Strategy* design pattern, where part of the algorithm is passed in as an argument).

For sorting, the **Delayed** interface also inherits the **Comparable** interface. **compareTo()** must be implemented so it produces a

reasonable comparison.

The output shows that that task creation order has no effect on

execution order—instead, the tasks are executed in delay order as

expected.

PriorityBlockingQueue

This is basically a priority queue that has blocking retrieval operations.

In the following example, A **Prioritized** is given a priority

number. Several instances of the **Producer** task insert

Prioritized objects into the **PriorityBlockingQueue**, but

with random delays between insertions. The single **Consumer** task is then presented with multiple options when it does a **take()**, and the

PriorityBlockingQueue hands it the **Prioritized** object

with the highest priority *at that moment*.

The **static counter** in **Prioritized** is an **AtomicInteger**.

This is necessary because there are multiple **Producer**s running in

parallel; without **AtomicInteger** you'll see duplicate **id** numbers.

This issue was covered in Concurrent Programming in the section

Constructors are not Thread-Safe.

// lowlevel/PriorityBlockingQueueDemo.java

import java.util.*;

import java.util.stream.*;

```
import java.util.concurrent.*;
```

```
import java.util.concurrent.atomic.*;
import onjava.Nap;
class Prioritized implements Comparable<Prioritized> {
private static AtomicInteger counter =
new AtomicInteger();
private final int id = counter.getAndIncrement();
private final int priority;
private static List<Prioritized> sequence =
new CopyOnWriteArrayList<>();
Prioritized(int priority) {
this.priority = priority;
sequence.add(this);
}
@Override
public int compareTo(Prioritized arg) {
return priority < arg.priority ? 1 :
(priority > arg.priority ? -1 : 0);
}
@Override
public String toString() {
```

```
return String.format(
"[%d] Prioritized %d", priority, id);
}
public void displaySequence() {
int count = 0;
for(Prioritized pt : sequence) {
System.out.printf("(%d:%d)", pt.id, pt.priority);
if(++count % 5 == 0)
System.out.println();
}
}
public static class EndSentinel extends Prioritized {
EndSentinel() { super(-1); }
}
}
class Producer implements Runnable {
private static AtomicInteger seed =
new AtomicInteger(47);
private SplittableRandom rand =
new SplittableRandom(seed.getAndAdd(10));
```

```
private Queue<Prioritized> queue;
Producer(Queue<Prioritized> q) {
queue = q;
}
@Override
public void run() {
rand.ints(10, 0, 20)
.mapToObj(Prioritized::new)
.peek(p -> new Nap(rand.nextDouble() / 10))
.forEach(p -> queue.add(p));
queue.add(new Prioritized.EndSentinel());
}
}
class Consumer implements Runnable {
private PriorityBlockingQueue<Prioritized> q;
private SplittableRandom rand =
new SplittableRandom(47);
Consumer(PriorityBlockingQueue<Prioritized> q) {
this.q = q;
}
```

```
@Override
public void run() {
while(true) {
try {
Prioritized pt = q.take();
System.out.println(pt);
if(pt instanceof Prioritized.EndSentinel) {
pt.displaySequence();
break;
}
new Nap(rand.nextDouble() / 10);
} catch(InterruptedException e) {
throw new RuntimeException(e);
}
}
}
}
public class PriorityBlockingQueueDemo {
public static void main(String[] args) {
PriorityBlockingQueue<Prioritized> queue =
```

```
new PriorityBlockingQueue<>();
CompletableFuture.runAsync(new Producer(queue));
CompletableFuture.runAsync(new Producer(queue));
CompletableFuture.runAsync(new Producer(queue));
CompletableFuture.runAsync(new Consumer(queue))
.join();
}
}
/* Output:
[15] Prioritized 2
[17] Prioritized 1
[17] Prioritized 5
[16] Prioritized 6
[14] Prioritized 9
[12] Prioritized 0
[11] Prioritized 4
[11] Prioritized 12
[13] Prioritized 13
[12] Prioritized 16
[14] Prioritized 18
```

[15] Prioritized 23

[18] Prioritized 26

[16] Prioritized 29

[12] Prioritized 17

[11] Prioritized 30

[11] Prioritized 24

[10] Prioritized 15

[10] Prioritized 22

[8] Prioritized 25

[8] Prioritized 11

[8] Prioritized 10

[6] Prioritized 31

[3] Prioritized 7

[2] Prioritized 20

[1] Prioritized 3

[0] Prioritized 19

[0] Prioritized 8

[0] Prioritized 14

[0] Prioritized 21

[-1] Prioritized 28

(0:12)(2:15)(1:17)(3:1)(4:11)

(5:17)(6:16)(7:3)(8:0)(9:14)

(10:8)(11:8)(12:11)(13:13)(14:0)

(15:10)(16:12)(17:12)(18:14)(19:0)

(20:2)(21:0)(22:10)(23:15)(24:11)

(25:8)(26:18)(27:-1)(28:-1)(29:16)

(30:11)(31:6)(32:-1)

**/*

As with the previous example, the creation order of the **Prioritized** objects is remembered in the **List sequence**, for comparison with the actual order of execution. The **EndSentinel** is a special type that tells the **Consumer**s to shut down.

Producer uses an **AtomicInteger** to seed the **SplittableRandom** so that different **Producer**s produce different sequences. This is required because multiple **Producer**s are created in parallel, and otherwise the construction process would not be thread-safe.

The **Producer**s and **Consumer** connect to each other through a **PriorityBlockingQueue**. Because the blocking nature of the queue provides all necessary synchronization, notice that no explicit

synchronization is necessary—you don’t think about whether the

queue has any elements in it when you’re reading from it, because the queue will block the reader when it is out of elements.

Lock-Free Collections

The Collections chapter emphasized collections as a fundamental programming tool, and this includes concurrency. For this reason, early collections like **Vector** and **Hashtable** have many methods using the **synchronized** mechanism. This caused unacceptable overhead when those collections were not used in multithreaded applications. In Java 1.2, the new collections library was unsynchronized, and the **Collections** class was given various **static synchronized** decoration methods to synchronize the different types of collections. Although this was an improvement because it gave you a choice about whether you use synchronization with your collection, the overhead is still based on **synchronized** locking. Java 5 added new collections specifically to increase thread-safe performance, using clever techniques to eliminate locking.

Lock-free collections have an intriguing feature: Modifications to the collections can happen at the same time that reads are occurring, as long as the readers can only see the results of *completed* modifications. This is implemented using a number of strategies. To give you a flavor of how they work, we'll look at a couple of them.

The Copying Strategy

With the "copying" strategy, a modification is performed on a separate copy of a portion of the data structure (or sometimes a copy of the whole thing), and this copy is invisible during the modification process. Only when the modification is complete is the modified structure safely swapped with the "main" data structure, and after that readers will see the modification.

In **CopyOnWriteArrayList**, a write copies the entire underlying array. The original array is left in place so reads can safely occur while the copied array is modified. When the modification is complete, an atomic operation swaps in the new array so new reads will see the new information. One of the benefits of **CopyOnWriteArrayList** is it does not throw **ConcurrentModificationException** when multiple iterators are traversing and modifying the list, so you don't write special code to protect against such exceptions, as you've had to

do in the past.

CopyOnWriteArraySet uses **CopyOnWriteArrayList** to achieve its lock-free behavior.

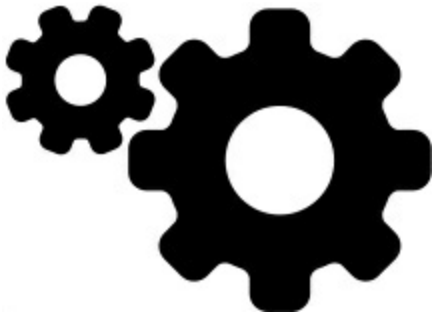
ConcurrentHashMap and **ConcurrentLinkedQueue** use similar techniques to allow concurrent reads and writes, but only portions of the collection are copied and modified rather than the entire collection. However, readers will still not see any incomplete modifications. **ConcurrentHashMap** doesn't throw **ConcurrentModificationException**s.

Compare-And-Swap (CAS)

In *Compare-And-Swap* (CAS), you take a value from memory and hold on to the original value while calculating a new one. Then you use the CAS instruction which compares the original value with the one currently in memory, and *if the two values are equal* swaps in the result of your calculation for the old value, all in a single atomic operation. If the original-value comparison fails, the swap does not take place because it means another thread has modified the memory in the meantime. In that case, your code must try again, taking a new original value and repeating the operation.

If the memory is only lightly contended, the CAS operation almost

always goes through with no repeated attempts, so it is very fast. In



contrast, a **synchronized** operation requires the cost of acquiring and releasing the lock every single time, which is much more expensive with no additional benefit. As contention over the memory increases, the operation using CAS slows down because it must repeat itself more often, but this is a dynamic response to more contention. It really is an elegant approach.

The best part is that many modern processors have a CAS instruction in their assembly language, and this is used by the CAS operations in the JVM (such as those in the **Atomic** classes). The CAS instruction is atomic in the hardware and as fast as you could hope for such an operation.

Summary

This appendix was included primarily so you have *some* understanding of low-level concurrency code when you encounter it, although it is far from a comprehensive treatment of the subject. For

that, you'll need to start with *Java Concurrency in Practice*, by Brian Goetz, Tim Peierls, Joshua Bloch, Joseph Bowbeer, David Holmes, and Doug Lea (Addison-Wesley, 2006). Ideally, that book will completely scare you away from attempting low-level concurrency in Java. If it doesn't, you're almost certainly suffering from the *Dunning-Kruger Effect*, a cognitive bias whereby "the less you know, the more confident you are in your abilities." Keep in mind that the current language designers are *still* cleaning up the messes made from the overconfidence of the early language designers (for example, look at how many of the methods in the **Thread** class are **deprecated**, and that **volatile** wasn't working correctly until Java 5).

Here are the steps to follow for concurrent programming:

1. Don't do it. Figure out some other way to make your program faster.

2. If you must do it, use the modern, high-level tools shown in Concurrent Programming—parallel **Stream**s and **CompletableFuture**s.

3. Don't share variables between tasks. Any information that must pass between tasks should use concurrent data structures from the **java.util.concurrent** library.

4. If you must share variables between tasks, either use one of the **java.util.concurrent.atomic** types, or apply **synchronized** to any method that can either directly or indirectly access those variables. It's very easy to get fooled into thinking you've got everything covered when you don't. Seriously, try to use step #3 instead.

5. If step #4 produces results that are somehow too slow, you can try to tune things using **volatile** or some other technique but if you are reading this book and think you are ready to try those approaches, you're out of your depth. Return to step #1.

It's usually possible to write concurrent programs using only **java.util.concurrent** library components, completely avoiding the challenges of applying **volatile** and **synchronized**. Note that I was able to do this with the examples in Concurrent Programming.

1. On some platforms, notably Windows, the default value can be remarkably hard to discover. You can adjust the stack size with the **-Xss** flag. ↩

2. From Brian Goetz, author of *Java Concurrency in Practice*, by Brian Goetz, Tim Peierls, Joshua Bloch, Joseph Bowbeer, David

Holmes, and Doug Lea (Addison-Wesley, 2006). ↩

3. Note that on a 64 bit processor this might not happen, eliminating the issue.↩

4. A corollary to this test is, “If someone implies that threading is straightforward, make sure that person is not making important decisions about your project. If that person already is, then you’ve got trouble.” ↩

5. The version I worked on; this might have been fixed in later standards↩

Appendix: Data Compression

The Java I/O library contains classes that read and write streams in a compressed format. You wrap these around other I/O classes to provide compression functionality.

These classes are not derived from the **Reader** and **Writer** classes, but instead are part of the **InputStream** and **OutputStream** hierarchies. This is because the compression library works with bytes, not characters. However, you might sometimes be forced to mix the

two types of streams. (Remember you can use

InputStreamReader and **OutputStreamWriter** to provide

easy conversion between one type and another.)

Compression class

Function

getCheckSum() produces

checksum for any

CheckedInputStream

InputStream (not just

decompression).

getCheckSum() produces

CheckedOutputStream

checksum for any

OutputStream (not just

compression).

Base class for compression

DeflaterOutputStream classes.

A

ZipOutputStream

DeflaterOutputStream

that compresses data into the

Zip file format.

A

GZIPOutputStream

DeflaterOutputStream

that compresses data into the

GZIP file format.

Base class for decompression

InflaterInputStream

classes.

An

InflaterInputStream

ZipInputStream

that decompresses data that

was stored in the Zip file

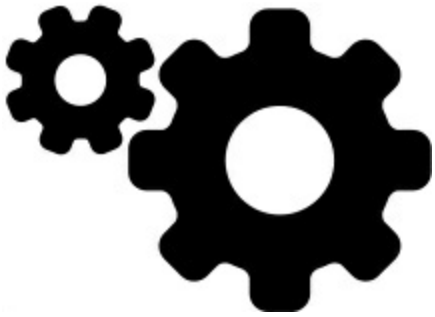
format.

An

InflaterInputStream

GZIPInputStream

that decompresses data that



was stored in the GZIP file

format.

Although there are many compression algorithms, Zip and GZIP are probably the most common. You can easily manipulate your compressed data with the many tools available for reading and writing these formats.

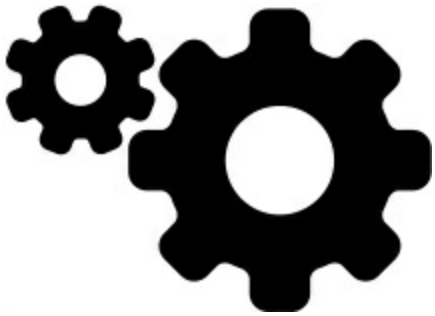
Simple Compression

with GZIP

The GZIP interface is simple and thus is probably more appropriate when you have a single stream of data to compress (rather than a container of dissimilar pieces of data). This example compresses a single file:

```
// compression/GZIPcompress.java
// {java GZIPcompress GZIPcompress.java}
// {VisuallyInspectOutput}
import java.util.zip.*;
```

```
import java.io.*;
public class GZIPcompress {
public static void main(String[] args) {
if(args.length == 0) {
System.out.println(
"Usage: \nGZIPcompress file\n" +
"\tUses GZIP compression to compress " +
"the file to test.gz");
System.exit(1);
}
try(
InputStream in = new BufferedInputStream(
new FileInputStream(args[0]));
BufferedOutputStream out =
new BufferedOutputStream(
```



```
new GZIPOutputStream(
```

```
new FileOutputStream("test.gz")))
) {
System.out.println("Writing file");
int c;
while((c = in.read()) != -1)
out.write(c);
} catch(IOException e) {
throw new RuntimeException(e);
}
System.out.println("Reading file");
try(
BufferedReader in2 = new BufferedReader(
new InputStreamReader(new GZIPInputStream(
new FileInputStream("test.gz"))))
) {
in2.lines().forEach(System.out::println);
} catch(IOException e) {
throw new RuntimeException(e);
}
}
```

}

Using the compression classes is straightforward; you wrap your output stream in a **GZIPOutputStream** or **ZipOutputStream**, and your input stream in a **GZIPInputStream** or **ZipInputStream**. All else is ordinary I/O reading and writing. This is an example of mixing the **char**-oriented streams with the byte-oriented streams; **in** uses the **Reader** classes, whereas **GZIPOutputStream**s constructor can accept only an **OutputStream** object, not a **Writer** object. When the file is opened, the **GZIPInputStream** is converted to a **Reader**.

Multifile Storage with Zip

The library that supports the Zip format is more extensive than the GZIP library. With it you can easily store multiple files, and there's even a separate class to make the process of reading a Zip file easy. The library uses the standard Zip format so it works seamlessly with all the Zip tools currently downloadable on the Internet. The following example has the same form as the previous example, but it handles as many command-line arguments as you want. In addition, it shows the **Checksum** classes calculating and verifying the checksum for the file.

There are two **Checksum** types: **Adler32** (which is faster) and **CRC32** (slower but slightly more accurate).

```
// compression/ZipCompress.java
// Uses Zip compression to compress any
// number of files given on the command line
// {java ZipCompress ZipCompress.java}
// {VisuallyInspectOutput}
import java.util.zip.*;
import java.io.*;
import java.util.*;
public class ZipCompress {
public static void main(String[] args) {
try(
FileOutputStream f =
new FileOutputStream("test.zip");
CheckedOutputStream csum =
new CheckedOutputStream(f, new Adler32());
ZipOutputStream zos = new ZipOutputStream(csum);
BufferedOutputStream out =
new BufferedOutputStream(zos)
```

```
) {
zos.setComment("A test of Java Zipping");
// No corresponding getComment(), though.
for(String arg : args) {
System.out.println("Writing file " + arg);
try(
InputStream in = new BufferedInputStream(
new FileInputStream(arg))
) {
zos.putNextEntry(new ZipEntry(arg));
int c;
while((c = in.read()) != -1)
out.write(c);
}
out.flush();
}
// Checksum valid only after the file is closed!
System.out.println(
"Checksum: " + csum.getChecksum().getValue());
} catch(IOException e) {
```

```
throw new RuntimeException(e);
}
// Now extract the files:
System.out.println("Reading file");
try(
FileInputStream fi =
new FileInputStream("test.zip");
CheckedInputStream csumi =
new CheckedInputStream(fi, new Adler32());
ZipInputStream in2 = new ZipInputStream(csumi);
BufferedInputStream bis =
new BufferedInputStream(in2)
) {
ZipEntry ze;
while((ze = in2.getNextEntry()) != null) {
System.out.println("Reading file " + ze);
int x;
while((x = bis.read()) != -1)
System.out.write(x);
}
```

```
if(args.length == 1)
System.out.println(
"Checksum: "+csumi.getChecksum().getValue());
} catch(IOException e) {
throw new RuntimeException(e);
}
// Alternative way to open and read Zip files:
try(
ZipFile zf = new ZipFile("test.zip")
) {
Enumeration e = zf.entries();
while(e.hasMoreElements()) {
ZipEntry ze2 = (ZipEntry)e.nextElement();
System.out.println("File: " + ze2);
// ... and extract the data as before
}
} catch(IOException e) {
throw new RuntimeException(e);
}
}
```

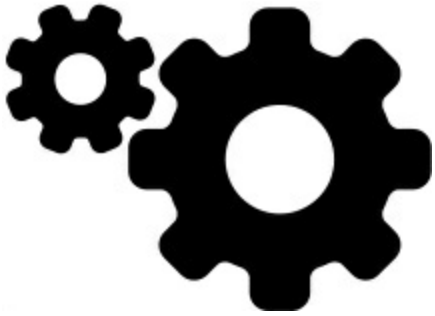
}

For each file to add to the archive, you must call **putNextEntry()** and pass it a **ZipEntry** object. The **ZipEntry** object contains an extensive interface that gets and sets all the data available on that particular entry in your Zip file: name, compressed and uncompressed sizes, date, CRC checksum, extra field data, comment, compression method, and whether it's a directory entry. However, even though the Zip format has a way to set a password, this is not supported in Java's Zip library. And although **CheckedInputStream** and **CheckedOutputStream** support both **Adler32** and **CRC32** checksums, the **ZipEntry** class supports only an interface for CRC. This is a restriction of the underlying Zip format, but it might limit you from using the faster **Adler32**.

To extract files, **ZipInputStream** has a **getNextEntry()** method that returns the next **ZipEntry** if there is one. As a more succinct alternative, you can read the file using a **ZipFile** object, which has a method **entries()** to return an **Enumeration** to the **ZipEntries**.

To read the checksum, you must somehow have access to the associated **Checksum** object. Here, a reference to the

CheckedOutputStream and **CheckedInputStream** objects is retained, but you can also just hold on to a reference to the **Checksum** object.



A baffling method in Zip streams is **setComment()**. As shown in **ZipCompress.java**, you can set a comment when you're writing a file, but there's no way to recover the comment in the **ZipInputStream**. Comments appear to be supported fully on an entry-by-entry basis only via **ZipEntry**.

You are not limited to files when using the **GZIP** or **Zip** libraries—you can compress anything, including data sent through a network connection.

Java Archives (Jars)

The Zip format is also used in the JAR (Java ARchive) file format, a way to collect a group of files into a single compressed file, just like Zip. However, like everything else in Java, JAR files are cross-platform, so you don't worry about platform issues. You can also

include audio and image files as well as class files.

A JAR file consists of a single file containing a collection of zipped files along with a “manifest” that describes them. (You can create your own manifest file; otherwise, the **jar** program will do it for you.) You can find out more about JAR manifests in the JDK documentation.

The **jar** utility that comes with the JDK automatically compresses the files of your choice. You invoke it on the command line:

jar [options] destination [manifest] inputfile(s)

The options are a collection of letters (no hyphen or any other indicator is necessary). Unix/Linux users will note the similarity to **tar** options. These are:

c

Creates a new or empty archive.

t

Lists the table of contents.

x

Extracts all files.

x file

Extracts the named file.

Says, “I’m going to give you the

name of the file.” If you don’t use

f

this, **jar** assumes its input will come from standard input, or, if it is creating a file, its output will go to standard output.

Says that the first argument is the

m

name of the user-created manifest file.

Generates verbose output

v

describing what **jar** is doing.

Only stores the files; doesn’t

0

compress the files (use to create a JAR file you put in your classpath).

Doesn’t automatically create a

M

manifest file.

If a subdirectory is included in the files put into the JAR file, that subdirectory is automatically added, including all of its subdirectories, etc. Path information is also preserved.

Here are some typical ways to invoke **jar**. The following command creates a JAR file called **myJarFile.jar** that contains all class files in the current directory, along with an automatically generated manifest file:

jar cf myJarFile.jar *.class

The next command is like the previous example, but it adds a user-created manifest file called **myManifestFile.mf**:

jar cmf myJarFile.jar myManifestFile.mf *.class

This produces a table of contents of the files in **myJarFile.jar**:

jar tf myJarFile.jar

This adds the “verbose” flag to give more detailed information about files in **myJarFile.jar**:

jar tvf myJarFile.jar

Assuming **audio**, **classes**, and **image** are subdirectories, this combines all subdirectories into the file **myApp.jar**. The “verbose” flag is also included to give extra feedback while the **jar** program is working:

jar cvf myApp.jar audio classes image

If you create a JAR file using the **0** (zero) option, that file can be placed in your CLASSPATH:

CLASSPATH="lib1.jar;lib2.jar;"

Then Java can search **lib1.jar** and **lib2.jar** for class files.

The **jar** tool isn't as general-purpose as a **Zip** utility. For example, you can't add or update files to an existing JAR file; you can create JAR files only from scratch. Also, you can't move files into a JAR file, erasing them as they are moved. However, a JAR file created on one platform is transparently readable by the **jar** tool on any other platform (a problem that sometimes plagues **Zip** utilities).

Appendix: Object Serialization

When you create an object, it exists for as long as you need it, but under no circumstances does it exist when the program terminates. While this makes sense at first, there are situations where it would be quite useful if an object existed and held its information even while the program wasn't running. Then, the next time you started the program,

the object would be there with the same information it had the previous time the program was running. You can achieve this effect by writing the information to a file or to a database, but in the spirit of making everything an object, it would be convenient to declare an object as “persistent,” and have all the details taken care of for you.

Java’s *object serialization* takes any object that implements the **Serializable** interface and turns it into a sequence of bytes that can later regenerate the original object. This is even true across a network, which means that the serialization mechanism automatically compensates for differences in operating systems. That is, you can create an object on a Windows machine, serialize it, and send it across the network to a Unix machine, where it is correctly reconstructed. You don’t worry about data representations on the different machines, the byte ordering, or any other details.

Object serialization can implement *lightweight persistence*. Persistence means that an object’s lifetime is not determined by whether a program is executing; the object lives *in between* invocations of the program. By taking a serializable object and writing it to disk, then restoring that object when the program is reinvoked, you’re able to produce the effect of persistence. The reason it’s called

“lightweight” is that you can’t define an object using some kind of “persistent” keyword and let the system take care of the details. Instead, you must explicitly serialize and deserialize the objects in your program. If you need a more serious persistence mechanism, consider a tool like Hibernate.

Object serialization was added to the language to support two major features. Java’s *Remote Method Invocation* (RMI) allows objects that live on other machines to behave as if they live on your machine. When messages are sent to remote objects, object serialization is necessary to transport the arguments and return values.

Object serialization was also necessary for JavaBeans (considered a failed technology at this writing). When a Bean is used, its state information is generally configured at design time. This state information must be stored and later recovered when the program is started; object serialization performs this task.

Serializing an object is simple as long as the object implements the **Serializable** interface, which is a tagging interface and has no methods. When serialization was added to the language, many standard library classes were changed to make them serializable, including all wrappers for the primitive types, all container classes,

and many others. Even **Class** objects can be serialized.

To serialize an object, you create some sort of **OutputStream** object, then wrap it inside an **ObjectOutputStream** object. Now you need only call **writeObject()** and your object is serialized and sent to the **OutputStream** (object serialization is byte-oriented, and thus uses the **InputStream** and **OutputStream** hierarchies). To reverse the process, you wrap an **InputStream** inside an **ObjectInputStream** and call **readObject()**. What comes back is, as usual, a reference to an upcast **Object**, so you must downcast to set things straight.

A particularly clever aspect of object serialization is that it not only saves an image of your object, but it also follows all the references contained in your object and saves *those* objects, and follows all the references in each of those objects, etc. This is sometimes called the "web of objects" that a single object can be connected to, and it includes arrays of references to objects as well as member objects. If you had to maintain your own object serialization scheme, maintaining the code to follow all these links could be mind-boggling. However, Java object serialization seems to pull it off flawlessly, no doubt using an optimized algorithm that traverses the web of objects.

The following example tests the serialization mechanism by making a "worm" of linked objects, each of which has a link to the next segment in the worm as well as an array of references to objects of a different class, **Data**:

```
// serialization/Worm.java
// Demonstrates object serialization
import java.io.*;
import java.util.*;
class Data implements Serializable {
private int n;
Data(int n) { this.n = n; }
@Override
public String toString() {
return Integer.toString(n);
}
}
public class Worm implements Serializable {
private static Random rand = new Random(47);
private Data[] d = {
new Data(rand.nextInt(10)),
```

```
new Data(rand.nextInt(10)),
new Data(rand.nextInt(10))
};
private Worm next;
private char c;
// Value of i == number of segments
public Worm(int i, char x) {
System.out.println("Worm constructor: " + i);
c = x;
if(--i > 0)
next = new Worm(i, (char)(x + 1));
}
public Worm() {
System.out.println("No-arg constructor");
}
@Override
public String toString() {
StringBuilder result = new StringBuilder(":");
result.append(c);
result.append("(");
```

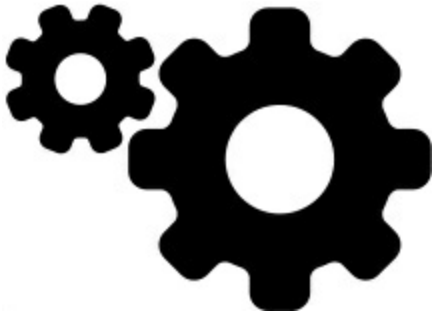
```
for(Data dat : d)
result.append(dat);
result.append(")");
if(next != null)
result.append(next);
return result.toString();
}
public static void
main(String[] args) throws ClassNotFoundException,
IOException {
Worm w = new Worm(6, 'a');
System.out.println("w = " + w);
try(
ObjectOutputStream out = new ObjectOutputStream(
new FileOutputStream("worm.dat"))
) {
out.writeObject("Worm storage\n");
out.writeObject(w);
}
try(
```

```
ObjectInputStream in = new ObjectInputStream(
new FileInputStream("worm.dat"))
) {
String s = (String)in.readObject();
Worm w2 = (Worm)in.readObject();
System.out.println(s + "w2 = " + w2);
}
try(
ByteArrayOutputStream bout =
new ByteArrayOutputStream();
ObjectOutputStream out2 =
new ObjectOutputStream(bout)
) {
out2.writeObject("Worm storage\n");
out2.writeObject(w);
out2.flush();
try(
ObjectInputStream in2 = new ObjectInputStream(
new ByteArrayInputStream(
bout.toByteArray()))
```

```
) {
String s = (String)in2.readObject();
Worm w3 = (Worm)in2.readObject();
System.out.println(s + "w3 = " + w3);
}
}
}
}
/* Output:
Worm constructor: 6
Worm constructor: 5
Worm constructor: 4
Worm constructor: 3
Worm constructor: 2
Worm constructor: 1
w = :a(853):b(119):c(802):d(788):e(199):f(881)
Worm storage
w2 = :a(853):b(119):c(802):d(788):e(199):f(881)
Worm storage
w3 = :a(853):b(119):c(802):d(788):e(199):f(881)
```

*/

Each **Data** object in the array inside **Worm** is initialized with a random number. (This way, you don't suspect the compiler of keeping



some kind of meta-information.) Each **Worm** segment is labeled with a **char** that's automatically generated in the process of recursively generating the linked list of **Worm**s. When you create a **Worm**, you tell the constructor how long you want it to be. To make the **next** reference, it calls the **Worm** constructor with a length of one less, etc. The final **next** reference is left as **null**, indicating the end of the **Worm**.

The point of all this was to make something reasonably complex that couldn't easily be serialized. The act of serializing, however, is simple. Once the **ObjectOutputStream** is created from some other stream, **writeObject()** serializes the object. Notice the call to **writeObject()** for a **String**, as well. You can also write all the primitive data types using the same methods as

DataOutputStream (they share the same interface).

There are two separate code sections that look similar. The first writes and reads a file, and the second, for variety, writes and reads a **ByteArray**. You can read and write an object using serialization to any **DataInputStream** or **DataOutputStream**, including a network.

The output shows that the deserialized object really does contain all links in the original object.

Note that no constructor, not even the no-arg constructor, is called in the process of deserializing a **Serializable** object. The entire object is restored by recovering data from the **InputStream**.

Finding the Class

You might wonder what's necessary to recover an object from its serialized state. For example, suppose you serialize an object and send it as a file or through a network to another machine. Could a program on the other machine reconstruct the object using only the contents of the file?

The best way to answer this question is (as usual) to perform an experiment. The following file goes in the subdirectory for this chapter:

```
// serialization/Alien.java
// A serializable class
import java.io.*;
public class Alien implements Serializable {}
```

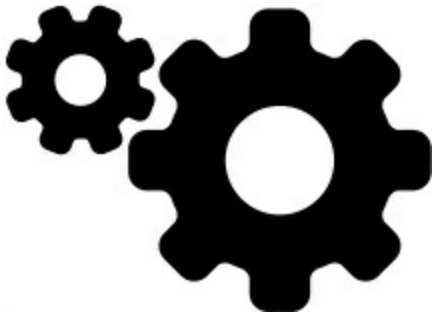
The file that creates and serializes an **Alien** object goes in the same directory:

```
// serialization/FreezeAlien.java
// Create a serialized output file
import java.io.*;
public class FreezeAlien {
public static void
main(String[] args) throws Exception {
try(
ObjectOutputStream out = new ObjectOutputStream(
new FileOutputStream("X.file"));
) {
Alien quellek = new Alien();
out.writeObject(quellek);
}
}
```

}

Once the program is compiled and run, it produces a file called **X.file** in the **serialization** directory. The following code is in a subdirectory called **xfiles**:

// serialization/xfiles/ThawAlien.java



// Recover a serialized file

// {java serialization.xfiles.ThawAlien}

// {RunFirst: FreezeAlien}

package serialization.xfiles;

import java.io.*;

public class ThawAlien {

public static void

main(String[] args) **throws** Exception {

ObjectInputStream in = **new** ObjectInputStream(

new FileInputStream(**new** File("X.file")));

Object mystery = in.readObject();

```
System.out.println(mystery.getClass());
}
}
/* Output:
class Alien
*/
```

To work, the JVM must be able find the associated **.class** file.

Controlling Serialization

The default serialization mechanism is trivial to use. But what about special needs? Perhaps you have special security issues and you don't want to serialize portions of your object, or perhaps it just doesn't make sense for one subobject to be serialized if that part needs creating anew when the object is recovered.

You can control the process of serialization by implementing the **Externalizable** interface instead of the **Serializable** interface. The **Externalizable** interface extends the **Serializable** interface and adds two methods, **writeExternal()** and **readExternal()**. These are automatically called for your object during serialization and

deserialization so you can perform your special operations.

The following example shows simple implementations of the **Externalizable** interface methods. Note that **Blip1** and **Blip2** are nearly identical except for a subtle difference (see if you can discover it by looking at the code):

```
// serialization/Blips.java
// Simple use of Externalizable & a pitfall
import java.io.*;
class Blip1 implements Externalizable {
public Blip1() {
System.out.println("Blip1 Constructor");
}
@Override
public void writeExternal(ObjectOutput out)
throws IOException {
System.out.println("Blip1.writeExternal");
}
@Override
public void readExternal(ObjectInput in)
throws IOException, ClassNotFoundException {
```

```
System.out.println("Blip1.readExternal");
}
}
class Blip2 implements Externalizable {
Blip2() {
System.out.println("Blip2 Constructor");
}
@Override
public void writeExternal(ObjectOutput out)
throws IOException {
System.out.println("Blip2.writeExternal");
}
@Override
public void readExternal(ObjectInput in)
throws IOException, ClassNotFoundException {
System.out.println("Blip2.readExternal");
}
}
public class Blips {
public static void main(String[] args) {
```

```
System.out.println("Constructing objects:");
Blip1 b1 = new Blip1();
Blip2 b2 = new Blip2();
try(
ObjectOutputStream o = new ObjectOutputStream(
new FileOutputStream("Blips.serialized"))
) {
System.out.println("Saving objects:");
o.writeObject(b1);
o.writeObject(b2);
} catch(IOException e) {
throw new RuntimeException(e);
}
// Now get them back:
System.out.println("Recovering b1:");
try(
ObjectInputStream in = new ObjectInputStream(
new FileInputStream("Blips.serialized"))
) {
b1 = (Blip1)in.readObject();
```

```
} catch(IOException | ClassNotFoundException e) {
throw new RuntimeException(e);
}
// OOPS! Throws an exception:
//- System.out.println("Recovering b2:");
//- b2 = (Blip2)in.readObject();
}
}
/* Output:
Constructing objects:
Blip1 Constructor
Blip2 Constructor
Saving objects:
Blip1.writeExternal
Blip2.writeExternal
Recovering b1:
Blip1 Constructor
Blip1.readExternal
*/
```

The reason that the **Blip2** object is not recovered is that trying to do

so causes an exception. Can you see the difference between **Blip1** and **Blip2**? The constructor for **Blip1** is **public**, while the constructor for **Blip2** is not, and that causes the exception upon recovery. Try making **Blip2**s constructor **public** and removing the **//-** comments to see the correct results.

When **b1** is recovered, the **Blip1** no-arg constructor is called. This is different from recovering a **Serializable** object, where the object is constructed entirely from its stored bits, with no constructor calls. With an **Externalizable** object, all the normal default construction behavior occurs (including the initializations at the point of field definition), and *then* **readExternal()** is called. Be aware of this—in particular, the fact that all the default construction always takes place—to produce the correct behavior in your **Externalizable** objects.

Here's an example that shows what you must do to fully store and retrieve an **Externalizable** object:

```
// serialization/Blip3.java
// Reconstructing an externalizable object
import java.io.*;
public class Blip3 implements Externalizable {
```

```
private int i;
private String s; // No initialization
public Blip3() {
System.out.println("Blip3 Constructor");
// s, i not initialized
}
public Blip3(String x, int a) {
System.out.println("Blip3(String x, int a)");
s = x;
i = a;
// s & i initialized only in non-no-arg constructor.
}
@Override
public String toString() { return s + i; }
@Override
public void writeExternal(ObjectOutput out)
throws IOException {
System.out.println("Blip3.writeExternal");
// You must do this:
out.writeObject(s);
```

```
out.writeInt(i);
}
@Override
public void readExternal(ObjectInput in)
throws IOException, ClassNotFoundException {
System.out.println("Blip3.readExternal");
// You must do this:
s = (String)in.readObject();
i = in.readInt();
}
public static void main(String[] args) {
System.out.println("Constructing objects:");
Blip3 b3 = new Blip3("A String ", 47);
System.out.println(b3);
try(
ObjectOutputStream o = new ObjectOutputStream(
new FileOutputStream("Blip3.serialized"))
) {
System.out.println("Saving object:");
o.writeObject(b3);
```

```
} catch(IOException e) {
throw new RuntimeException(e);
}
// Now get it back:
System.out.println("Recovering b3:");
try(
ObjectInputStream in = new ObjectInputStream(
new FileInputStream("Blip3.serialized"))
) {
b3 = (Blip3)in.readObject();
} catch(IOException | ClassNotFoundException e) {
throw new RuntimeException(e);
}
System.out.println(b3);
}
}
/* Output:
Constructing objects:
Blip3(String x, int a)
A String 47
```

Saving object:

Blip3.writeExternal

Recovering b3:

Blip3 Constructor

Blip3.readExternal

A String 47

**/*

The fields **s** and **i** are initialized only in the second constructor, but not in the no-arg constructor. This means if you don't initialize **s** and **i** in **readExternal()**, **s** is **null** and **i** is zero (since the storage for the object gets wiped to zero in the first step of object creation). If you comment out the two lines of code following the phrases "You must do this:" and run the program, you'll see that when the object is recovered, **s** is **null** and **i** is zero.

If you inherit an **Externalizable** object, you'll typically call the base-class versions of **writeExternal()** and **readExternal()** to provide proper storage and retrieval of the base-class components. So to make things work correctly, you must not only write the important data from the object during the **writeExternal()** method (there is no default behavior that writes any of the member objects for an **Externalizable** object), but you must also recover

that data in the **readExternal()** method. This can be a bit confusing at first because the default construction behavior for an **Externalizable** object can make it seem like some kind of storage

and retrieval takes place automatically. It does not.

The transient Keyword

When you're controlling serialization, there might be a particular subobject you don't want Java's serialization mechanism to automatically save and restore. This is commonly the case if that subobject represents sensitive information you don't want to serialize, such as a password. Even if that information is **private** in the object, once it is serialized, it's possible for someone to access it by reading a file or intercepting a network transmission.

One way to prevent sensitive parts of your object from being serialized is to implement your class as **Externalizable**, as shown previously. Then nothing is automatically serialized, and you can explicitly serialize only the necessary parts inside **writeExternal()**.

If you’re working with a **Serializable** object, however, all serialization happens automatically. To control this, you can turn off serialization on a field-by-field basis using the **transient** keyword, which says, “Don’t bother saving or restoring this—I’ll take care of it.” For example, consider a **Logon** object that keeps information about a particular login session. Suppose that, once you verify the login, you want to store the data, but without the password. The easiest way to do this is by implementing **Serializable** and marking the **password** field as **transient**. Here’s what it looks like:

```
// serialization/Logon.java
// Demonstrates the "transient" keyword
import java.util.concurrent.*;
import java.io.*;
import java.util.*;
import onjava.Nap;
public class Logon implements Serializable {
private Date date = new Date();
private String username;
private transient String password;
public Logon(String name, String pwd) {
```

```
username = name;
password = pwd;
}
@Override
public String toString() {
return "logon info: \n username: " +
username + "\n date: " + date +
"\n password: " + password;
}
public static void main(String[] args) {
Logon a = new Logon("Hulk", "myLittlePony");
System.out.println("logon a = " + a);
try(
ObjectOutputStream o =
new ObjectOutputStream(
new FileOutputStream("Logon.dat"))
) {
o.writeObject(a);
} catch(IOException e) {
throw new RuntimeException(e);
```

```
}
new Nap(1);
// Now get them back:
try(
ObjectInputStream in = new ObjectInputStream(
new FileInputStream("Logon.dat"))
) {
System.out.println(
"Recovering object at " + new Date());
a = (Logon)in.readObject();
} catch(IOException | ClassNotFoundException e) {
throw new RuntimeException(e);
}
System.out.println("logon a = " + a);
}
}
```

```
/* Output:
```

logon a = logon info:

username: Hulk

date: Tue May 09 06:07:47 MDT 2017

password: myLittlePony

Recovering object at Tue May 09 06:07:49 MDT 2017

logon a = logon info:

username: Hulk

date: Tue May 09 06:07:47 MDT 2017

password: null

**/*

The **date** and **username** fields are ordinary (not **transient**), and thus are automatically serialized. However, the **password** is **transient**, so it is not stored to disk; also, the serialization mechanism makes no attempt to recover it. When the object is recovered, the **password** field is **null**. Note that while **toString()** assembles a **String** object using the overloaded **+** operator, a **null** reference is automatically converted to the **String** "null."

You can also see that the **date** field is stored to and recovered from disk and not generated anew.

Since **Externalizable** objects do not store any of their fields by default, the **transient** keyword is for use with **Serializable** objects only.

An Alternative to Externalizable

If you're not keen on implementing the **Externalizable** interface, there's another approach. You can implement the **Serializable** interface and *add* (notice I say "add" and not "override" or "implement") methods called **writeObject()** and **readObject()** that are automatically called when the object is serialized and deserialized, respectively. That is, if you provide these two methods, they are used instead of the default serialization.

The methods must have these exact signatures:

private void writeObject(ObjectOutputStream stream)
throws IOException;

private void readObject(ObjectInputStream stream)
throws IOException, ClassNotFoundException

From a design standpoint, things get really weird here. First of all, you might think that, because these methods are not part of a base class or the **Serializable** interface, they ought to be defined in their own

interface(s). But notice they are defined as **private**, which means they are called only by other members of this class. However, you don't actually call them from other members of this class, but instead the **writeObject()** and **readObject()** methods of the **ObjectOutputStream** and **ObjectInputStream** objects call your object's **writeObject()** and **readObject()** methods. (Notice my tremendous restraint in not launching into a long diatribe on using the same method names here. In a word: confusing.) You might wonder how the **ObjectOutputStream** and **ObjectInputStream** objects have access to **private** methods of your class. We can only assume this is part of the serialization magic. [1] Anything defined in an interface is automatically **public**, so if **writeObject()** and **readObject()** must be **private**, then they can't be part of an interface. Since you must follow the signatures exactly, the effect is the same as if you're implementing an interface.

It would appear that when you call **ObjectOutputStream.writeObject()**, the **Serializable** object you pass it to is interrogated (using reflection, no doubt) to see if it implements its own **writeObject()**. If so, the normal serialization process is skipped and the custom **writeObject()** is

called. The same situation exists for **readObject()**.

There's one other twist. Inside your **writeObject()**, you can choose to perform the default **writeObject()** action by calling **defaultWriteObject()**. Likewise, inside **readObject()** you can call **defaultReadObject()**. Here is a simple example that demonstrates how you can control the storage and retrieval of a **Serializable** object:

```
// serialization/SerialCtl.java
// Controlling serialization by adding your own
// writeObject() and readObject() methods
import java.io.*;
public class SerialCtl implements Serializable {
private String a;
private transient String b;
public SerialCtl(String aa, String bb) {
a = "Not Transient: " + aa;
b = "Transient: " + bb;
}
@Override
public String toString() { return a + "\n" + b; }
```

```
private void writeObject(ObjectOutputStream stream)
throws IOException {
stream.defaultWriteObject();
stream.writeObject(b);
}
private void readObject(ObjectInputStream stream)
throws IOException, ClassNotFoundException {
stream.defaultReadObject();
b = (String)stream.readObject();
}
public static void main(String[] args) {
SerialCtl sc = new SerialCtl("Test1", "Test2");
System.out.println("Before:\n" + sc);
try (
ByteArrayOutputStream buf =
new ByteArrayOutputStream();
ObjectOutputStream o =
new ObjectOutputStream(buf);
) {
o.writeObject(sc);
```

```
// Now get it back:
try (
ObjectInputStream in =
new ObjectInputStream(
new ByteArrayInputStream(
buf.toByteArray()));
) {
SerialCtl sc2 = (SerialCtl)in.readObject();
System.out.println("After:\n" + sc2);
}
} catch(IOException | ClassNotFoundException e) {
throw new RuntimeException(e);
}
}
}
/* Output:
Before:
Not Transient: Test1
Transient: Test2
After:
```

Not Transient: Test1

Transient: Test2

/

In this example, one **String** field is ordinary and the other is **transient**, to prove that the non-**transient** field is saved by the **defaultWriteObject()** method and the **transient** field is saved and restored explicitly. The fields are initialized inside the constructor rather than at the point of definition to prove they are not initialized by some automatic mechanism during deserialization.

If you use the default mechanism to write the non-**transient** parts of your object, you must call **defaultWriteObject()** as the first operation in **writeObject()**, and **defaultReadObject()** as the first operation in **readObject()**. These are strange method calls. It would appear, for example, that you are calling **defaultWriteObject()** for an **ObjectOutputStream** and passing it no arguments, and yet it somehow turns around and knows the reference to your object and how to write all the non-**transient**

parts. Spooky.

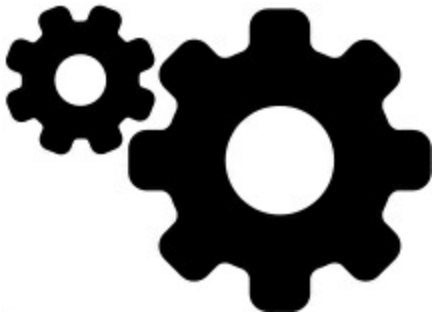
The storage and retrieval of the **transient** objects uses more familiar code. And yet, think about what happens here. In **main()**, a **SerialCtl** object is created and serialized to an **ObjectOutputStream**. (Notice here that a buffer is used instead of a file—it's all the same to the **ObjectOutputStream**.) The serialization occurs in the line:

o.writeObject(sc);

The **writeObject()** method must be examining **sc** to see if it has its own **writeObject()** method. (Not by checking the interface—there isn't one—or the class type, but by actually hunting for the method using reflection.) If it does, it uses that. A similar approach holds true for **readObject()**. Perhaps this was the only practical way they could solve the problem, but it's certainly strange.

Versioning

You might change the version of a serializable class (objects of the original class might be stored in a database, for example). This is supported, but you'll probably do it only in special cases, and it



requires an extra depth of understanding that we will not attempt to achieve here. The JDK documents downloadable from *http://java.oracle.com* cover this topic thoroughly.

Using Persistence

It’s appealing to use serialization technology to store some of the state of your program to easily restore the program to the current state later. But before you can do this, some questions must be answered. What happens if you serialize two objects that both have a reference to a third object? When you restore those two objects from their serialized state, do you get only one occurrence of the third object? What if you serialize your two objects to separate files and deserialize them in different parts of your code?

Here’s an example that shows the problem:

```
// serialization/MyWorld.java
import java.io.*;
import java.util.*;
```

```
class House implements Serializable {}
class Animal implements Serializable {
private String name;
private House preferredHouse;
Animal(String nm, House h) {
name = nm;
preferredHouse = h;
}
@Override
public String toString() {
return name + "[" + super.toString() +
"], " + preferredHouse + "\n";
}
}
public class MyWorld {
public static void main(String[] args) {
House house = new House();
List<Animal> animals = new ArrayList<>();
animals.add(
new Animal("Bosco the dog", house));
```

```
animals.add(
new Animal("Ralph the hamster", house));
animals.add(
new Animal("Molly the cat", house));
System.out.println("animals: " + animals);
try(
ByteArrayOutputStream buf1 =
new ByteArrayOutputStream();
ObjectOutputStream o1 =
new ObjectOutputStream(buf1)
) {
o1.writeObject(animals);
o1.writeObject(animals); // Write a 2nd set
// Write to a different stream:
try(
ByteArrayOutputStream buf2 =
new ByteArrayOutputStream();
ObjectOutputStream o2 =
new ObjectOutputStream(buf2)
) {
```

```
o2.writeObject(animals);
// Now get them back:
try(
ObjectInputStream in1 =
new ObjectInputStream(
new ByteArrayInputStream(
buf1.toByteArray()));
ObjectInputStream in2 =
new ObjectInputStream(
new ByteArrayInputStream(
buf2.toByteArray()))
) {
List
animals1 = (List)in1.readObject(),
animals2 = (List)in1.readObject(),
animals3 = (List)in2.readObject();
System.out.println(
"animals1: " + animals1);
System.out.println(
"animals2: " + animals2);
```

```
System.out.println(
"animals3: " + animals3);
}
}
} catch(IOException | ClassNotFoundException e) {
throw new RuntimeException(e);
}
}
}
/* Output:
animals: [Bosco the dog[Animal@15db9742],
House@6d06d69c
, Ralph the hamster[Animal@7852e922], House@6d06d69c
, Molly the cat[Animal@4e25154f], House@6d06d69c
]
animals1: [Bosco the dog[Animal@7ba4f24f],
House@3b9a45b3
, Ralph the hamster[Animal@7699a589], House@3b9a45b3
, Molly the cat[Animal@58372a00], House@3b9a45b3
]
```

animals2: [Bosco the dog[Animal@7ba4f24f],

House@3b9a45b3

, Ralph the hamster[Animal@7699a589], House@3b9a45b3

, Molly the cat[Animal@58372a00], House@3b9a45b3

]

animals3: [Bosco the dog[Animal@4dd8dc3],

House@6d03e736

, Ralph the hamster[Animal@568db2f2], House@6d03e736

, Molly the cat[Animal@378bf509], House@6d03e736

]

**/*

It's possible to use object serialization to and from a **byte** array as a way of doing a *deep copy* of any object that's **Serializable**. (A deep copy means you're duplicating the entire web of objects, rather than just the basic object and its references.) Object copying is covered in depth in the Appendix: Passing and Returning Objects.

Animal objects contain fields of type **House**. In **main()**, a **List** of these **Animal**s is created and serialized, twice to one stream, then again to a separate stream. When these are deserialized and printed, you see the output shown for one run (the objects are in different memory locations for each run).

You might expect that the deserialized objects have different addresses from their originals. But notice that in **animals1** and **animals2**, the same addresses appear, including the references to the **House** object that both share. On the other hand, when **animals3** is recovered, the system has no way of knowing that the objects in this other stream are aliases of the objects in the first stream, so it makes a completely different web of objects.

As long as you're serializing everything to a single stream, you'll recover the same web of objects you wrote, with no accidental duplication of objects. You can change the state of your objects in between the time you write the first and the last, but that's your responsibility; the objects are written in their current state (and with whatever connections they have to other objects) at the time you serialize them.

The safest way to save the state of a system is to "atomically" serialize that state. If you serialize some things, do some other work, and serialize some more, etc., then you will not store the system safely. Instead, put all the objects that comprise the state of your system in a single container and write that container out in one operation. Then you can restore it with a single method call.

The following example is an imaginary computer-aided design (CAD) system that demonstrates the approach. In addition, it throws in the issue of **static** fields; if you look at the JDK documentation, you'll see that **Class** is **Serializable**, so it should be easy to store the **static** fields by serializing the **Class** object. That seems like a sensible approach, anyway.

```
// serialization/AStoreCADState.java
// Saving the state of a fictitious CAD system
import java.io.*;
import java.util.*;
import java.util.stream.*;
enum Color { RED, BLUE, GREEN }
abstract class Shape implements Serializable {
private int xPos, yPos, dimension;
private static Random rand = new Random(47);
private static int counter = 0;
public abstract void setColor(Color newColor);
public abstract Color getColor();
Shape(int xVal, int yVal, int dim) {
xPos = xVal;
```

```
yPos = yVal;
dimension = dim;
}
public String toString() {
return getClass() + "color[" + getColor() +
"] xPos[" + xPos + "] yPos[" + yPos +
"] dim[" + dimension + "]\n";
}
public static Shape randomFactory() {
int xVal = rand.nextInt(100);
int yVal = rand.nextInt(100);
int dim = rand.nextInt(100);
switch(counter++ % 3) {
default:
case 0: return new Circle(xVal, yVal, dim);
case 1: return new Square(xVal, yVal, dim);
case 2: return new Line(xVal, yVal, dim);
}
}
}
```

```
class Circle extends Shape {
private static Color color = Color.RED;
Circle(int xVal, int yVal, int dim) {
super(xVal, yVal, dim);
}
public void setColor(Color newColor) {
color = newColor;
}
public Color getColor() { return color; }
}
class Square extends Shape {
private static Color color = Color.RED;
Square(int xVal, int yVal, int dim) {
super(xVal, yVal, dim);
}
public void setColor(Color newColor) {
color = newColor;
}
public Color getColor() { return color; }
}
```

```
class Line extends Shape {
private static Color color = Color.RED;
public static void
serializeStaticState(ObjectOutputStream os)
throws IOException { os.writeObject(color); }
public static void
deserializeStaticState(ObjectInputStream os)
throws IOException, ClassNotFoundException {
color = (Color)os.readObject();
}
Line(int xVal, int yVal, int dim) {
super(xVal, yVal, dim);
}
public void setColor(Color newColor) {
color = newColor;
}
public Color getColor() { return color; }
}
public class AStoreCADState {
public static void main(String[] args) {
```

```
List<Class<? extends Shape>> shapeTypes =
Arrays.asList(
Circle.class, Square.class, Line.class);
List<Shape> shapes = IntStream.range(0, 10)
.mapToObj(i -> Shape.randomFactory())
.collect(Collectors.toList());
// Set all the static colors to GREEN:
shapes.forEach(s -> s.setColor(Color.GREEN));
// Save the state vector:
try(
ObjectOutputStream out =
new ObjectOutputStream(
new FileOutputStream("CADState.dat"))
) {
out.writeObject(shapeTypes);
Line.serializeStaticState(out);
out.writeObject(shapes);
} catch(IOException e) {
throw new RuntimeException(e);
}
```

```
// Display the shapes:
System.out.println(shapes);
}
}
/* Output:
[class Circlecolor[GREEN] xPos[58] yPos[55] dim[93]
, class Squarecolor[GREEN] xPos[61] yPos[61] dim[29]
, class Linecolor[GREEN] xPos[68] yPos[0] dim[22]
, class Circlecolor[GREEN] xPos[7] yPos[88] dim[28]
, class Squarecolor[GREEN] xPos[51] yPos[89] dim[9]
, class Linecolor[GREEN] xPos[78] yPos[98] dim[61]
, class Circlecolor[GREEN] xPos[20] yPos[58] dim[16]
, class Squarecolor[GREEN] xPos[40] yPos[11] dim[22]
, class Linecolor[GREEN] xPos[4] yPos[83] dim[6]
, class Circlecolor[GREEN] xPos[75] yPos[10] dim[42]
]
*/
```

The **Shape** class **implements Serializable**, so anything that inherits **Shape** is automatically **Serializable** as well. Each **Shape** contains data, and each derived **Shape** class contains a

static field that holds the color of all of those types of **Shape**s. (Placing a **static** field in the base class would result in only one field, since **static** fields are not duplicated in derived classes.) Methods in the base class can be overridden to set the color for the various types (**static** methods are not dynamically bound, so these are normal methods). The **randomFactory()** method creates a different **Shape** each time you call it, using random values for the **Shape** data.

Circle and **Square** are straightforward extensions of **Shape**; the only difference is that **Circle** initializes **color** at the point of definition and **Square** initializes it in the constructor. We'll leave the discussion of **Line** for later.

In **main()**, one **ArrayList** is used to hold the **Class** objects and the other to hold the shapes.

Recovering the objects is fairly straightforward:

```
// serialization/RecoverCADState.java
// Restoring the state of the fictitious CAD system
// {RunFirst: AStoreCADState}
import java.io.*;
import java.util.*;
```

```
public class RecoverCADState {
@SuppressWarnings("unchecked")
public static void main(String[] args) {
try(
ObjectInputStream in =
new ObjectInputStream(
new FileInputStream("CADState.dat"))
) {
// Read in the same order they were written:
List<Class<? extends Shape>> shapeTypes =
(List<Class<? extends Shape>>)in.readObject();
Line.deserializeStaticState(in);
List<Shape> shapes =
(List<Shape>)in.readObject();
System.out.println(shapes);
} catch(IOException | ClassNotFoundException e) {
throw new RuntimeException(e);
}
}
}
```

/ *Output:*

[class Circlecolor[RED] xPos[58] yPos[55] dim[93]

, class Squarecolor[RED] xPos[61] yPos[61] dim[29]

, class Linecolor[GREEN] xPos[68] yPos[0] dim[22]

, class Circlecolor[RED] xPos[7] yPos[88] dim[28]

, class Squarecolor[RED] xPos[51] yPos[89] dim[9]

, class Linecolor[GREEN] xPos[78] yPos[98] dim[61]

, class Circlecolor[RED] xPos[20] yPos[58] dim[16]

, class Squarecolor[RED] xPos[40] yPos[11] dim[22]

, class Linecolor[GREEN] xPos[4] yPos[83] dim[6]

, class Circlecolor[RED] xPos[75] yPos[10] dim[42]

]

**/*

The values of **xPos**, **yPos**, and **dim** were all stored and recovered successfully, but there's something wrong with the retrieval of the **static** information. It's all "3" going in, but it doesn't come out that way. **Circle**s have a value of 1 (**RED**, which is the definition), and **Square**s have a value of 0 (remember, they are initialized in the constructor). It's as if the **static**s didn't get serialized at all! That's right—even though class **Class** is **Serializable**, it doesn't do

what you expect. So to serialize **static**s, you must do it yourself. This is the purpose of the **serializeStaticState()** and **deserializeStaticState() static** methods in **Line**. They are explicitly called as part of the storage and retrieval process. (Note that the order of writing to the serialize file and reading back from it must be maintained.) Thus to make these programs run correctly, you must:

1. Add a **serializeStaticState()** and **deserializeStaticState()** to the shapes.
2. Remove the **ArrayList shapeTypes** and all code related to it.
3. Add calls to the new serialize and deserialize static methods in the shapes.

Another issue you might think about is security, since serialization also saves **private** data. For security, those fields should be marked as **transient**. But then you must design a secure way to store that information so when you do a restore, you can reset those **private** variables.

XML—

An important limitation of object serialization is it is a Java-only

solution: Only Java programs can deserialize such objects. A more interoperable solution is to convert data to XML format, which allows it to be consumed by a large variety of platforms and languages. Because of its popularity, there are a confusing number of options for programming with XML, including the **javax.xml.*** libraries distributed with the JDK. I've chosen to use Elliotte Rusty Harold's open-source XOM library (downloads and documentation at www.xom.nu) because it seems the simplest and most straightforward way to produce and modify XML using Java. In addition, XOM emphasizes XML correctness.

As an example, suppose you have **APerson** objects containing first and last names that you'd like to serialize into XML. The following **APerson** class has a **getXML()** method that uses XOM to produce the **APerson** data converted to an XML **Element** object, and a constructor that takes an **Element** and extracts the appropriate **APerson** data (notice that the XML examples are in their own subdirectory):

```
// serialization/APerson.java
// Use the XOM library to write and read XML
// nu.xom.Node comes from http://www.xom.nu
import nu.xom.*;
```

```
import java.io.*;
import java.util.*;
public class APerson {
private String first, last;
public APerson(String first, String last) {
this.first = first;
this.last = last;
}
// Produce an XML Element from this APerson object:
public Element getXML() {
Element person = new Element("person");
Element firstName = new Element("first");
firstName.appendChild(first);
Element lastName = new Element("last");
lastName.appendChild(last);
person.appendChild(firstName);
person.appendChild(lastName);
return person;
}
// Constructor restores a APerson from XML:
```

```
public APerson(Element person) {
first = person
.getFirstChildElement("first").getValue();
last = person
.getFirstChildElement("last").getValue();
}
@Override
public String toString() {
return first + " " + last;
}
// Make it human-readable:
public static void
format(OutputStream os, Document doc)
throws Exception {
Serializer serializer =
new Serializer(os,"ISO-8859-1");
serializer.setIndent(4);
serializer.setMaxLength(60);
serializer.write(doc);
serializer.flush();
```

```
}
public static void
main(String[] args) throws Exception {
List<APerson> people = Arrays.asList(
new APerson("Dr. Bunsen", "Honeydew"),
new APerson("Gonzo", "The Great"),
new APerson("Phillip J.", "Fry"));
System.out.println(people);
Element root = new Element("people");
for(APerson p : people)
root.appendChild(p.getXML());
Document doc = new Document(root);
format(System.out, doc);
format(new BufferedOutputStream(
new FileOutputStream("People.xml")), doc);
}
}
/* Output:
[Dr. Bunsen Honeydew, Gonzo The Great, Phillip J. Fry]
<?xml version="1.0" encoding="ISO-8859-1"?>
```

<people>

<person>

<first>Dr. Bunsen</first>

<last>Honeydew</last>

</person>

<person>

<first>Gonzo</first>

<last>The Great</last>

</person>

<person>

<first>Phillip J.</first>

<last>Fry</last>

</person>

</people>

*/

The XOM methods are fairly self-explanatory and are found in the XOM documentation.

XOM also contains a **Serializer** class you see used in the **format()** method to turn the XML into a more readable form. If you just call **toXML()** you'll get everything run together, so the

Serializer is a convenient tool.

Deserializing **APerson** objects from an XML file is also simple:

```
// serialization/People.java
// nu.xom.Node comes from http://www.xom.nu
// {RunFirst: APerson}
import nu.xom.*;
import java.io.File;
import java.util.*;
public class People extends ArrayList<APerson> {
public People(String fileName) throws Exception {
Document doc =
new Builder().build(new File(fileName));
Elements elements =
doc.getRootElement().getChildElements();
for(int i = 0; i < elements.size(); i++)
add(new APerson(elements.get(i)));
}
public static void
main(String[] args) throws Exception {
People p = new People("People.xml");
```

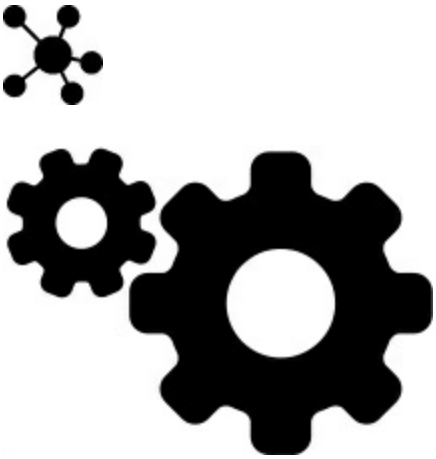
```
System.out.println(p);
}
}
/* Output:
[Dr. Bunsen Honeydew, Gonzo The Great, Phillip J. Fry]
*/
```

The **People** constructor opens and reads a file using XOM's **Builder.build()** method, and the **getChildElements()** method produces an **Elements** list (not a standard Java **List**, but an object that only has a **size()** and **get()** method—Harold did not want to force people to use a particular version of Java, but still wanted a type-safe container). Each **Element** in this list represents a **APerson** object, so it is handed to the second **APerson** constructor. Note this requires you know ahead of time the exact structure of your XML file, but this is often true with these kinds of problems. If the structure doesn't match what you expect, XOM will throw an exception. It's also possible for you to write more complex code to explore the XML document, rather than making assumptions about it, for cases when you have less concrete information about incoming XML structure.

To get these examples to compile, put the JAR files from the XOM distribution into your classpath.

This has only been a brief introduction to XML programming with Java and the XOM library; for more information see www.xom.nu.

1. The section “Interfaces and type information” at the end of the Type Information chapter shows how it’s possible to access **private** methods from outside of the class.↩



Appendix: Benefits and Costs of Static Type Checking

This is an edited collection of essays I’ve written over the years that tries to put the debate between statically-checked and dynamic languages into perspective,

and a foreword describing my recent

insights on the topic.

Foreword

My primary interest in software development has always been programmer productivity. Programmer cycles are expensive, CPU cycles are cheap, and I believe we should not pay for the latter with the former.

My initial experiences with static type checking were first with assembly language (no type checking at all), followed by pre-ANSI C, which allowed many problems to slip through. Then C++ appeared and checked the type of function arguments and return values, and thus found many errors (and influenced ANSI C to adopt this approach). This error discovery made me a big fan. Time passed, and we were burdened with more and more coding overhead to support more type checking. In the meantime, I began experimenting with dynamic languages, and eventually discovered Python and its marvelous productivity. This made me start to wonder if we weren't missing something in our pursuit of static perfection. (I have also ventured into the extremes of static type checking while writing Atomic Scala.

I tended to hear things like “more static checking is always better” and “you can only solve simple problems with dynamic languages; they aren’t suited to real-world applications.”

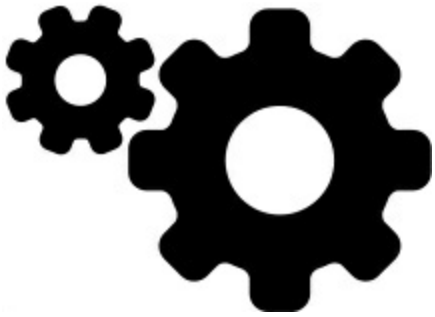
My goal in writing these essays was to explain the benefits of dynamic languages and to question the idea that static type checking was “free,” that there are no costs associated with all those features. And that sometimes those costs hold us back.

My assumption throughout was always that people simply didn’t understand, and that if I just explained harder, they would eventually get it.

Then something interesting happened. Time passed, and people created more and more large, real-world applications using languages like Python and Ruby. Dynamic languages like Groovy and Clojure appeared for the JVM, and folks began writing impressive programs with these.

After seeing what these languages could do, there were no remaining legitimate arguments to justify the idea that certain things can only be accomplished with static languages. At that point, some people started saying they just “preferred static type checking.”

Only recently did it hit me:



This is a cultural issue, an issue of belief.

That’s why all my explanations kept failing. A group of people had gotten comfortable with a set of beliefs, and I was challenging those and making them uncomfortable. So they fought back, and dug in harder.

Programming languages create cultural communities.

With this new perspective, which seems obvious in hindsight, the issues and choices now look quite different to me. Some issues can be argued with reason and experimentation. But other issues are part of the core belief system of a community, and if you join, you sign up for those and go where they take you.

Static Type Checking vs. Testing

How can we get maximal leverage on the problems we try to solve? Whenever a new tool (especially a programming language) appears,

that tool provides some kind of abstraction that may or may not hide needless detail from the programmer. I have come, however, to always be on watch for a Faustian bargain, especially one that tries to convince me to ignore all the hoops I must jump through to achieve this abstraction. Perl is an excellent example of this—the immediacy of the language hides the meaningless details of writing a program, but the unreadable syntax (based, I know, on backward-compatibility with Unix tools like awk, sed and grep) is a significant price to pay.

Over the years, I've slowly come to understand the relationship of more traditional programming languages and their orientation towards static type checking. This began, long ago, with a two-month love affair with Perl, which gave me productivity through rapid turnaround (The affair was terminated because of Perl's reprehensible treatment of references and classes; only later did I see the real problems with the syntax). Issues of static-vs-dynamic type checking were not visible with Perl, since you can't build projects large enough to see these issues, and the syntax obscures everything in smaller programs.

After I worked with Python—a language which can build large, complex systems—I noticed that, despite an apparent carelessness

about type checking, Python programs seemed to work quite well without much effort, and without the kinds of problems expected from a language that doesn't have the static type checking we've all come to "know" is the only correct way of solving the programming problem. This became a puzzle to me: if static type checking is so important, why are people able to build big, complex Python programs (in much shorter time and with much less effort than the static counterparts) without the disaster I was so sure would ensue?

This shook my unquestioning acceptance of static type checking (acquired when moving from C to C++, where the improvement was dramatic) enough that the next time I examined the issue of checked exceptions in Java, I asked "why"? which produced a big discussion wherein I was told that if I kept advocating unchecked exceptions, cities would fall and civilization as we know it would cease to exist. In *Thinking in Java*, 3rd edition, I advocated the use of **RuntimeException** as a wrapper class to "turn off" checked exceptions. Every time I do it now, it seems right (I note that Martin Fowler came up with the same idea at roughly the same time), but I still get the occasional email that warns me I am violating all that is right and true, civilizations will fall, etc.

But deciding that checked exceptions seem like more trouble than they're worth[1] did not answer the question "why does Python work so well, when conventional wisdom says it should produce massive failures?" Python and similar dynamically-typed languages are lazy about type checking. Instead of putting the strongest possible constraints upon the type of objects, as early as possible (as C++ and Java do), languages like Ruby, SmallTalk and Python put the loosest possible constraints on types, and evaluate types only if they have to. That is, you can send any message to any object, and the language only cares that the object can accept the message—it doesn't require that the object be a particular type, as Java and C++ do. For example, for speaking pets in Java, the code looks like this:

```
// staticchecking/petspeak/PetSpeak.java
// Speaking pets in Java
// {java staticchecking.petspeak.PetSpeak}
package staticchecking.petspeak;
interface Pet {
void speak();
}
class Cat implements Pet {
public void speak() {
```

```
System.out.println("meow!");
}
}
class Dog implements Pet {
public void speak() {
System.out.println("woof!");
}
}
public class PetSpeak {
static void command(Pet p) { p.speak(); }
public static void main(String[] args) {
Pet[] pets = { new Cat(), new Dog() };
for(Pet pet : pets)
command(pet);
}
}
/* Output:
meow!
woof!
*/
```

Note that **command()** must know exactly the type of argument it's going to accept—a **Pet**—and it will accept nothing else. Thus, I must create a hierarchy of **Pet**, and inherit **Dog** and **Cat** so I can upcast them to the generic **command()** method.

For the longest time, I assumed that upcasting was an inherent part of object-oriented programming, and found the questions about upcasting from SmallTalkers and the like to be annoying. But when I started working with Python I found the following curiosity. The above code can be translated directly into Python:

```
# staticchecking/PetSpeak.py
# Speaking pets in Python
class Pet:
def speak(self): pass
class Cat(Pet):
def speak(self):
print("meow!")
class Dog(Pet):
def speak(self):
print("woof!")
def command(pet):
```

```
pet.speak()
pets = [ Cat(), Dog() ] # (1)
for pet in pets: # (2)
command(pet)
output = """
meow!
woof!
"""
```

If you've never seen Python before, you'll notice it redefines the meaning of a terse language, but in a very good way. You think C/C++ is terse? Let's throw away those curly braces. Indentation already has meaning to the human mind, so we'll use that instead to indicate scope. Argument types and return types? Let the language sort it out. During class creation, base classes are indicated in parentheses. **def** means we are creating a function or method definition. On the other hand, Python is explicit about the **this** argument (called **self** by convention) for method definitions.

Comments start with a **#** and continue to the end of the line.

The definition for the **Pet** class uses the **pass** keyword, which is similar to saying **abstract** in Java. It just means there's no

definition here.

Note that **command(pet)** just says it takes some object called **pet**, but it doesn't give any information about what the type of that object must be. That's because it doesn't care, as long as you can call **speak()**, or whatever else your function or method wants to do. We'll look at this more closely in a minute.

Also, **command(pet)** is just an ordinary function, which is OK in Python. That is, Python doesn't insist you make everything an object, since sometimes a function is what you want.

[1] In Python, lists and maps/dictionaries/associative arrays are both so important they are built into the core of the language, so I don't need to import any special library to use them. Here, a list is created containing two new objects, of type **Cat** and **Dog**. The constructors are called, but no **new** is necessary (and now you'll go back to Java and realize that no **new** is necessary there, either. It's just a redundancy inherited from C++).

[2] Iterating through a sequence is also important enough that it's a native operation in Python. The **for** selects each item from the list **pets** into the variable **pet**.

The output is the same as the Java version, and is captured in the

definition of the **output** variable. Triple quoting creates a multiline string.

Python makes an excellent pseudo-coding language, with the wonderful attribute that it can actually be executed. This means you can quickly try out ideas in Python, and when you get one that works, you can rewrite it in Java, C++ or your language of choice. Or maybe you realize the problem is already solved in Python, so why bother rewriting it? (That's usually as far as I get). I've taken to giving exercise hints in Python during seminars, because then I'm not giving away the whole picture, but people can see the form I'm looking for in a solution so they can move ahead. And I'm able to verify that the form is correct. This is why Python is often called "executable pseudocode."

For this discussion, the interesting part is this: because the **command(pet)** method doesn't care about the type it's getting, I don't have to upcast. So I can rewrite the Python program without using base classes:

```
# staticchecking/NoBasePetSpeak.py
# Speaking pets without base classes
class Cat:
def speak(self):
```

```
print("meow!")

class Dog:

def speak(self):

print("woof!")

class Bob:

def bow(self):

print("thank you, thank you!")

def speak(self):

print("Welcome to the neighborhood!")

def drive(self):

print("beep, beep!")

def command(pet):

pet.speak()

pets = [ Cat(), Dog(), Bob() ]

for pet in pets:

command(pet)

output = """

meow!

woof!

Welcome to the neighborhood!
```

"""

Since **command(pet)** only cares whether it can send the **speak()** message to its argument, I've removed the base class **Pet**, and even added a totally non-pet class called **Bob** which happens to have a **speak()** method, so it also works in the **command(pet)** function.

At this point, a statically-typed language sputters with rage, insisting this kind of sloppiness will cause disaster and mayhem. Clearly, at some point the "wrong" type will be used with **command()** or will otherwise slip through the system. The benefit of simpler, clearer expression of concepts is simply not worth the danger. Even if that benefit is a productivity increase of 5 to 10 times over that of Java or C++.

What happens when such a problem occurs in a Python program—an object somehow gets where it shouldn't be? Python reports all errors as exceptions. So you do find out there's a problem, but it's virtually always at run time. "Aha!" you say, "There's your problem: you can't guarantee the correctness of your program because you don't have the necessary compile-time type checking."

This program can even be rewritten in the **Go** language, like this:

// staticchecking/petspeak.go

```
package main

import "fmt"

type Cat struct {}

func (this Cat) speak() { fmt.Printf("meow!\n")}

type Dog struct {}

func (this Dog) speak() { fmt.Printf("woof!\n")}

type Bob struct {}

func (this Bob) bow() {

fmt.Printf("thank you, thank you!\n")

}

func (this Bob) speak() {

fmt.Printf("Welcome to the neighborhood!\n")

}

func (this Bob) drive() {

fmt.Printf("beep, beep!\n")

}

type Speaker interface {

speak()

}

func command(s Speaker) { s.speak() }
```

```
// If "Speaker" is never used
// anywhere else, it can be anonymous:
func command2(s interface { speak() }) { s.speak() }
func main() {
command(Cat{})
command(Dog{})
command(Bob{})
command2(Cat{})
command2(Dog{})
command2(Bob{})
```

}

/ *Output:*

meow!

woof!

Welcome to the neighborhood!

meow!

woof!

Welcome to the neighborhood!

**/*

Go has no **class** keyword, but you can create the equivalent of basic classes using the above form: what you would ordinarily define as a class, you instead define as a **struct**, within which dwell your data fields (there are none here). For each method, you start with the **func** keyword, then—in order to attach the method to your class—you put parentheses containing the object reference, which can be any identifier but I use **this** here to remind you that it's like the **this** in C++ or Java. Then you define the rest of the function as you do for any other function in Go. (Note there's also no inheritance in Go, so this form of "object-orientedness" is relatively primitive, and probably the main thing that keeps me from spending more time with the language.

Composition, however, is straightforward).

The **command()** and **command2()** functions both use structural/duck typing: the exact type of the argument is unimportant as long as it contains a **speak()** method. I show two approaches here: **command()** uses an externally-defined **Speaker** interface, but if that interface is never used anywhere else, you can define it anonymously, inline, as seen in **command2()**.

main() demonstrates that **command()** and **command2()** are indeed indifferent to the exact type of their arguments, as long as there's a **speak()**. However, just like C++ template functions, the types are checked at compile time. (The syntax **Cat{}** creates an anonymous **Cat struct**).

Type Checking is Just One Kind of Testing

When I wrote *Thinking in C++*, 1st edition, I incorporated a very crude form of testing: I wrote a program that would automatically extract all the code from the book (using comment markers placed in the code to

find the beginning and ending of each listing). It then built makefiles that would compile all the code. This way I could guarantee that all the code in my books compiled and so, I reasoned, I could say “if it’s in the book, it’s correct.” I ignored the nagging voice that said “compiling doesn’t mean it executes properly,” because it was a big step to automate the code verification in the first place (as anyone who looks at programming books knows, many authors still don’t put much effort into verifying code correctness). But naturally, some of the examples didn’t run right, and when enough of these were reported over the years I began to realize I could no longer ignore the issue of testing. I came to believe:

If it’s not tested, it’s broken.

If a program compiles in a statically typed language, it just means it has passed some tests, which means the syntax is guaranteed to be correct (Python checks some syntax at compile time, as well. It just doesn’t have as many syntax constraints). But there’s no guarantee of correctness just because the compiler passes your code. If your code seems to run, that’s also no guarantee of correctness.

The only guarantee of correctness, regardless of whether your language is strongly or “flexibly” typed, is whether it passes all the

tests that define the correctness of your program. And you have to write some of those tests yourself. These, of course, are unit tests. Once you become “test infected,” you don’t go back.

It’s very much like going from old C to C++. Suddenly, the compiler performs many more tests for you. You can work faster. But those syntax tests only go so far. The compiler cannot know how you expect the program to behave, so you must “extend” the compiler by adding unit tests (regardless of the language you’re using). If you do this, you can make sweeping changes (refactoring code or modifying design) in a rapid manner because you know that your suite of tests will back you up, and immediately fail if there’s a problem—just like a compilation fails when there’s a syntax problem.

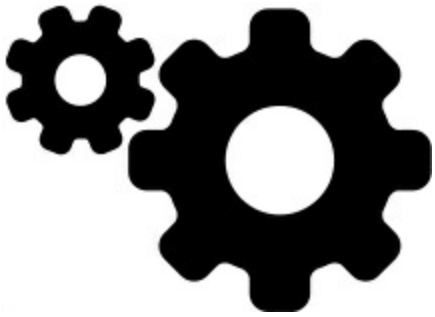
But without a full set of unit tests (at the very least), you can’t guarantee the correctness of a program. To claim that the static type checking constraints in C++ or Java will prevent you from writing broken programs is clearly an illusion (you know this from personal experience). In fact, what we need is

Strong testing, not strong typing.

So this, I assert, is an aspect of why Python works. C++ tests happen at compile time (with a few minor special cases). Some Java tests happen

at compile time (syntax checking), and some happen at run time (array-bounds checking, for example). Most Python tests happen at runtime rather than at compile time, but they do happen, and that's the important thing (not when). And because I can get a Python program up and running in far less time than it takes you to write the equivalent C++ or Java program, I can start running the real tests sooner: unit tests, tests of my hypothesis, tests of alternate approaches, etc. And if a Python program has adequate unit tests, it can be as robust as C++ or Java programs which also have adequate unit tests (although the tests in Python are faster to write).

Robert Martin is a long-time inhabitant of the C++ community. He's written books and articles, consulted, taught, etc. A pretty hard-core, strong-static type checking guy. Or so I would have thought, until I read this weblog entry. Robert came to more or less the same conclusion I have, but he did so by becoming "test infected" first, then realizing that the compiler was just one (incomplete) form of testing, then understanding that a dynamically-typed language could be much more productive but create programs just as robust as those written in



statically-typed languages, by providing adequate testing.

Of course, Martin also received the usual “how can you possibly think this?” comments. Which is the very question that led me to begin struggling with the static/dynamic typing concepts in the first place. And certainly both of us began as static type checking advocates. Sometimes it takes an earth-shaking experience—like becoming test-infected or learning a different kind of language—to cause a re-evaluation of beliefs.

How to Argue about

Typing

Many people observe that type checking is a religious discussion best avoided. I often agree, having started more than my share of fires in this area. However, there are a few issues surrounding types and type checking that capture the essential distinctions between programming languages. This understanding makes the pitfalls worth the risk, so in this section–from which I drew the closing keynote address at the

2004 Python Conference (PyCon)—I will look at various issues and arguments surrounding the concept of type, and in particular examine the phenomenon of “structural typing” a.k.a. “latent typing” (also unfortunately sometimes called “weak typing”), why the concept is powerful, and how it is expressed in different languages.

Background: When I was in junior high school in Southern California, they tried to teach me Spanish by showing us films about “E Man” (a dog, I think), and albondigas (meatballs). That’s about all I remember, because I reacted strongly when the teacher would speak Spanish to us, then expect us to reply with something meaningful. I was not conscious enough to see the motivation for learning this, and the effort seemed painful. The same was true for playing the guitar (it makes your fingers hurt) and any number of other potential abilities that never manifested.

So I sympathize with those who resist learning more than one language. I’ll probably only ever know a few phrases of non-English languages, and it is only through experience I’ve discovered the incredible value of learning more than one programming language.

The biggest payoff is this: I can now think about things in Java or C++ I was unable to conceive of before I learned Python. And from what

I've read and the code I've seen, very few single-language users are able to conceive of these things, either. Your language really does constrain your thoughts.

A number of years ago, I began noticing that a number of programming language features revolve around particular philosophies of type checking. These philosophies had as their foundation the idea that a particular way of doing things will always yield better results. In addition, the meanings of various terms tend to be given in the context of the language that one knows and likes best. I stepped into the middle of this when I began using the term "weak typing" (which I have since observed is quite different from "weakly typed"). At the time, the term seemed to come from an authoritative source, but now I'm unable to track it down and discover its genesis. In Java, I also produced a hailstorm of protest when I asserted (in *Thinking in Java*, 3rd edition) that checked exceptions—where the compiler forces you to write code to handle the exceptions from particular calls, rather than allowing you to decide whether or not to handle the exception at that time—are an experiment in that language that largely cause more trouble than it is worth (not to say they aren't useful sometimes, but they get in the way more than they help). Both

of these discussions seem to touch deep nerves in fundamental belief systems.

The value of what I originally called “weak typing,” but which is more predominantly called “structural” or “latent” typing is fascinating, whatever we choose to call it. Basically, it’s how you say “I don’t care what this type is” in certain programming constructs (“…but I still care that the type behaves correctly…”). In C++, this construct is the template. Java uses the term “generic” which implies the same thing, but in practice it can only be as generic as the root class **Object**. But in Python (and SmallTalk), it’s just the way you define any function, as **speak()** is defined here:

```
# staticchecking/DogsAndRobots.py
def speak(anything):
anything.talk()
class Dog:
def talk(self): print("Arf!")
def reproduce(self): pass
class Robot:
def talk(self): print("Click!")
def oilChange(self): pass
a = Dog()
```

```
b = Robot()
speak(a)
speak(b)
output = """
Arf!
Click!
"""
```

speak() doesn’t care about the type of its argument. I can pass any object that supports the **talk()** method.

This example easily translates to C++2:

```
// staticchecking/DogsAndRobots.cpp
#include <iostream>
using namespace std;
class Dog {
public:
void talk() { cout << "Arf!" << endl; }
void reproduce() {}
};
class Robot {
public:
```

```
void talk() { cout << "Click!" << endl; }
void oilChange() {}
};
template< class T> void speak(T speaker) {
speaker.talk();
}
int main() {
Dog d;
Robot r;
speak(d);
speak(r);
}
/* Output:
Arf!
Click!
*/
```

Here’s the same program written in Go:

```
// staticchecking/dogsandrobots.go
package main
import "fmt"
```

```
type Dog struct {}
func (this Dog) talk() { fmt.Printf("woof!\n")}
func (this Dog) reproduce() {}
type Robot struct {}
func (this Robot) talk() { fmt.Printf("Click!\n") }
func (this Robot) oilChange() {}
func speak(speaker interface { talk() }) {
speaker.talk();
}
func main() {
```

```
speak(Dog{})
speak(Robot{})
}
/* Output:
woof!
Click!
*/
```

It’s almost as if you’re inventing a new type: “the type acceptable to **speak()**,” because it certainly doesn’t refer to any other type that exists in the system. You might also argue that **speak()** defines two basic categories of types: those acceptable to **speak()** and everything else. Neither of these definitions work for me. It appears there is either no type specified for **x**, or that the type constraints on **x** are weakened to allow many different types.

After dealing with terminology, this section looks at the way structural/latent typing is achieved in Python and C++, and what generics look like in Java (which doesn’t support structural types).

Weakly Typed vs. Weak

Typing

C++-Proxy

“C++ has strong, static type checking.”

Wonk

“C/C++ is weakly typed because it has casts and unions.”

Proxy

“That’s a bit extreme, isn’t it? How about if we say that C++ is strongly, statically typed with a hole in the type system: casts (and who really uses unions, anyway?).”

Wonk

“Nope. If a language allows an object to accept any incorrect message, it’s weakly typed. Java also allows casts, but it checks them, both at compile time to see if the cast is feasible, and at run time to ensure it is correct. So Java is strongly typed, C++ is weakly typed.”

Proxy

“So you’re saying that if the language is strong everywhere but it has a single trap door, you’re going to call the whole thing weak?”

Wonk

“Totally weak, dude.”

Clearly, one of the issues revolves around definitions and how closely you stick to them. So first we have to decide “what is a type?” Here are two different ways to define type. An object can be:

1. Syntactically compatible: The object provides all the expected operations (type names, function signatures, interfaces).

Or:

2. Semantically compatible: The object’s operations all behave in the expected way (state semantics, logical axioms, proofs).

The first approach is often considered *type* (it provides a particular

interface) and the second is usually called *class* (describes implementation constraints). I think this fits closely with the issue at hand: we are predominantly concerned with the operations that can be performed upon objects, and the only semantics of interest are whether those operations are safe and if the language system consistently reports unsafe operations (e.g. C++ allows old-style unchecked casts and doesn't report anything if you use them).

Does the language apply the type constraints to the symbols, or to the objects?

You apply the type constraints to the symbols especially if you have limited run-time support (C++). It's also possible to do both, as with Java, which constrains the types and usage of all symbols at compile time, but also has enough runtime support to perform limited dynamic checks. If it can't check something statically (array bounds or null pointers, for example), it checks them dynamically.

Are the constraints applied before the program runs(static type checking) or while the program is running (dynamic type checking)?

Again, Java does some of both. But dynamically-checked languages seem to have both more flexibility and at the same time better ability

to make sure an object is properly treated. They can afford to treat the symbols casually because the objects guard themselves against improper use at runtime, rather than relying on the compiler to guard them.

Does the language “guess” the type based on usage (type inference), or does it know via a declaration somewhere (manifest typing)?

Type inference is sometimes confused with dynamic typing, because the symbols can appear to have no type (or no fixed type). Scala is a good example of a type-inference language, and it is much nicer to use when defining types.

If a language is statically typed, does it ever relax the type constraints a bit to allow more flexible programming? (This is sometimes called *gradual typing*).

This is my key area of interest in this section. Note that in the dog-robot example above, many people reach the conclusion that because the **anything** in the **speak()** argument list is not constrained, there is no type safety. However, strong type safety is maintained—you still cannot send an improper message to an object.

Lexicon

Static typing: Types are checked at compile time.

Dynamic typing: Types are checked at run time.

Strong typing: You can't successfully apply an improper operation (send a bad message) to an object.

"Weakly typed" : You can successfully perform an improper operation on an object. There may or may not be common confusion with the following term, but people use it anyway.

Latent typing/Structural typing: Type constraints are relaxed in a few specific cases to make programming more flexible and powerful.

Type inference: You don't have to say what the types are, the language system figures out types based on how they are used (Scala does this).

Manifest typing: You must specify the types when you create them.

Duck Typing: A term apparently adopted by Ruby, to describe structural/latent typing. "If it walks like a duck and talks like a duck, it's a duck." The value of duck typing seems to be the ability to create an adapted object without creating a new adapter class (see *Adapter* in the Patterns chapter).

The phrase “Implicit typing” would seem to neatly describe what I’m talking about here: an implied type is created when you define a function, template, or generic. Unfortunately, Fortran has already co-opted this term, with its “first letter of the identifier implies Real or Integer” scheme. I’m tempted to vary it slightly to “implied typing”

since it is so close to the mark, but I’m sure we’d end up with the same issue as “weakly” vs. “weak.” (I’ve notice a number of people using the term “implicitly typed” on the web).

la·tent

1. *Present or potential but not evident or active. In existence but not manifest. Latent talent.*

2. *Psychology. Present and accessible in the unconscious mind but not consciously expressed.*

A fingerprint that is not apparent to the eye but can be made sufficiently visible, as by dusting or fuming, for use in identification.

It’s there, but not explicit. That’s a pretty good word after all. Or:

If you only need something that quacks,

don’t worry about checking that it’s also a

duck.—Andrew Dalke

Of course with latent typing we are not even interested in naming it a duck in the first place. I believe that the duck is there even if I see only scant evidence for its existence.

Templates & Latent Typing

vs. Java Generics

Before templates were introduced to C++, you created generic containers using macros. For the library designer this was painful, for the client programmer somewhat less so. When templates were introduced, I explained that if C++ had a singly-rooted hierarchy (everything ultimately inherits from **Object**), these would not be as necessary since the containers could be written to hold **Object**, and therefore automatically hold everything. This is the way SmallTalk had done it and that seemed pretty successful.

Of course SmallTalk used latent typing, and so did not require the casts. When Java followed this prescription, it had static typing and so you had the benefit of containers built with a singly-rooted hierarchy. But with Java you had to cast everything up and down all the time.

The solution introduced in Java 5 is the so-called *generic*, which

implies “anything” but which is actually constrained. This solution makes collections more civilized:

```
// staticchecking/drc/DogAndRobotCollections.java
// {java staticchecking.drc.DogAndRobotCollections}
package staticchecking.drc;
import java.util.*;
class Dog {
public void talk() {
System.out.println("Woof!");
}
public void reproduce() { }
}
class Robot {
public void talk() {
System.out.println("Click!");
}
public void oilChange() { }
}
public class DogAndRobotCollections {
public static void main(String[] args) {
```

```
List<Dog> dogList = new ArrayList<>();
List<Robot> robotList = new ArrayList<>();
for(int i = 0; i < 10; i++)
dogList.add(new Dog());
//- dogList.add(new Robot()); // Compile-time error
for(int i = 0; i < 10; i++)
robotList.add(new Robot());
//- robotList.add(new Dog()); // Compile-time error
dogList.forEach(Dog::talk);
robotList.forEach(Robot::talk);
}
}
/* Output:
Woof!
Woof!
Woof!
Woof!
Woof!
Woof!
Woof!
```

Woof!

Woof!

Woof!

Click!

Click!

Click!

Click!

Click!

Click!

Click!

Click!

Click!

Click!

/

This is definitely an improvement for collections and a few other things. However, you cannot say “I don’t care what type this is” for an argument, like you can in C++. So you cannot say in Java:

class Communicate {

public static <T> void speak(T speaker) {

speaker.talk();

}

}

You can only say, “This thing can be no more specific than **Object**.”

So this compiles, because I call an **Object** method for it:

```
public class NothingButObject {
public <T> String f(T anyObject) {
return anyObject.toString();
}
}
```

This turns out to work just fine when you’re dealing with Java collections, which are already constrained to hold nothing more specific than **Object** (so they hold any type).

But to say something more general than that, to write true “generic code,” you cannot (Java 8, however, allows “Assisted Latent Typing,” described at the end of the Generics chapter). To apply the **communicate()** function to dogs and robots, you must do this:

```
// staticchecking/dr/DogsAndRobots.java
// {java staticchecking.dr.DogsAndRobots}
package staticchecking.dr;
interface Speaks { void talk(); }
```

```
class Dog implements Speaks {
public void talk() {
System.out.println("Woof!");
}
public void reproduce() { }
}
class Robot implements Speaks {
public void talk() {
System.out.println("Click!");
}
public void oilChange() { }
}
class Communicate {
public static <T extends Speaks>
void speak(T speaker) {
speaker.talk();
}
}
public class DogsAndRobots {
public static void main(String[] args) {
```

```
Dog d = new Dog();
Robot r = new Robot();
Communicate.speak(d);
Communicate.speak(r);
}
}
/* Output:
Woof!
Click!
*/
```

You must constrain the generic type accepted by the function to conform to a class or interface which contains the operations you are calling inside that function.

But of course this is no better, and actually more confusing, than simply using the interface alone as the argument:

```
class Communicate {
public static void speak(Speaks speaker) {
speaker.talk();
}
}
```

What I was really hoping for in Java generics was true latent typing:

<T> void f(T objectOfAnyType) {

objectOfAnyType.anyOperation();

}

What I got was cleanup of templates and a few other features, but none of the power of true generic (latent) types (until, as mentioned earlier, Java 8). The primary argument against latent types in Java is that “it isn’t type safe,” which I hope to show is incorrect later in this appendix.

C++ templates always allowed true generic code. Their downfall was that early compilers produced terrible error messages for template code (they’ve gotten better since), but many people came to the

conclusion that templates were therefore bad.

Another argument against C++ templates is that they cause code bloat because a copy of the template is laid down each time you instantiate it for a new type. However, code bloat of this kind generally results from a misunderstanding of the feature; in particular, putting all your code

inside the template instead of inheriting or using composition. The base class or member objects hold the code that doesn't need to be templatized (or reproduced).

It's very powerful to say "it doesn't matter what type this object is, as long as I can perform these operations on it." This is the foundation, for example, of the C++ *Standard Template Library* (STL) algorithms. The algorithms work on containers, which themselves are designed to be as unconstraining as possible so they can hold any kind of object. It's as if there's an "implied singly-rooted hierarchy" in C++ (with a very simple root class).

Flexibility vs. (Perceived)

Safety

Java Wonk

Static type checking is necessary for safety.

Me

But Java does some checking at run-time. That's why you need **ClassCastException**.

Wonk

OK, I'll say this, then: For safety, as much static type checking as possible is always desirable.

Me

Isn’t it possible to occlude the meaning of the code if you have too much type-checking ceremony around it? And we still haven’t made a dent in the “20 working lines of code per day per programmer” statistic.

Wonk

You’re just complaining about finger typing. I have tools like Eclipse that do a lot of typing for me, so I get the best of both worlds: reduced finger typing and greater type checking.

Me

Yes, but code is read much more than it is written. By making the reader do more work you’re slowing down the development process.

Wonk

On the contrary, this makes the code more explicit and thus easier to understand.

Me

I find Python code much faster to read precisely because it’s shorter and more straightforward, and thus it seems much easier to understand than when I’m constantly interrupted by all the

ceremony of Java.

Wonk

I don’t know Python so I don’t believe you. And I’m positive I want the guaranteed safety provided by Java’s static type checking.

Me

What do you mean, “guaranteed?” With the failure rate of software development projects at least 50%, and possibly as high as 80%?

Wonk

That’s not verifiable. And Java has improved the success rate over C++. It’s sure made my life easier.

Me

True, few are willing to admit their failures so we can’t get an exact number except to say it’s very high, and very expensive. How can you argue this is a sure thing when the failure rates continue to be so high? It does seem that Java improves the success of projects over C++, but how can you say that anything is working when everything is mostly failing?

Wonk

But you want to reduce the amount of type checking. That makes it worse.

Me

No, the amount of type checking is at least the same. It's just when it happens that changes.

Wonk

If you make it happen at run-time instead of at compile time, things can slip through the cracks.

Me

Let's look at an example where run-time checking happens in Java. Pre-Java 5 collections allow you to put any object in, then you must cast it back to the desired type when you pull it out. The correctness of the cast is checked at runtime.

Wonk

Yes, very bad. You can put the wrong type into a collection. I could put a **Dog** into a collection of **Cat**. Hey, I think that's an example in your book.

Me

Yes, that would be a problem, but you'd get a runtime exception when it happened, so you'd find out about it.

Wonk

But with static typing like we get with Java generics it won't happen at all. That's a big worry solved.

Me

This happens to you a lot?

Wonk

Well … no. Actually, I don't remember the last time it happened. But I'm sure the problem is just lurking, waiting to crash an important program.

Me

As long as you find out when it happens, you still find out. And you can do that through unit testing.

Wonk

Static checking is better than unit testing, since I don't have to write the tests.

Me

You eventually have to write some tests. There's always a line

where it goes beyond language syntax and becomes the semantics of your particular program. Without your own tests you cannot have a verifiably correct program.

Wonk

Unit tests are good, yes.

Me

So what I'm suggesting is that by acknowledging that you have to write your own tests anyway—and thus perform dynamic checking of your application—you can consider moving the line and making things a bit more dynamic. I think the benefit you get in easier-to-write, easier-to-read code will far outweigh the loss of a bit of the static type checking. Keep as much of it as possible, but move a little bit into the runtime arena.

Wonk

Static type checking is too important. It's what Java is about. More static type checking is always better.

Is Latent/Structural Typing Necessary?

In the end we have to ask whether Latent/Structural typing is an essential feature. What does it really do?

It allows you to cut across class hierarchies, calling methods that are not part of a common interface.

Classes only share the methods in their common base class. C++ has no ultimate **Object** base class, so the need for latent typing is more immediately obvious. Java has a singly-rooted hierarchy and **className** can only call **Object** methods in **T**. They are “generic,” as long as you don’t step out of the bounds of what’s already generic (**Object**). This works fine for collections and any other code which only needs the fundamental operations of **Object**.

However, it’s still possible to have disjoint hierarchies in Java, with common methods but no common interfaces. The original authors of two separate class hierarchies cannot be expected to predict every commonality that might occur, nor to anticipate you might write a single piece of code that is applied to both of them.

This is more likely to happen in existing hierarchies, ones that are handed to you. To perform common operations across multiple disjoint hierarchies, you are forced to write duplicate code. Thinking this is OK is effectively saying “it’s OK to duplicate code,” although it may seem like it’s just a little bit and not very often.

But what if this is another feature you haven’t been using because you

didn’t know about it? Like objects for a procedural programmer, for example. Or aspects, which can greatly simplified some architectures. C++ programmers benefit by using templates for more than just container classes (although template metaprogramming seems beyond what most people do).

Even if you do argue that all classes can be shoehorned into a hierarchy to achieve a common interface, there is also the argument of the maintenance overhead that results from the extra code. As Java programmers we’ve been like frogs in saucepans (a myth—apparently they do jump out when the water gets too hot), adjusting to more and more code to do basic things. Over time, Java added syntax to reduce some of that code, and this is an admirable development. It still requires more finger-typing than may be necessary. The counter-argument is that we have tools like Eclipse to do the typing for us, but the overhead of reading and maintaining the code—which is where most of the money ends up going—still increases.

Consider the opposite view. At the Software Development Conference

2004, James Hobart pointed out the distinction between “probability” and “possibility.” Here, it is arguably more probable that C++ will have disjoint class hierarchies than will Java. Java generics seem to work adequately for collections. It’s possible you might encounter disjoint class hierarchies that you’d like a single piece of code to cut across. But perhaps the probability is not that high it will happen very often in practice. This Hobart called “going down the happy path.” In Java, we have no choice but to take this path, but in other languages we may see through experience what is lost by doing so.

We’re Really Talking about

Testing

In the end, these are all just different kinds of tests. We can consider them on a spectrum:

Testing by the compiler (static type checking)

Testing by the run-time system (dynamic type checking + more)

Unit testing of your classes

Conformance testing of your program

The compiler and run-time system can only know so much. There can only be a certain set of tests general enough they can be applied to every program. At some point you must begin writing your own tests

to test the semantics of your particular program, to ensure its correctness.

What we are talking about, then, is not whether tests are critical (they are), but when and how these tests take place. More importantly, about balancing the expressiveness and clarity of a language with the place in the spectrum where these tests occur. My opinion: programs are prose, and must be readable. Static checking is good if it doesn't impact the clarity, expressiveness, and productivity of the language. If

those are impacted, the checking should be moved to reduce that impact.

This opinion is based on my belief and experience that you cannot rely on static checking to verify program correctness, and therefore it is unreasonable to obscure the meaning of your program with high-ceremony syntax under the illusion it is somehow safer. For full safety, you'll always need run-time tests. Given this, to me it makes no sense to make your life harder by obscuring the code because of this illusion.

Determinism

Albert Einstein was very disturbed by the Heisenberg uncertainty principle (you can't know both position and momentum of small particles). He believed that "God does not play dice with the universe" and postulated a "hidden variable" theory that, when discovered, would allow us to completely determine everything.

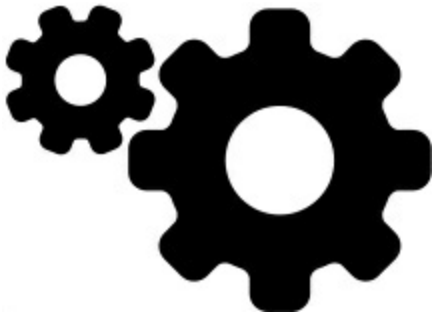
Bell's theorem showed there is no hidden variable theory.

Steven Hawking describes how you can have higher determinism nearer to an event (in space-time) than further away. The effect of the uncertainty principle is cumulative in space-time.

The Greeks believed there was fate and free will together, which people have always found confusing, since we demand one or the other exclusively. Perhaps Hawking's approach explains the dichotomy.

It may be possible to create programs that are provably correct, but my guess is that these programs will fill only a small fraction of the general solution space.

Static type checking is only one kind of testing, and very limited in its effect—as you move out in space time from the point of compilation, the "software uncertainty principle" adds more and more noise to the results. Only by testing throughout will you get a program that is as



correct as you are able to describe it.

The Cost of

Productivity

Some very interesting analyses have come out of my discussions of latent typing, especially those by an anonymous blogger named "Pixel." Although there are places where Pixel misunderstood what I was saying (or more likely I didn't say it clearly enough), in general he or she states the "Java case" reasonably well.

That case includes the regular argument that people are just as productive in Java as they could be in Python, an argument which is almost universally made in the abstract, without any direct experience in both languages. I have regular experience in both languages, and the result is always: To get a lot done, use Python. The testing doesn't come, as Pixel argues, with special hand-testing, but by using the actual data that you're trying to manipulate. You just get there faster, and start finding the real problems, using real data, faster. I have this

experience over and over.

And the kinds of problems I solve are only theoretically solvable using Java. It would take at least 5-10 times longer to do it, and that assumes you wouldn't give up or get lost first. For example, you can translate something from Python, but it's much easier with the Python design as a roadmap, and the resulting code would still be much bigger, messier, and (a big point of argument, since people regularly claim that the more verbose Java is easier to maintain because it's so much more explicit) harder to maintain.

In the follow up, Pixel ends by asking "How much value do you put on checking as much as possible at compile time?" This oversimplifies the issue. If the type checking came at no cost, the answer is as easy and obvious as Pixel implies with this question. I've generally found that most folks who argue that static type checking must be preserved and increased at all costs have no experience of a down side. And if you don't see any down side, you think arguing against it is obviously crazy.

I know because I began firmly in the static type checking camp, having seen the benefits of moving from pre-ANSI C to C++. C++ static type checking found lots of errors that (especially pre-ANSI) C didn't, so it

was a clear win. And the extension of this philosophy to Java was thus obvious. But that was my sole dimension of experience for many years. It was only when I began using a more dynamic, more succinct language (Python) that I got a new dimension.

The experience most people have goes something like this: they have had enough exposure to Python (or substitute your dynamic language of choice) to keep it in the back of their mind. A problem arises that might require a one shot solution. Knowing how much effort Java is, they think this is a good place to try Python, since it might save some effort. Then they have the watershed experience of solving the problem in far less time than it would take in Java. The next time a similar problem arises, they reach for Python more quickly, until they start using Python as a preferred tool, only using Java when there's no other choice.

During this process, the experience of being dramatically more productive in Python repeats itself over and over. It's not a philosophical argument (because the answer is "obviously" that the statically typed language is better), it's direct experience. The correctness and quality of the resulting programs is consistently very high.

Then you reach the intellectual vs. experiential crisis: you “know” that Java is “better,” but your experience is that Python is “better.” How can this be, when all the arguments you “know” to be true clearly show that a static typing language must be “better.” At that point you start trying to resolve this crisis by seriously questioning your preconceptions. But the only arguments you hear back are the ones you yourself (I myself) previously “knew” were true, and have been shown from experience to be uncertain.

In my experience there’s a balance between the value of static typing and the resulting impact it makes on your productivity. The argument that “static is obviously better” is generally made by folks who haven’t had the experience of more productivity in an alternative language. When you have this experience, you see that the overhead of static typing isn’t always beneficial, because sometimes it slows you down enough it ends up having a big impact on productivity.

I can’t quantify this. I haven’t been able to come up with a from-first-principles mathematical proof, probably because it depends on human factors, like how much time it takes to remember how to open a file and put the try block in the right places and remember how to read lines, then remember what you were really trying to accomplish by

reading that file (although this experience is greatly improved in Java 8). In Python, I can process each line in a file by saying:

```
for line in open("FileName.txt"):
# Process line
```

(Python 3 adds a context manager to automatically close the file, not shown here). I didn't have to look that up, or to even think about it, because it's so natural. I always had to look up how to open files and read lines in Java. I You can argue that Java wasn't intended to do text processing and I'd agree with you, but unfortunately it seems like Java is mostly used on servers where a very common task is to process text. There are studies about how much time it takes to recover from interruptions, but I can't make any direct connection other than to say it seems to me this must have a big influence, both when writing the code (yes, I know that much of it is automated with Eclipse and similar editors) and reading the code.

Java is what it is. Demonstrating that Java generics don't support latent typing was primarily meant to get people to show me how Java generics really do support latent typing in the event I had misunderstood something. They didn't, and I didn't, so that's the case.

In the end, I've realized that the requirement that you must use

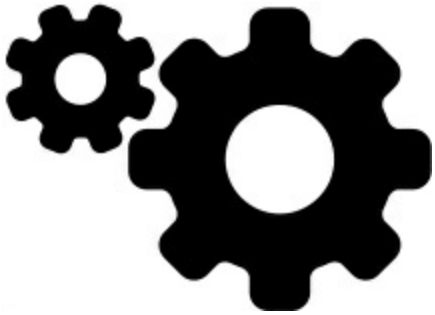
interfaces everywhere really isn't that big of a deal. In Python, which is a succinct language, it would really stick out, but Java is unashamedly verbose, and many people seem to like the verbosity and feel it is a benefit. Requiring a few extra interfaces here and there is not much of an impact on the resulting Java code, and is indeed in keeping with the Java language philosophy (it would probably surprise people if latent typing did have direct support in the language).

So I understand that Java generics are really just autocasting for nicer use of containers, and that's good and useful but you can only take Java generics so far.

It is possible to do latent typing in Java, but you must really want to do it because it requires more effort. Let's revisit the dogs and robots program one more time, this time using reflection to produce a method that implements latent typing:

```
// staticchecking/latent/Latent.java
// {java staticchecking.latent.Latent}
package staticchecking.latent;
import java.lang.reflect.*;
class Dog {
public void talk() {
```

```
System.out.println("Woof!");
}
public void reproduce() {}
}
class Robot {
public void talk() {
System.out.println("Click!");
}
public void oilChange() {}
}
class Mime {
public void walkAgainstTheWind() {}
public String toString() { return "Mime"; }
```



```
}
class Communicate {
public static void speak(Object speaker) {
```

```
try {
Class<? extends Object> spkr =
speaker.getClass();
Method talk =
spkr.getMethod("talk", (Class[])null);
talk.invoke(speaker, new Object[]{});
} catch(NoSuchMethodException e) {
System.out.println(
speaker + " cannot talk");
} catch(IllegalAccessException e) {
System.out.println(
speaker + " IllegalAccessException");
} catch(InvocationTargetException e) {
System.out.println(
speaker + " InvocationTargetException");
}
}
}
public class Latent {
public static void main(String[] args) {
```

```
Communicate.speak(new Dog());
Communicate.speak(new Robot());
Communicate.speak(new Mime());
}
}
/* Output:
Woof!
Click!
Mime cannot talk
*/
```

I can thus call **speak()** on anything, and it will only invoke **talk()** on objects that actually have a **talk()** method.

Static vs. Dynamic

I received this letter from a reader. I have edited it a bit and also "corrected" the terminology, as described after the letter.

I'm a professor at Trinity University teaching a course in programming languages. Static typing is something that we have talked about a fair bit and one of my students came across your web page which we used quite nicely to fuel a discussion in one class. Personally I lean toward static typing and I was wondering if you

can comment on two things for me.

The first point is my general reason for liking static typing. Basically, static typing provides a proof that some aspect of the program works. Granted, the type system doesn't prove everything is OK and testing is still needed, but at least some aspect is proven correct. Why this seems to matter to me is that complete testing requires the number of tests grow at least exponentially with code size. Anything less will leave many paths through the code untested. No matter how productive one can be in a certain language, writing an exponential number of test cases will overwhelm that. Given this, isn't it worth the reliability to have some aspects proven correct by the compiler?

The more interesting question I have is what you think about ML and its derivatives in regard to the strong testing vs. static typing argument. These languages have the advantage of dynamically-typed languages in that they rarely require the user to specify types, however, they infer the types for all expressions and are statically typed. In this regard, their typing system is far safer than a language where dynamic checks are required (Java) or where users can coerce the type system into errors (C/C++).

The comparison of ML to Scheme came immediately to my mind

when I read your article on strong testing vs. strong typing because Scheme does all of its type checking dynamically and gives the user complete flexibility when writing code. However, in my experience, it is very hard to write large programs in and the fact that Scheme accepts a chunk of code doesn't mean it is anywhere close to being correct. ML is the opposite in that is does static type checking on everything even without the user specifying the type of anything. When I get my ML code to compile, it works the majority of the time and one or two simple tests will uncover any bugs that remain. With Microsoft releasing F# into the .NET framework, it is likely that many more programmers will be exposed to the ML style of coding. I just have to wonder if you would feel that having strong static typing without the coder specifying the types leads to the best of both worlds.

First, I'm at least partially responsible for the mix-up in terminology that has propagated around this, and I have not had the time nor inclination to go back into previous articles and fix this up. It also seems that things are not as clearly defined in the computer world around these terms. So to try to help rectify the situation:

Weak typing: Allows incorrect messages to be sent to objects. C

and C++ allow you to successfully cast to the wrong type, and are thus viewed as having weak typing (although Stroustrup once said that "C++ was strongly typed with a couple of holes in the type mechanism"). I have argued in the past that "weakly typed" (a term I originally used to mean "latent typing") was distinct from "weak typing," but I think the terminology differences are far too subtle and not worth arguing over. In addition, the idea of latent typing confuses the issue; C++ (static typing, arguably weak typing in isolated spots), Python and Ruby (dynamically typed) all support structural/latent typing (Ruby calls it "duck typing").

Dynamic typing: Type checking still happens, and it can be strong typing, but it happens at runtime rather than at compile-time. A strongly-typed dynamic language still only allows you to send valid messages to objects.

To clarify an important point: I'm not against static type checking. The problems as I see them are that:

1. There is an illusion that static type checking can solve all of your problems, followed by the conclusion that more static type checking is always better.
2. Additional forms of static type checking are often added to a

language without regard to the actual cost. In extreme cases you spend all your time arguing with the compiler.

In general, my attitude is that static typing is desirable as long as it doesn't cost you too much. As you point out, type inference as found in ML and Scala gives you static type checking without requiring that you give extra information that the compiler can figure out itself.

I do seek the "best of all worlds," as you suggest. The question is whether a particular implementation of static type checking is helping more than it is impeding. I am often accused of just complaining about "finger typing," but what I observe is much more than just the extra carpal assaults (much of which, it has been pointed out, can be automatically generated by tools such as Eclipse and IntelliJ).

The real issue is the limits of the human mind to manage complexity. The hard boundary is the famous number "seven plus or minus two," the number of things that we can hold in our mind at any one moment. I assert that all progress in computer programming comes by improving the mental model to make it simpler for us to manipulate the essential concepts. The reason I find Python so fascinating is it seems to regularly grasp and incorporate new perspectives on "simpler" and "essential concepts." Much of my fascination is in how

this seems to happen, and I currently have little or no sense of the secret behind it. The language design seems to incorporate the psychology of computer programming.

Despite this, I've had some leanings back in the direction of static type checking. As you point out, the goal is to create solid components—the question is how to accomplish that? In a dynamic language you have the flexibility to do rapid experimentation which is highly productive, but to ensure that your code is airtight you must be both proficient and diligent at unit testing. In a language that leans towards static type checking, the compiler will ensure that certain things will not slip through the cracks, and this is helpful, although the resulting language will typically make you work harder for a desired result, and the reader must also work harder to understand what you've done. I think the impact of this is much greater than we imagine.

In addition, I think statically typed languages only give the illusion of program correctness. In fact, they can only go so far in determining the correctness of a program, by checking the syntax. But I think such languages encourage people to think everything is OK, when in fact the requirement for developer testing is just as important. I also suspect that the extra effort required to run the gauntlet of the compiler saps

some of the energy required for developer testing. And you bring up an interesting question in suggesting that a dynamically-typed language may require more unit testing than a statically typed language. Of this I am not convinced; I suspect the amount may be roughly the same and if I am correct it implies that the extra effort required to jump through the static type-checking hoops may be less fruitful than we might believe.

What is the best of both worlds? In my own experience, it's very helpful to create models in a dynamic language, because there is a very low barrier to redesigning as you learn. You're able to quickly try out your ideas to see how they work with actual data, to get some real feedback about the veracity of the model, and change the model rapidly to conform to your new understanding.

I think this approach has great benefits over simply modeling with UML. Those produce a model that is a fantasy and only after some complex transformations do you have something that expresses and tests your ideas. My experience with complex transformations of this kind is that they weigh you down and discourage you from experimenting and making changes. With a dynamic language, on the other hand, the model becomes the code and vice-versa, and so you're

able to experiment without inertia. I think this lightness is very important, because it is far closer to the way our brains work.

Once you've worked out and tested a model using a dynamic language, is it then worth transforming it into a statically-typed language? My experience with Python has not compelled me to do this for two reasons:

1. Once I get something working in Python, it seems to work pretty well. The benefits of transforming the model into a statically-typed language at that point are few. Others' experience with significant Python programs seems to support this—large Python programs seem surprisingly bug-free.
2. I usually find that any program that is used regularly will be changed. It is much easier to change the program in Python than it is in a statically typed language, so I have further incentive to leave it in Python.

I certainly don't mean to imply it never makes sense to transform a debugged Python model into Java, just that I haven't been compelled to. I could easily see many business situations where:

1. You begin by "sketching out" a preliminary model, using "UML lite" and/or CRC cards.

2. You implement this model in Python or Ruby, whichever language the developers are comfortable with. At this point you leave the paper model behind, and the code becomes your model. Python is often described as “executable pseudocode” and this becomes very helpful during modeling and experimentation.
3. You experiment and evolve this “live” model until it seems like you’ve worked out the kinks and it will do the trick.
4. You then translate into Java or C++ or some other language that the project constraints dictate.

By developing the model in a language that encourages change, my experience is that you end up with a better model, and this produces a distinct benefit when that model is translated to your implementation language.

In the end, my primary interest is in productivity and scalability. Visual Basic is a very productive language for small projects (and there are lots of those, so it solves lots of problems) but it doesn’t scale well. Perl also falls into this category, although its apparent successor, Ruby, seems to implement the object paradigm reasonably well and seems to scale to larger projects. Python has been used on a number of significantly large projects and despite its lack of static type checking,

the results appear to have very low bug counts.

This last point is a major puzzle—we believe that static type checking prevents bugs, and yet a dynamically-typed language produces very good results anyway. As I have tried to delve more deeply into this mystery, many of my preconceptions—the major one being that static type checking is essential—have been challenged. An initial response to this is often to simply deny it's the case, but once you begin denying evidence your theories rapidly become nothing more than fantasies. In my own experience it can be very hard to put my finger on exactly why Python works so well. However, in trying to do so I have discovered many things and gained greater understanding about other languages. My guess is that Python allows me to think more clearly about concepts of the problem I'm trying to solve. It is less distracting because it doesn't force me to think so much about rules imposed by the language—rules that are basically arbitrary when I'm trying to produce an effective model of my problem space. By getting out of the way, Python and similar dynamic languages allow me to spend more of my brain's "seven plus or minus two" items on the problem itself, and less on the details of the language implementation. I have had this experience more than once, for example when going from C++ to Java

where I no longer had to worry about **operator=** and the copy-constructor. Having Java take care of more things for you definitely seems to improve programmer productivity, and I've had the same experience with Python.

In the end, I can still see value in taking a model that was evolved using Python or Ruby and reimplementing it in Java. Much of this value is in fitting into an existing Java development environment, but it also seems likely you might discover some bugs because of static type checking. It would be interesting to hear experiences and bug counts from people who have done this experiment.

You asked a question about whether type inference a la ML might give us the best of both worlds. I like type inference because it reduces the overhead on the programmer, but it is also a static typing mechanism (it doesn't work unless there's enough context to infer the static type). Also, it only touches on the different benefits offered by a dynamic language.

We need help to create accurate programs, and it's pretty hard to argue against static typing. The type system is the water where our object-oriented fish swim, and allowing holes and back doors seems to say "these things are true about a type, but you can only rely on it if

people know what they are doing and are behaving well," which is not very reassuring. Static typing actually helps us think about our object models by ensuring their proper behavior.

The question is not whether type checking is a good thing. I'd say it unequivocally is. The question is, when does the type checking occur, and how much does static checking cost vs. dynamic checking. In C++, effectively all the type checking is static. In Java, it is both static and dynamic (I think any language that tries to achieve thorough type checking will require some dynamic type checking), and in Python and other dynamic languages it is predominantly dynamic. As you note, in most dynamic languages not all execution paths are tested by the compiler, and this can be somewhat of a problem, but how bad is it? I suspect that if we applied the same unit tests to both a Java program and its equivalent Python version we would exercise all the execution paths. I think that the unit tests are at a high enough level in both cases that you end up with the same number. Put another way, I don't think you need extra unit tests to produce syntax checking, but that the syntax checking will fall out naturally when the unit tests exercise the class interfaces. I don't have direct evidence for this other than not having to do this extra work myself.

One of the things that Java generics accomplishes is the static type checking of collection classes. This prevents **ClassCastException**s at runtime, which is somewhat useful, but if that were the only reason for Java generics it wouldn't be worth the complexity of the syntax (fortunately, with some effort they can create generic code, as I showed earlier). The resulting **ClassCastException**s don't happen that often, and are not difficult to find when they do. This is a case where dynamic type checking is adequate.

I have also pointed out that checked exceptions do not scale well, and easily get in the way even for small programs. The fact that no language designed since Java has duplicated this experiment makes, I think, a strong argument against it. However, I have found that the Java 1.4 **RuntimeException(Throwable cause)** constructor eliminates most of the complaints I have about checked exceptions—if they get in the way, I can turn them off with only a minor amount of coding. Thus, I can choose to leave them on or turn them off.

These are a couple of examples where too much static type checking, no matter how well-intentioned, gets in the way of both the creation and the examination of code. Despite that, I actually like static type

checking, appropriately used. Python 3 even adds an optional type annotation mechanism, enforced by external static checking tools. But I resist any implications that “all static checking is good, so more is always better.” If you think about this you can easily imagine it taken to extremes, and in a number of cases Java has done exactly that, without doing a cost-benefit analysis of the results. It is the illusion that there is no cost to static type checking which I argue against.

1. The checking, not the exception. I believe that a single, consistent error reporting mechanism is essential, although in the end error reporting might not actually be conflated with exceptions—see the Go language, for example.↩

2. You can try it out without the pain of installing a C++ compiler here↩

Appendix: The Positive Legacy of C++ and Java

In various discussions there are assertions that C++ was a poorly-

designed language. I think it’s helpful to understand both C++ and Java language choices to see the bigger perspective.

That said, I hardly use C++ anymore. When I do, it’s either examining legacy code, or to write performance-critical sections, typically as small as possible to be called from other programs written in other languages.

Because I was on the C++ Standards Committee for its first 8 years, I saw these decisions being made. They were all extremely carefully considered, far more so than many of the decisions made in Java. However, as people have rightly pointed out, the resulting language was complicated and painful to use and full of weird rules I forget as soon as I’m away from it for a little while—and I figured out those rules from first principles while I wrote books, not just by memorizing them.

To understand how the language can be both unpleasant and complicated, and well designed at the same time, you must keep in mind the primary design decision upon which everything in C++ hung: compatibility with C. Bjarne Stroustrup (the language’s original creator) decided—and correctly so, it would appear—that the way to

get the masses of C programmers to move to objects was to make the move transparent: to allow them to compile their C code unchanged under C++. This was a huge constraint, and has always been C++'s greatest strength … and its bane. It's what made C++ as successful as it was, and as complex as it is.

It also fooled the Java designers who didn't understand C++ well enough. For example, they thought operator overloading was too hard for programmers to use properly. Which is basically true in C++, because C++ has both stack allocation and heap allocation and you must overload your operators to handle all situations and not cause memory leaks. Difficult indeed. Java, however, has a single storage allocation mechanism and a garbage collector, which makes operator overloading trivial—as was shown in C# (but had already been shown in Python, which predated Java). But for many years, the party line from the Java team was "Operator overloading is too complicated." This and many other decisions where someone clearly didn't do their homework is why I have a reputation for disdaining many of the choices made by Gosling and the Java team. (Java 7 and 8 have included far better decisions, for some reason. But the backwards-compatibility constraint will always prevent the really great

improvements. The language can never be what it might have been.)

There are plenty of other examples. Primitives “had to be included for efficiency.” The right answer is to stay true to “everything is an object” and provide a trap door to do lower-level activities when efficiency was required (this would also have allowed for the hotspot technologies to transparently make things more efficient, as they eventually did). Oh, and the fact you can’t use the floating point processor directly to calculate transcendental functions (it’s done in software instead). I’ve written about issues like this as much as I can stand, and the answer I hear has always been some tautological reply to the effect that “this is the Java way.”

When I wrote about how badly generics were designed, I got the same response, along with “we must be backward compatible with previous decisions made in Java” (Even though they were bad decisions). Lately more and more people have gained enough experience with generics to see they really are very hard to use—indeed, C++ templates are much more powerful and consistent (and much easier to use now that compiler error messages are tolerable). People have even been taking reification seriously—something that would be helpful but won’t put that much of a dent in a design that is crippled by rigid constraints.

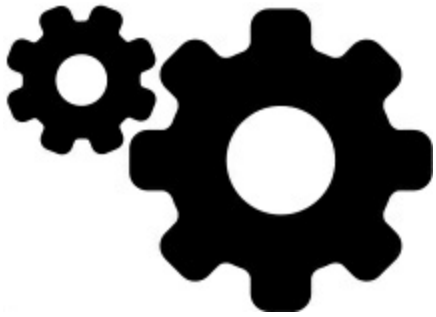
The list goes on to the point where it’s just tedious. Does this mean Java was a failure? Absolutely not. Java brought the mainstream of programmers into the world of garbage collection, virtual machines and a consistent error handling model. With all its flaws, it moved us up a level, to the point where we are now ready for higher-level languages.

At one point, C++ was the leading language and people thought it would always be so. Many think the same about Java, but Java has made it even easier to replace itself, because of the JVM. It’s now possible for someone to create a new language and have it run as efficiently as Java in short order. Previously, getting a correct and efficient compiler took most of the development time for a new language.

And we are seeing this happen—both with higher-level static languages like Scala, and with dynamic languages, both new and ports, like Groovy, Clojure, JRuby and Jython. This is the future, and the transition is much smoother because you can easily use these new languages in conjunction with existing Java code, and you can rewrite bottlenecks in Java if necessary.

At this writing Java is the number one programming language in the

world. However, Java will eventually diminish, just as C++ did, relegated to special cases (or perhaps just to support legacy code, since it doesn't have the same connection to hardware as C++ does). But the unintentional benefit, the true accidental brilliance of Java is that it has created a very smooth path for its own replacements, even if Java itself has reached the point where it can no longer evolve. All future languages should learn from this: either create a culture where you can be refactored (as Python and Ruby have done) or allow competitive species to thrive.



Appendix: Becoming a Programmer

A mashup of blog posts I wrote in 2003, 2006, 2007 and 2009.

How I Got Started in

Programming

This was a rather long and circuitous path. In freshman algebra in high school (1971), the extraordinarily weird teacher had a thing for computers and managed to get an ASR-33 teletype with a 300-baud acoustic phone coupler (which I learned to whistle at and get a response) along with accounts on the HP-1000 computer that the high school district used. We were able to create and run BASIC programs and save them on punch tape. I was fascinated and went home to write programs in the evenings that I would bring back and key in whenever I could. I invented HOSRAC.BAS which was a horse-racing simulation, using asterisks to represent the horses as they moved (this was on paper printout, so it took a little imagination).

My friend Daniel (the same one who designs my book covers now) had a brother who was making money for a time by providing pinball machines to bars and restaurants. He had a slot machine where I got all of that out of my system, can’t stand the things now, and also one of the very first Pong games (and I now almost never play computer games. Perhaps I’m a humorless sort, but it seems like programming is far more intriguing and challenging than playing a computer game).

I got involved in photography and journalism later in high school, and

majored in journalism during my first year of college. I decided I had learned enough about that from school, and changed to physics. Several colleges later I completed a physics degree at UC Irvine and added enough engineering classes to make it a double major if I had chosen a particular field of engineering, but I was trying to be broad, so my undergraduate degree is in “applied physics.” As an undergraduate I took a smattering of computer programming classes here and there, enough for entertainment but nothing that provided any depth. I think those classes helped add to my foundation by regularly trickling in little bits of information, but I had none of the depth or perspective necessary to really understand anything. I didn’t make any distinction between the computer and the compiler or interpreter (and only had a vague sense of compiler vs. interpreter); it was all the infallible computer to me and the idea that a bug could exist in the language or operating system was so purely theoretical I never considered the possibility.

I went to Cal Poly San Luis Obispo for graduate school because (A) I really liked the area (B) they accepted me and even gave me a teaching job and a fellowship, but most important (C) I couldn’t imagine working at a job longer than one summer. I was definitely not ready to

join the working world.

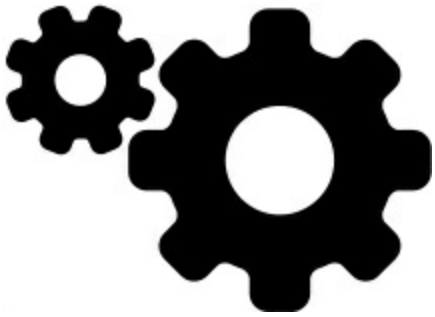
As a physics student I studied solar power systems, which were big at the time (California gave a tax credit if you put a solar system on your house or business, and many business sprang up because of that), and Cal Poly seemed to promise these things in their engineering department. However, to get a degree in Solar Engineering would have taken many years because the necessary classes were not offered often enough. As a result, I took whatever graduate engineering classes were offered, and got a broad education (as was my wont) including mechanical, solar, electrical and electronic engineering. The class I taught was an introduction to electrical engineering for non-Electrical Engineering majors. The graduate engineering classes that were offered most often were in computer engineering, so I ended up with a degree in that. I was also taking art courses, a couple of dance classes, and a few computer science courses (Pascal and data structures), but in computer engineering I finally struggled through the steps of how a processor worked, and I carried that with me ever since. That was really the foundation of my knowledge of computers.

When I did start working, it was as a computer engineer, with a fair amount of hardware and relatively simple and low-level programming.

I began to teach myself C because it seemed the ideal embedded systems language, and slowly started to understand more about programming languages. At one company we actually built our compiler from sources, which was a bit of an eye-opener for me (A compiler is just another piece of software! Imagine that).

When I went to work at the University of Washington School of Oceanography (for Tom Keffer, who later founded Rogue Wave), we decided to use C++. I had only one book to learn from (Stroustrup's; not a beginner text) and ended up having to struggle through and understand language features by examining the intermediate C code that was generated by the C++ preprocessor. Painful, but intensely educational. I have used that experience ever since, because it gave me the ability to dissect a language and see it for what it is. I suppose that is also where I began to learn critical thinking.

So the concepts didn't come all at once. Instead they trickled in over time, and everything I know has taken time to assimilate. If I seem to get a new concept easily now, it's only because it's a variation on the accumulation of concepts I already know. In the Cal Poly computer science graduate program (which would take students who had non-CSci undergrad degrees), the students used to say that it took a year of



being confused about computers before anything at all started to make sense (and they were in an immersion program). People often have unrealistic expectations of themselves when they try to learn about computers—usually they want a high-paying job within a few weeks, and they've heard that computer programming pays the big bucks. But the best learning process starts with someone being interested in computers, and learning more and more as time passes, and generally teaching themselves. That's primarily what I have done; even though I had a strong foundation via computer engineering, I didn't have many programming courses, but instead am self-taught. And I'm constantly learning new things. In this business, learning new things is a large part of the profession.

A Career in Computing

I regularly receive requests for career advice, and I've tried to capture the answers here.

The question that people ask is usually the wrong one: "should I learn

C++ or Java?” In this essay, I shall try to lay out my view of the true issues involved in choosing a career in computing.

Note I am not talking here to the people who already know it is their calling. You’re going to do it regardless of what anyone says, because it’s in your blood and you can’t get away from it. You know the answer already: C++ AND Java AND shell scripting AND Python AND a host of other languages and technologies that you’ll learn as a matter of course. You already know several of these languages, even if you’re only 14.

The person who asks me this question may be coming from another career. Or perhaps they are coming from a field like web development and they’ve figured out that HTML is only kind of like programming, and they’d like to try building something more substantial. But I especially hope that, if you are asking this question, you’ve realized that to be successful in computing, you must teach yourself how to learn, and never stop learning.

The more I do this, the more it seems to me that software is more akin to writing than anything else. And we haven’t figured out what makes a good writer, we only know when we like what someone writes. This is not some kind of engineering where all we have to do is put

something in one end and turn the crank. It is tempting to think of software as deterministic—that's what we want it to be, and that's the reason we keep coming up with tools to help us produce the behavior we desire. But my experience keeps indicating the opposite, that it is more about people than processes, and the fact it runs on a deterministic machine becomes less and less of an influence, just like the Heisenberg principle doesn't affect things on a human scale.

My father built custom homes, and in my youth I would occasionally work for him, mostly doing grunt labor and sometimes hanging sheet rock. He and his lead carpenter would tell me they gave me these jobs for my own good—so I wouldn't go into the business. It worked.

So I can also use the analogy that building software is like building a house. We don't refer to everyone who works on a house as if they were exactly the same. There are concrete masons, roofers, plumbers, electricians, sheet rockers, plasterers, tile setters, laborers, rough carpenters, finish carpenters, and of course, general contractors. Each of these requires a different set of skills, which requires a different amount of time and effort to acquire. House-building is also subject to boom and bust cycles, like programming. To get in quick, you might take a job as a laborer or a sheet rocker, where you can start getting

paid without much of a learning curve. As long as demand is strong, you have steady work, and your pay might even go up if there aren't enough people to do the work. But as soon as there's a downturn, carpenters and even the general contractor can hang the sheet rock themselves.

When the Internet was first booming, all you had to do was spend some time learning HTML and you could get a job and earn some pretty good money. When things turn down, however, it rapidly becomes clear there is a hierarchy of desirable skills, and the HTML programmers (like the laborers and sheet rockers) go first, while the highly-skilled code smiths and carpenters are retained.

What I'm trying to say here is: Don't go into this business unless you are ready to commit to lifelong learning. Sometimes it seems like programming is a well-paying, reliable job—but the only way you can make sure of this is if you are always making yourself more valuable. Of course you can find exceptions. There are always those people who learn one language and are just competent enough and perhaps savvy enough to stay employed without doing much to expand their abilities. But they are surviving by luck, and they are ultimately vulnerable. To make yourself less vulnerable, you must continuously improve your

abilities, by reading, going to user groups, conferences, and seminars. The more depth you have in this field, the more valuable you will be, which means you have more stable job prospects and can command higher salaries.

Another approach is to look at the field in general, and find a place where you already have talents. For example, my brother is interested in software, and dabbles with it, but his business is in installing computers, fixing them and upgrading them. He's always been meticulous, so when he installs or fixes your computer you know it is in excellent shape when he's done; not just the software, but all the way down to the cables, which are bundled neat and out of the way. He's always had more work than he could do, and he never noticed the dot-com bust. And needless to say, his work cannot be offshored.

I stayed in college a long time, and managed to get by in various ways. I even began a Ph.D. program at UCLA, which was mercifully cut short —I say mercifully because I no longer loved being in college, and the reason I stayed in college for so long was because I enjoyed it so much. But what I enjoyed was typically the off-track stuff. Art and dance classes, working on the college newspaper, and the handful of computer programming classes I took (which were off-track because I

was a physics undergrad and a computer engineering graduate student). Although I was far from exceptional academically (a delightful irony is that many colleges that would not have accepted me as a student now use my books in their courses), I really enjoyed the life of the college student, and had I finished a Ph.D. I probably would have taken the easy path and ended up a professor.

But as it turns out, some of the greatest value I got from college was from those same off-track courses, the ones that expanded my mind beyond "stuff we already know." I think this is especially true in computing because you are always programming to support some other goal, and the more you know about that goal the better you'll perform (I've encountered some European graduate programs that require the study of computing in combination with some other specialty, and you build your thesis by solving a domain-specific problem in that other specialty).

I also think knowing more than just programming vastly improves your problem-solving skills (just as knowing more than one programming language vastly improves your programming skills). On multiple occasions I have encountered people, trained only in computer science, who seem more limited in their thinking than those

from some other background, like math or physics, which requires more rigorous thinking and is less prone to “it works for me” solutions.

In one session at a conference I organized, one of the topics was to come up with a list of features for the ideal job candidate:

Learning as a lifestyle. For example, learn more than one language; nothing opens your eyes more to the strengths and limitations of a language than learning another one.

Know where and how to get new knowledge.

Study prior art.

We are tool users.

Learn to do the simplest thing.

Understand the business (Read magazines. Start with *Fast Company*, which has very short and interesting articles. Then you’ll know whether to read others)

You are personally responsible for errors. “It works for me” is not an acceptable strategy. Find your own bugs.

Become a leader: someone who communicates and inspires.

Who are you serving?

There is no right answer … and always a better way. Show and discuss your code, without emotional attachment. You are not your code.

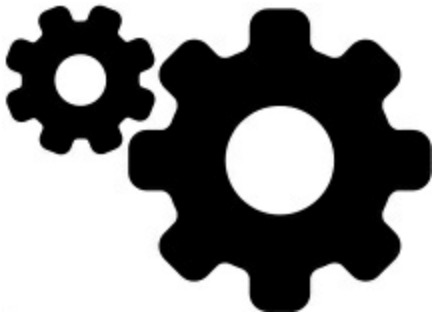
It’s an asymptotic journey towards perfection.

Take whatever risks you can—the best risks are the scary ones, but in trying you will feel more alive than you can imagine. It’s best if you don’t plan for a particular outcome, because you often miss the true possibilities if you’re too attached to a result. My best adventures are ones that start with “lets do a little experiment and see where it takes us.”

Some people are disappointed by this answer, and reply “yes, that’s all very interesting and useful. But really, what should I learn? C++ or Java?” I’ll fend these off by repeating here: I know it seems like all the ones and zeroes should make everything deterministic, so such questions should have a simple answer, but they don’t. It’s not about making one choice and being done with it. It’s about continuous learning and sometimes, bold choices. Trust me, your life will be more exciting this way.

Further Reading

I found all these to be stimulating takes on the subject:



Teach Yourself Programming In Ten Years, by Peter Norvig.

How To Be A Programmer, by Robert Read.

A speech by Steve Jobs to inspire a group of graduating college students.

Kathy Sierra: Does College Matter?

Paul Graham on College.

Joel Spolsky: Advice for Computer Science College Students.

James Shore: Five Design Skills Every Programmer Should Have.

Steve Yegge: The Truth About Interviewing.

The Mythical 5%

A commencement address I gave for

Neumont University, a school in Salt Lake

City dedicated to teaching computer

programming.

So here you are, about to be unleashed upon the world. This is a lot

like taking someone and teaching them all the parts of English speech,

then saying “go out and write stories,” but it’s probably all any school can do. And a more theoretical background wouldn’t help; this is not to say theory is bad, because you’ll need some eventually. But there’s a recent movement that preaches “practice before theory” and I, apparently like Neumont, find that knowing how to do something is very helpful when trying to understand the theory behind it—for me, the theory takes a lot longer to grasp and it’s very useful to be functional while my brain is catching up.

There’s only so much you can learn in school, and it’s only tenuously connected with what you end up doing in your work. So I’m going to try to soften the blow a little, and arm you with a few insights to help when you crash into the actual world of software development.

You’ve come from very structured learning. We even call it a science. It promises there is the same kind of structure and activities in the world. More importantly, you’ve come to expect a certain high level of success, similar to what you’ve experienced with your projects and assignments. But the world does not behave.

The statistics are sobering: 50-80% of programming projects fail. These numbers are so broad because people don’t brag about their failures, so we have to guess. In any event, this makes the world sound

pretty unreliable. Engineering gets better results, mostly because it must. Bad software usually just annoys people but bad engineering can kill.

An even more fascinating metric is this: 5% of programmers are 20x more productive than the other 95%. If this were a science, like it claims, we could figure out how to get everyone to the same level.

Let's say this follows the 80-20 rule. Roughly 80% of programmers don't read books, don't go to conferences, don't continue learning, don't do anything but what they covered in college. Maybe they've gotten a job in a big company where they can do the same thing over and over. The other 20% struggle with their profession: they read, try to learn things, listen to podcasts, go to user group meetings and sometimes a conference. 80% of this 20% are not very successful yet; they're still beginning, still trying. The other 20% of this 20%—that's about 5% of the whole who are 20x more productive.

So how do you become one of these mythical 5%?

These people are not those who can remember all the moves and have fingers that fly over the keyboard erupting system commands. In my experience those in the 5% must struggle to get there, and struggle to stay there, and it's the process of continuous learning that makes the

difference.

Because of what I do, I've met more than my share of these people. They read a lot, and are always ready to tackle a new concept if it looks worthwhile. I think if they do go to conferences they're very selective about it. Most of their time is spent being productive, figuring things out.

The big issue is knowing that you're going after that 20x productivity increase. Which means getting leverage on everything you do. Never just "bashing something out," but using the best tools, techniques, and ideas at your disposal. Always doing your best.

And deeper than that, understanding that the leverage point doesn't always come from the obvious thing, or from what we've been told, or the commonly-held belief about what works. Being able to analyze and understand a situation and discover the hinge points of a problem is essential; this takes a clear mind and detached perspective. For example, sometimes the choice of programming language makes a huge difference, but often, it's relatively unimportant. Regardless, people will still spend all their time on one decision while something else might actually have a far greater influence. Architectural decisions, for example.

So you must learn continuously and teach yourself new technologies, but it's not that simple. It's definitely good to learn more about programming, but you can't *just* learn more about programming. For example here are two of the biggest pain points:

1. Code is read much more than it is written. If people can't read your story, they can't improve it or fix it. Unreadable code has a real cost, and we call it "technical debt."
2. Code reviews are the most effective ways to find software defects, and yet we usually "don't have time for them."

Coming from the world of ones and zeroes we'd like to believe that things are deterministic, that we can provide a set of inputs and get the same outputs every time. I know because I believed this for a long time, and it took some hard knocks when I was a physics undergraduate to begin—only to begin—to wake me up. Many years later I was in a workshop and one of the other attendees told me what I had been learning all those years; she said:

"All models are wrong. Some are useful."

We are in a young business. Primitive, really—we don't know much about what works, and we keep thinking we've found the silver bullet that solves all problems. As a result, we go through these multi-year

boom and bust cycles as new ideas come in, take off, exceed their grasp, then run out of steam. But some ideas seem to have staying power. For example, many of the ideas in agile methodologies seem to be making some real impacts in productivity and quality. This is because they focus more on the issues of people working together and less on technologies.

A man I've learned much from, Gerald Weinberg, wrote his first couple of books on the technology of programming. Then he switched, and wrote or coauthored 50 more on the process of programming, and he is most famous for saying "no matter what they tell you, it's always a people problem."

Usually the things that make or break a project are process and people issues. The way you work on a day-to-day basis. Who your architects are, who your managers are, and who you are working with on the programming team. How you communicate, and most importantly how you solve process and people problems when they come up. The fastest way to get stuck is to think it's all about technology and to believe you can ram your way through the other things. Those other things are the most likely ones to stop you cold.

In my first jobs, I saw lots of managers making stupid decisions, and

so, logically, I came to the conclusion that managers and management was stupid. It's a commonly held belief in our profession: if you're not smart enough to deal with the technology, you go into management. Over time I very slowly learned that the task of management wasn't stupid, it's just very, very hard. That's why all those stupid decisions are still made; management is much harder than technology because it involves virtually no deterministic factors. It's all guesswork, so if you don't have good intuition you'll probably make stupid decisions. Napoleon wanted lucky generals rather than smart ones.

Here's an example: some companies have adopted a policy where, at the end of a predetermined period, each team gets evaluated and the bottom 10% or 20% are fired. In response to this policy, a smart manager who has a good team hires extra people who can be thrown overboard without damaging the team. It's not a good policy; in fact it's abusive and eats away at company morale from within. It's one of the things you probably didn't learn here, and yet the kind of thing you must know, even if it seems to have nothing directly to do with programming.

Here's another example: People will ask you the shortest possible time it will take to finish a particular task. You'll do your best to guess what

that is, and they'll assume you can actually do it. What you must tell them for an estimate like this, and for all your estimates, is there's a 0% probability you actually get it done in that period of time, that such a guess is only the beginning of the probability curve. Each guess must be accompanied by such a probability curve, so all the probabilities combined produce a real curve indicating when the project might likely be done. You can learn more about this by reading a small book called Waltzing with Bears.

You must pay attention to economics and business, both of which are far-from-exact sciences. Listen to books and lectures on tape while you commute. Understanding the underlying business issues may allow you to detect the fortunes of the company you're working for and take action early. When I first started working I looked askance at people who paid attention to business issues—that was suit stuff, not real technology. But those people were the smart ones.

A great source of information is podcasts. Anyone can produce these so many of them are bad, but there are some real gems out there, podcasts that specifically cover topics in our profession. I learn a lot from these, and they help me stay current.

Here's another thing you probably didn't learn here. Both the world of

business and the world of programming is legendary for flailing about with fads that promise to get things done better. The easy fads are patently ridiculous, or become so in short order. The harder ones to spot contain some reason or truth that prevents you from quickly dismissing them. Sometimes you must pick out the good stuff and throw the rest away, and to do this you must exercise critical thinking.

I saw a grocery bag that said “studies show children and teens who eat dinner with their families at least 5 times a week are 50% less likely to use alcohol.” The bag’s implied conclusion was that eating dinner together prevents alcoholism. Is eating dinner together the dominant factor? Or is there something else that causes both eating dinner together and reduced alcoholism?

Here are some more things which many people have seriously believed:

Companies don’t have to make a profit anymore. It’s the new economy.

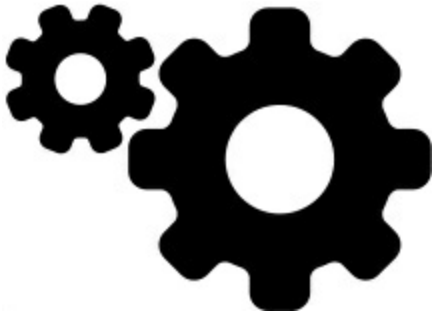
Real estate always goes up, even if salaries don’t.

A university must be a traditional campus and not an office building.

It’s even harder when you come from the world of ones and zeros

where we really, really want to believe that everything can be deterministic. It's harder than that when you understand that adding people into the mix and scaling up a system changes the dominant factors, while everyone around you still believes it should all be deterministic.

There's a book that uses studies to debunk beliefs about managing people and projects; it happens to be software-based but the thinking



could be applied almost everywhere. This book is called Peopleware; it's small and fun to read and I recommend it to almost everyone. Alas, it really isn't a book of answers, it just firmly destroys many closely-held ideas about how people work in business situations that involve programming. The best thing is it reminds you how easy it is to take a wrong idea and build a bad world around it. It helps you ask questions.

So when you go into your new job with your head filled with technical knowledge from the last couple of years, and you add what I've told you today, you may be tempted to assume that everyone at the

company has foolishly gotten themselves trapped with bad ideas. But there's one more very important maxim from Gerald Weinberg which doesn't really answer anything as much as it gives you a way to understand what happens. He says: "Things are the way they are because they got that way … one logical step at a time." It's the legendary frog in the saucepan (Another myth; They actually jump out). So from your fresh new perspective things might look ridiculous, but remember that each decision on the way was made by someone weighing the issues and making what seemed like the best choice at the time. This viewpoint doesn't solve the problem but it can make you more compassionate about people who are stuck there.

You'll need to make many mistakes to figure things out. So be humble, and keep asking questions.

Writing Software Is

Like … Writing

I finally figured out the right analogy for software development. Alas, the target audience for this analogy won't be happy with it.

Why do we need an analogy? We know what we do. We program computers, with all that entails. And we know what that means, because we do it.

But to the stakeholders—managers, CEOs, customers, shareholders, etc.—software development is a mystery. They don't want to know everything about it, but they want to know enough to predict the behavior of software development, at least approximately.

So stakeholders need an abstraction. An analogy. But for the analogy to be useful, it must hide the things that aren't important, and show the things that are. We've been flailing about with this problem for a long time, but we've always been putting it in *our* terms, and it all makes sense to us, so we can't differentiate between a useful analogy and one that is less than helpful.

Mathematicians and engineers were the original programmers, so naturally we tried making it a science, then engineering. Mostly we discovered that no matter how much we want software to be like mathematical proofs or bridge-building, it isn't.

The stakeholders, trying to follow our analogies, asked questions that were important to them. "If programming is like math, why are programs always broken? Math is right or wrong, software is just broken." And later, after we gave up on the science analogy, "If programmers are like engineers, I can replace one engineer with another and get similar results, right?"

This latter has been a huge source of consternation among stakeholders. By and large, engineers have similar productivity levels. And the results produced are verifiable. There's a lot of consistency in engineering, and if we call it "software engineering," then there should be similar consistency in software.

The two typical approaches to this problem have been either big denial ("ignore the differences and pretend all software development is the same") or little denial ("The differences are accidental. We can force consistency").

Big denial just doesn't work. But little denial has produced repeated attempts at "standardization of software engineers," the most notable of which is certification. If only we had a certification process, the argument goes, software engineers would be like real engineers, and they'd all be consistent.

Fortunately certification has never gotten very far, because programmers could never be bothered to take such a thing seriously, and employers want to hire the best programmers without regard to whether they have any particular degrees or credentials. And the certification programs that *do* exist are always done for money, and that seems to inevitably flatten the curve. I don't know anyone, for

example, that takes the basic Sun Java Certification seriously. The more advanced Java certifications seem interesting, but they also appear much more like workshops and less like tests to me.

At one point I ridiculed this attempt to make all programmers identical cogs in a machine by reducing our activity to its simplest behavior in *Programming as Typing* (the following section in this appendix).

So we're not scientists, and we're not engineers. How do we describe what we do to non-programmers in a way that makes sense to them? In particular, in a way that explains why there's such a big difference in programmers, in programming projects, and in the success and failure of projects?

Here's my proposal. I think it explains everything. It is very unsatisfying to stakeholders that want completely predictable behavior, and who want to replace one programmer with another and get identical results. (That's still not going to happen. The only compensation for the unpredictability is approaches like the Agile methods, which increases the bandwidth of communication with the stakeholders).

We're writers.

Most people can put words together into sentences. They can communicate adequately without being great writers. Most programmers can write some kind of program. It might not be very good, but most companies don't really need it to be very good. Most companies only need basic programming skills. A college degree in computer "science" from anywhere is good enough, and the job is just a job. It doesn't require much in the way of continuing education, conferences, workshops, or someone who is so interested in the craft of programming they are always trying to learn more.

Such people can write, but it's just basic writing. They are not essayists or novelists—and keep in mind there are lots of published articles and novels that are not particularly well-written or worth reading. Obviously such things seem to sell well enough to make the effort and risk worthwhile all around.

But someone who dedicates themselves to writing, who goes through the struggle of figuring it out and discovering their own place in the world—this is a very different kind of writer (of prose or programs) than the average. This person can produce more functionality faster, and the results are clearer and deeper than ordinary code.

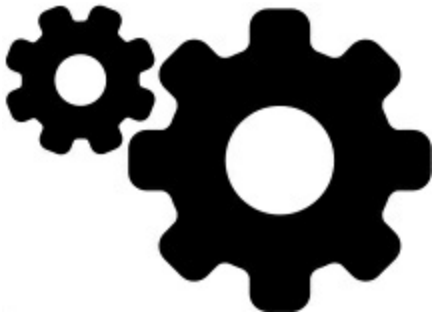
Writing a novel is a very impressive feat. Doing something that might

be worth publishing—that's an even greater feat. But the vast majority of published novels aren't worth reading. Only a small fraction of writers create something really worthwhile, and no one, really, knows how they do it. Each good novelist comes to their art in their own way.

And what about nonfiction? Every year there are about 5000 novels published, and about 50,000 nonfiction books. Most of those nonfiction books are merely functional, not great reading. But they contain useful information and enough people buy them to make it all worthwhile (to the publisher, at least).

This answers one of the biggest questions—why you can't replace a programmer with just any other programmer and get similar results.

It also suggests re-evaluating the kind of project you're creating when you decide who your team should be, and how it will run. The creation of mysteries and young adult fiction and so-called "bodice rippers" and the vast sea of nonfiction books all have their own particular structure and constraints (you'd be surprised at how rigid and controlling publishers are about these things, as if they are manufacturing some kind of basic commodity—"the murder must happen in the first ten



pages," etc.). None of these are the mass-market bestsellers ("killer apps") that are sold because of the author's voice and style. The mass-market bestsellers usually don't coincide with great writers, since most people don't have the patience to read these meta-craftsmen, just as most programmers don't read the source code for compilers.

Although stakeholders won't necessarily understand the intricate details of the writing and publishing process, they typically understand there are different types of writing, and that the craft of writing is a weird, unfathomable and artistic process which can't guarantee results. So even though "software is writing" is not necessarily going to increase the predictability of what we do, it may at least help non-programmers to understand its unpredictability.

Programming as

Typing

How can we see, through new eyes, the

problems we face when building

software?

(This started as a reply to John Camara, then took on a life of its own.)

I believe by now it is safe to assume that
the majority of software developers and
managers of software projects have come
to accept the importance of testing so I
feel it’s unnecessary to comment on
testing.

I’ve learned not to trust lots of noise about something. It usually doesn’t correlate to reality. A friend works for a company that’s just now learning about unit testing, and apparently testing in general. I’ve consulted with companies where testing is still a new thing. My guess is that the majority of software developers have not yet accepted the importance of testing, and it’s only the noisemakers on the leading edge who are learning and talking about it, and thus giving the impression it’s now well accepted.

Another example of noise vs. reality: people are always saying there are still more COBOL and FORTRAN programmers out there than any other kind. But when was the last time you saw one, much less talked to one? By that metric, they don’t exist. But apparently there are lots of

them.

Now as important as it may be to have a second pair of eyes on a problem I feel it's not the most important benefit of code reviews. I feel that code reviews provide a means of mentoring each other.

Yes, it's one thing to show examples and talk about how you would, in theory, use a particular language feature properly. But when someone actually has a vested interest in a piece of code, that code becomes real and important. (I create toy examples in books out of necessity only).

I think the more abstract the concept, the more important it is to work with a project that people are actually trying to build, to take it out of the realm of ideas. For example, when teaching OO design (which is more abstract than programming), I encourage people to bring their own designs, so we can work on them together. This makes better use of the training or consulting time, because people can actually gain forward motion on their projects and so have more of a vested interest in the seminar.

This form of mentoring is likely to be the only form of mentoring that the majority

of developers experience these days.

After all, mentoring has lost most, if not all, priority in these sad times of ever decreasing costs at all costs. We have simply forgotten how important it is to pass collective experiences from generation to generation.

This may come from (perceived) efficiency considerations. Mentoring on a regular basis may appear to be just a cost for a project—interference with getting things done. Whereas carving out a week for training between projects is a discrete chunk of time, you do it and you're done, then people can get back to slinging code as fast as they can. Or any number of other scenarios.

I think the problem is that while many programmers understand that programming happens in the mind, and the code itself is just an artifact of the process, outside the field, the code looks like it's what you're doing. (An understandable perception, since the code is the core deliverable). So if it's about the code and not the mental process behind the code, it makes sense you would do whatever you can to produce the code as fast and as cheaply as possible, and to discard

anything that appears to hinder the creation of code. From this follows the logical thought that coding is typing. If this is true, you want to see people typing all the time. Also, 10 people can type faster than one person so if you can hire ten offshore programmers cheaper than one US programmer, you're going to get a lot more typing done, so you'll get big economic leverage.

In reality, study after study indicates that success comes from who you hire. This suggests that programming is not a mass-production activity where programmers are replaceable components.

I think a good analogy is writing a novel. Suppose you want to create a Stephen King novel (I'm not much of a fan, but this is exactly the kind of book that publishers stay up nights trying to figure out how to mass produce). You can say, "A book is made up of words, and words are created by typing, so to create a book we must get a bunch of people typing. The more people we can get typing, the faster we'll create a book. And the cheaper the typist, the cheaper it is to create books."

It's hard to argue with that logic. After all, a book is made up of words. And words are created by typing, etc. But anyone who reads novels knows there must be a fundamental flaw in the logic, because there are authors whom you like and others whom you can't stand. The choice

of words and the structure of the book makes the difference, and that is based on the person writing the book. We know you can't replace one author with 10 lesser writers and get anything like what the author could produce, or anything you'd want to read.

Another example is a house. Like software, it's comprised of subsystems that fit together. Like software, you have a bunch of people working on it, and it's even true that some of those people are replaceable. It doesn't much matter who is nailing up the wallboard. But you really notice the design of the house, and you notice how well it was put together, and those things are determined by the architect and the builder.

I've been struggling with this general problem for a long time. That is, the "logical" arguments that are very hard to refute, like "software is created by typing." True on the surface, but not really the essence of the issue. But if you keep the argument on those terms, you can't really get anywhere, because the logic is irrefutable. Even if that logic completely misses the real issue.

This is probably why I keep fighting with the static-dynamic language debate, because it has the same feel to me. You can come up with all kinds of reasons that static checking is a good thing, until you have an

experience programming in a dynamic language where you are vastly more productive than with a static language. But that experience defies the logic used to back up the reasoning behind static languages (*I believe now it is predominantly cultural rather than logical/rational*).

Here's another one. I think "details matter," and that environmental noise really does wear you down (studies show that noise makes you tired). What I'm talking about here is visual and complexity noise. So I was disappointed when, for example, Ruby turned out to have **begin** and **end** statements, and it uses **new** to create objects. These are all noise artifacts from previous languages, required to support their compilers. If your language creates all objects on the heap, you don't need to say **new** to distinguish between heap and stack objects (like you do in C++, which was mindlessly mimicked by Java). And everyone always indents their code, so you can use indentation to establish scope. Besides the fact that I'm justifying the design minimalism of Python here, when I put these ideas out I will probably get many perfectly reasonable rationalizations about why this is the best way of doing things. And without questioning the fundamental principles upon which those arguments are founded, those arguments

are pretty airtight, even if they really come down to “I’m used to that and I don’t want to think differently about it.”

Java has always required a lot of extra typing. But the fact that Eclipse, NetBeans, IntelliJ Idea, and other IDEs generate code for you seems to justify enormous amounts of visual noise, and for those in the midst of it, that’s OK, and even desirable. “It’s clearer because it’s more explicit” (Python even has a maxim: “Explicit is better than implicit”). This is even taken to extremes with the idea, supported by a surprising number of folks, that every class should have an associated interface, which to my mind makes the code far more complicated and confusing. Which costs money, because everyone who works with that code must wade through all those extra layers of complication.

All of this detail is expensive, even with a tool that generates a lot of code for you. But if you’re in the middle of it, it’s all you see and it makes sense because it seems to work. And of course, if you compare one Java project to another, you aren’t questioning the cost of using the language.

In contrast, when I teach OO design, my favorite approach is to (A) work on a project that the client is actually working on and (B) move quickly through the design process and model the result in a dynamic

language (I know Python best). In most cases, the client doesn't know Python, but that doesn't matter. We still very quickly get a model of the system up and running, and in the process we discover problems that our initial design pass didn't see. So because of the speed and agility of a dynamic language, design issues appear early and quickly and we can refine the design before recasting it in a heavyweight language.

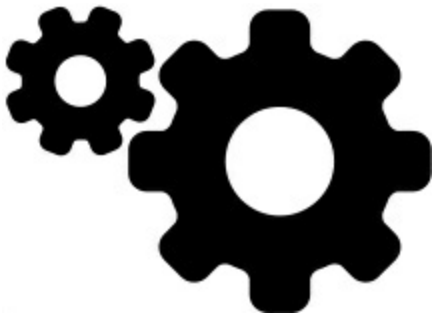
And I would argue that if the initial code is done in the heavyweight language instead, then (A) There is resistance to putting the design into code because it is much more work intensive; it isn't a lightweight activity, and (B) There is resistance to making changes to the design for the same reason.

And yet, I will probably get any number of perfectly reasonable arguments to the effect that this approach doesn't make sense. I usually find that these arguments are not based on experience, but on logic that follows from fundamental assumptions about the world of programming.

It may not even be possible to prove things logically when it comes to programming. So many of the conclusions that we draw this way appear wrong. This is what I like about the book *Peopleware,* and also

Software Conflict 2.0. These books point out places where we operate based on what seems perfectly logical, and yet is wrong (one of my favorite studies in *Peopleware* shows that, of all forms of estimation, the most productive approach is when no estimate at all is made).

The story I heard about Greek natural philosophers (what we call physicists today) is that they were more interested in the arguments about how something worked than they were about how that thing actually worked. So they didn't drop small and large stones to find out if one fell faster than they other, they argued based on their assumptions.



It seems to me that we're in the same situation when we try to argue about programming. A large part of the Enlightenment came from the move to the scientific method, which seems like a small, simple step but turned out to be very big, with very big impact. To wit, you can argue about how you think something will happen, but then you must go out and actually do the experiment. If the experiment disagrees

with your argument, you must change your argument and try another experiment.

The key is in doing the experiment, and in paying attention to the results, rather than starting with belief and trying to wrestle the world into line with that belief. Even after some 500 years, human society is still trying to come to terms with the age of reason.

I think the essence of what the agilists are doing is a perfect analogy to the discovery of the scientific method. Instead of making stuff up—and if you look back at all the "solutions" we've invented to solve software complexity problems, that's primarily what they are—you do an experiment and see what happens. And if the experiment denies the arguments you've used in the past, you can't discard the results of the experiment. You have to change something about your argument.

Of course, you aren't forced to change your argument. But even if it doesn't happen overnight, those that look at the experiments and realize that something is different than the way they thought it was, those people will move past you and forge into new territory. Territory that your company cannot enter if they refuse to change their ideas.

Do What You Love

*"In 1960, a researcher interviewed 1500 business-school students and

classified them in two categories: those who were in it for the money—1245 of them—and those who were going to use the degree to do something they cared deeply about—the other 255 people. Twenty years later, the researcher checked on the graduates and found that 101 of them were millionaires—and all but one of those millionaires came from the 255 people who had pursued what they loved to do!*

"Now, you may think that your passion for Icelandic poetry of the baroque period, or butterfly collecting, or golf—or social justice—might consign you to a permanent separation between what you love and what you do for a living, but it isn't necessarily so. Vladimir Nabokov, one of the greatest novelists of this century, was far more passionate about butterfly collecting than writing. His first college teaching job, in fact, was in lepidoptery. Research on more than 400,000 Americans over the past 40 years indicates that pursuing your passions—even in small doses, here and there each day—helps you make the most of your current capabilities and encourages you to develop new ones." —From *The Other 90%* by Robert K. Cooper, Three Rivers Press 2001.

Also, see Po Bronson's book *What Should I Do With My Life?* for more exploration of these ideas.

Document Outline

- Writing Software Is Like … Writing
- Programming as Typing
- Do What You Love