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CORE
JAVA
Volume I: Fundamentals

TWELFTH EDITION

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Cay S. Horstmann

Core Java, Volume I: Fundamentals

Twelfth Edition

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Addison-Wesley

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Preface

To the Reader

In late 1995, the Java programming language burst onto the Internet scene and gained instant celebrity status. The promise of Java technology was that it would become the *universal glue* that connects users with information wherever it comes from—web servers, databases, information providers, or any other imaginable source. Indeed, Java is in a unique position to fulfill this promise. It is an extremely solidly engineered language that has gained wide acceptance. Its built-in security and safety features are reassuring both to programmers and to the users of Java programs. Java has built-in support for advanced programming tasks, such as network programming, database connectivity, and concurrency.

Since 1995, twelve major revisions of the Java Development Kit have been released. Over the course of the last 25 years, the Application Programming Interface (API) has grown from about 200 to over 4,000 classes. The API now spans such diverse areas as user interface construction, database management, internationalization, security, and XML processing.

The book that you are reading right now is the first volume of the twelfth edition of *Core Java*. Each edition closely followed a release of the Java Development Kit, and each time, I rewrote the book to take advantage of the newest Java features. This edition has been updated to reflect the features of Java 17.

As with the previous editions, *this book still targets serious programmers who want to put Java to work on real projects*. I think of you, the reader, as a programmer with a solid background in a programming language other than Java. I assume that you don't like books filled with toy examples (such as toasters, zoo animals, or "nervous text"). You won't find any of these in the book. My goal is to enable you to fully understand the Java language and library, not to give you an illusion of understanding.

In this book you will find lots of sample code demonstrating almost every language and library feature. The sample programs are purposefully simple to focus on the major points, but, for the most part, they aren't fake and they don't cut corners. They should make good starting points for your own code.

I assume you are willing, even eager, to learn about all the advanced features that Java puts at your disposal. For example, you will find a detailed treatment of

- Object-oriented programming
- Reflection and proxies
- Interfaces and inner classes
- Exception handling
- Generic programming
- The collections framework
- The event listener model
- Graphical user interface design
- Concurrency

With the explosive growth of the Java class library, a one-volume treatment of all the features of Java that serious programmers need to know is no longer possible. Hence, the book is broken up into two volumes. This first volume concentrates on the fundamental concepts of the Java language, along with the basics of user-interface programming. The second volume, *Core Java, Volume II: Advanced Features*, goes further into the enterprise features and advanced user-interface programming. It includes detailed discussions of

- The Stream API
- File processing and regular expressions
- Databases
- XML processing

- Annotations
- Internationalization
- Network programming
- Advanced GUI components
- Advanced graphics
- Native methods

When writing a book, errors and inaccuracies are inevitable. I'd very much like to know about them. But, of course, I'd prefer to learn about each of them only once. You will find a list of frequently asked questions and bug fixes at `http://horstmann.com/corejava`. Strategically placed at the end of the errata page (to encourage you to read through it first) is a form you can use to report bugs and suggest improvements. Please don't be disappointed if I don't answer every query or don't get back to you immediately. I do read all e-mail and

appreciate your input to make future editions of this book clearer and more informative.

A Tour of This Book

Chapter 1 gives an overview of the capabilities of Java that set it apart from other programming languages. The chapter explains what the designers of the language set out to do and to what extent they succeeded. A short history of Java follows, detailing how Java came into being and how it has evolved.

In **Chapter 2**, you will see how to download and install the JDK and the program examples for this book. Then I'll guide you through compiling and running a console application and a graphical application. You will see how to use the plain JDK, a Java IDE, and the JShell tool.

Chapter 3 starts the discussion of the Java language. In this chapter, I cover the basics: variables, loops, and simple functions. If you are a C or C++ programmer, this is smooth sailing because the syntax for these language features is essentially the same as in C. If you come from a non-C background such as Visual Basic, you will want to read this chapter carefully.

Object-oriented programming (OOP) is now in the mainstream of programming practice, and Java is an object-oriented programming language. **Chapter 4** introduces encapsulation, the first of two fundamental building blocks of object orientation, and the Java language mechanism to implement it—that is, classes and methods. In addition to the rules of the Java language, you will also find advice on sound OOP design. Finally, I cover the marvelous `javadoc` tool that formats your code comments as a set of hyperlinked web pages. If you are familiar with C++, you can browse through this chapter quickly. Programmers coming from a non-object-oriented background should expect to spend some time mastering the OOP concepts before going further with Java.

Classes and encapsulation are only one part of the OOP story, and **Chapter 5** introduces the other—namely, *inheritance*. Inheritance lets you take an existing class and modify it according to your needs. This is a fundamental technique for programming in Java. The inheritance mechanism in Java is quite similar to that in C++. Once again, C++ programmers can focus on the differences between the languages.

Chapter 6 shows you how to use Java's notion of an *interface*. Interfaces let you go beyond the simple inheritance model of Chapter 5. Mastering interfaces allows you to have full access to the power of Java's completely object-oriented approach to programming. After covering interfaces, I move on to *lambda expressions*, a concise way for expressing a block of code that can be executed at a later point in time. I then explain a useful technical feature of Java called *inner classes*.

Chapter 7 discusses *exception handling*—Java's robust mechanism to deal with the fact that bad things can happen to good programs. Exceptions give you an efficient way of separating the normal processing code from the error handling. Of course, even after hardening your program by handling all exceptional conditions, it still might fail to work as expected. In the final part of this chapter, I give you a number of useful debugging tips.

Chapter 8 gives an overview of generic programming. Generic programming makes your programs easier to read and safer. I show you how to use strong typing and remove unsightly and unsafe casts, and how to deal with the complexities that arise from the need to stay compatible with older versions of Java.

The topic of **Chapter 9** is the collections framework of the Java platform. Whenever you want to collect multiple objects and retrieve them later, you should use a collection that is best suited for your circumstances, instead of just tossing the elements into an array. This chapter shows you how to take advantage of the standard collections that are prebuilt for your use.

Chapter 10 provides an introduction into GUI programming. I show how you can make windows, how to paint on them, how to draw with geometric shapes, how to format text in multiple fonts, and how to display images. Next, you'll see how to write code that responds to events, such as mouse clicks or key presses.

Chapter 11 discusses the Swing GUI toolkit in great detail. The Swing toolkit allows you to build cross-platform graphical user interfaces. You'll learn all about the various kinds of buttons, text components, borders, sliders, list boxes, menus, and dialog boxes. However, some of the more advanced components are discussed in Volume II.

Chapter 12 finishes the book with a discussion of concurrency, which enables you to program tasks to be done in parallel. This is an important and exciting application of Java technology in an era where most processors have multiple cores that you want to keep busy.

The **Appendix** lists the reserved words of the Java language.

Conventions

As is common in many computer books, I use `monospace type` to represent computer code.

NOTE:

Notes are tagged with “note” icons that look like this.

TIP:

Tips are tagged with “tip” icons that look like this.

CAUTION:

When there is danger ahead, I warn you with a “caution” icon.

C++ NOTE:

There are many C++ notes that explain the differences between Java and C++. You can skip over them if you don’t have a background in C++ or if you consider your experience with that language a bad dream of which you’d rather not be reminded.

Java comes with a large programming library, or Application Programming Interface (API). When using an API call for the first time, I add a short summary description at the end of the section. These descriptions are a bit more informal but, hopefully, also a little more informative than those in the official online API documentation. The names of interfaces are in italics, just like in the official documentation. The number after a class, interface, or method name is the JDK version in which the feature was introduced, as shown in the following example:

Application Programming Interface 9

Programs whose source code is on the book's companion web site are presented as listings, for instance:

Listing 1.1 `InputTest/InputTest.java`

Sample Code

The web site for this book at `http://horstmann.com/corejava` contains all sample code from the book. See Chapter 2 for more information on installing the Java Development Kit and the sample code.

Register your copy of *Core Java, Volume I: Fundamentals, Twelfth Edition,* on the InformIT site for convenient access to updates and/or corrections as they become available. To start the registration process, go to `informit.com/register` and log in or create an account. Enter the product ISBN (9780137673629) and click Submit. Look on the Registered Products tab for an Access Bonus Content link next to this product, and follow that link to access any available bonus materials. If you would like to be notified of exclusive offers on new editions and updates, please check the box to receive email from us.

Acknowledgments

This content is currently in development.

Chapter 1. An Introduction to Java

In this chapter

The first release of Java in 1996 generated an incredible amount of excitement, not just in the computer press, but in mainstream media such as the *New York Times*, the *Washington Post*, and *BusinessWeek*. Java has the distinction of being the first and only programming language that had a ten-minute story on National Public Radio. A $100,000,000 venture capital fund was set up solely for products using a *specific* computer language. I hope you will enjoy a brief history of Java that you will find in this chapter.

1.1 Java as a Programming Platform

In the first edition of this book, my coauthor Gary Cornell and I had this to write about Java:

“As a computer language, Java’s hype is overdone: Java is certainly a *good* programming language. There is no doubt that it is one of the better languages available to serious programmers. We think it could *potentially* have been a great programming language, but it is probably too late for that. Once a language is out in the field, the ugly reality of compatibility with existing code sets in.”

Our editor got a lot of flack for this paragraph from someone very high up at Sun Microsystems, the company that originally developed Java. The Java language has a lot of nice features that we will examine in detail later in this chapter. It has its share of warts, and some of the newer additions to the language are not as elegant as the original features because of compatibility requirements.

But, as we already said in the first edition, Java was never just a language. There are lots of programming languages out there, but few of them make much of a splash. Java is a whole *platform*, with a huge library, containing lots of reusable code, and an execution environment that provides services such as security, portability across operating systems, and automatic garbage collection.

As a programmer, you will want a language with a pleasant syntax and comprehensible semantics (i.e., not C++). Java fits the bill, as do dozens of other fine languages. Some languages give you portability, garbage collection, and the like, but they don't have much of a library, forcing you to roll your own if you want fancy graphics or networking or database access. Well, Java has everything—a good language, a high-quality execution environment, and a vast library. That combination is what makes Java an irresistible proposition to so many programmers.

1.2 The Java "White Paper" Buzzwords

The authors of Java wrote an influential white paper that explains their design goals and accomplishments. They also published a shorter overview that is organized along the following 11 buzzwords:

1. Simple
2. Object-Oriented
3. Distributed
4. Robust
5. Secure
6. Architecture-Neutral
7. Portable

8. Interpreted
9. High-Performance
10. Multithreaded
11. Dynamic

In the following subsections, you will find a summary, with excerpts from the white paper, of what the Java designers say about each buzzword, together with a commentary based on my experiences with the current version of Java.

NOTE:

The white paper can be found at `www.oracle.com/technetwork/java/langenv-140151.html`. You can retrieve the overview with the 11 buzzwords at `http://horstmann.com/corejava/java-an-overview/7Gosling.pdf`.

1.2.1 Simple

> *We wanted to build a system that could be programmed easily without a lot of esoteric training and which leveraged today's standard practice. So even though we found that C++ was unsuitable, we designed Java as closely to C++ as possible in order to make the system more comprehensible. Java omits many rarely used, poorly understood, confusing features of C++ that, in our experience, bring more grief than benefit.*

The syntax for Java is, indeed, a cleaned-up version of C++ syntax. There is no need for header files, pointer arithmetic (or even a pointer syntax), structures, unions, operator overloading, virtual base classes, and so on. (See the C++ notes interspersed throughout the text for more on the differences between Java and C++.) The designers did not, however, attempt to fix all of the clumsy features of C++. For example, the syntax of the `switch` statement is unchanged in Java. If you know C++, you will find the transition to the Java syntax easy.

At the time Java was released, C++ was actually not the most commonly used programming language. Many developers used Visual Basic and its drag-and-drop programming environment. These developers did not find Java simple. It took several years for Java development environments to catch up. Nowadays, Java development environments are far ahead of those for most other programming languages.

> *Another aspect of being simple is being small. One of the goals of Java is to enable the construction of software that can run stand-alone on small machines. The size of the basic interpreter and class support is about 40K; the basic standard libraries and thread support (essentially a self-contained microkernel) add another 175K.*

This was a great achievement at the time. Of course, the library has since grown to huge proportions. There are now separate editions with a smaller library, suitable for embedded devices and smart cards.

1.2.2 Object-Oriented

> *Simply stated, object-oriented design is a programming technique that focuses on the data—objects—and on the interfaces to those objects. To make an analogy with carpentry, an "object-oriented" carpenter would be mostly concerned with the chair he is building, and secondarily with the tools used to make it; a "non-object-oriented" carpenter would think primarily of his tools. The object-oriented facilities of Java are essentially those of C++.*

Object orientation was pretty well established when Java was developed. The object-oriented features of Java are comparable to those of C++. The major difference between Java and C++ lies in multiple inheritance, which Java has replaced with a simpler concept of interfaces. Java has a richer capacity for runtime introspection (discussed in Chapter 5) than C++.

1.2.3 Distributed

Java has an extensive library of routines for coping with TCP/IP protocols like HTTP and FTP. Java applications can open and access objects across the Net via URLs with the same ease as when accessing a local file system.

Nowadays, one takes this for granted—but in 1995, connecting to a web server from a C++ or Visual Basic program was a major undertaking.

1.2.4 Robust

Java is intended for writing programs that must be reliable in a variety of ways. Java puts a lot of emphasis on early checking for possible problems, later dynamic (runtime) checking, and eliminating situations that are error-prone. . . . The single biggest difference between Java and C/C++ is that Java has a pointer model that eliminates the possibility of overwriting memory and corrupting data.

The Java compiler detects many problems that in other languages would show up only at runtime. As for the second point, anyone who has spent hours chasing memory corruption caused by a pointer bug will be very happy with this aspect of Java.

1.2.5 Secure

Java is intended to be used in networked/distributed environments. Toward that end, a lot of emphasis has been placed on security. Java enables the construction of virus-free, tamper-free systems.

From the beginning, Java was designed to make certain kinds of attacks impossible, among them:

- Overrunning the runtime stack—a common attack of worms and viruses
- Corrupting memory outside its own process space
- Reading or writing files without permission

Originally, the Java attitude towards downloaded code was “Bring it on!” Untrusted code was executed in a sandbox environment where it could not impact the host system. Users were assured that nothing bad could happen because Java code, no matter where it came from, could never escape from the sandbox.

However, the security model of Java is complex. Not long after the first version of the Java Development Kit was shipped, a group of security experts at Princeton University found subtle bugs that allowed untrusted code to attack the host system.

Initially, security bugs were fixed quickly. Unfortunately, over time, hackers got quite good at spotting subtle flaws in the implementation of the security architecture. Sun, and then Oracle, had a tough time keeping up with bug fixes.

After a number of high-profile attacks, browser vendors and Oracle became increasingly cautious. For a time, remote code had to be digitally signed. Nowadays, delivering Java applications via a browser is a a distant memory.

NOTE:

Even though in hindsight, the Java security model was not as successful as originally envisioned, Java was well ahead of its time. A competing code delivery mechanism from Microsoft, called ActiveX, relied on digital signatures alone for security. Clearly this was not sufficient: As any user of Microsoft's own products can confirm, programs from well-known vendors do crash and create damage.

1.2.6 Architecture-Neutral

> *The compiler generates an architecture-neutral object file format. The compiled code is executable on many processors, given the presence of the Java runtime system. The Java compiler does this by generating bytecode instructions which have nothing to do with a particular computer architecture. Rather, they are designed to be both easy to*

interpret on any machine and easy to translate into native machine code on the fly.

Generating code for a "virtual machine" was not a new idea at the time. Programming languages such as Lisp, Smalltalk, and Pascal had employed this technique for many years.

Of course, interpreting virtual machine instructions is slower than running machine instructions at full speed. However, virtual machines have the option of translating the most frequently executed bytecode sequences into machine code—a process called just-in-time compilation.

Java's virtual machine has another advantage. It increases security because it can check the behavior of instruction sequences.

1.2.7 Portable

Unlike C and C++, there are no "implementation-dependent" aspects of the specification. The sizes of the primitive data types are specified, as is the behavior of arithmetic on them.

For example, an `int` in Java is always a 32-bit integer. In C/C++, `int` can mean a 16-bit integer, a 32-bit integer, or any other size that the compiler vendor likes. The only restriction is that the `int` type must have at least as many bytes as a `short int` and cannot have more bytes than a `long int`. Having a fixed size for number types eliminates a major porting headache. Binary data is stored and transmitted in a fixed format, eliminating confusion about byte ordering. Strings are saved in a standard Unicode format.

The libraries that are a part of the system define portable interfaces. For example, there is an abstract `Window` *class and implementations of it for UNIX, Windows, and the Macintosh.*

The example of a `Window` class was perhaps poorly chosen. As anyone who has ever tried knows, it is an effort of heroic proportions to implement a user interface that looks good on Windows, the Macintosh, and ten flavors of UNIX. Java 1.0 made the heroic effort, delivering a simple toolkit that provided common user interface elements on a number of platforms.

Unfortunately, the result was a library that, with a lot of work, could give barely acceptable results on different systems. That initial user interface toolkit has since been replaced, and replaced again, and portability across platforms remains an issue.

However, for everything that isn't related to user interfaces, the Java libraries do a great job of letting you work in a platform-independent manner. You can work with files, regular expressions, XML, dates and times, databases, network connections, threads, and so on, without worrying about the underlying operating system. Not only are your programs portable, but the Java APIs are often of higher quality than the native ones.

1.2.8 Interpreted

> *The Java interpreter can execute Java bytecodes directly on any machine to which the interpreter has been ported. Since linking is a more incremental and lightweight process, the development process can be much more rapid and exploratory.*

This was a real stretch. Anyone who has used Lisp, Smalltalk, Visual Basic, Python, R, or Scala knows what a "rapid and exploratory" development process is. You try out something, and you instantly see the result. For the first 20 years of Java's existence, development environments were not focused on that experience. It wasn't until Java 9 that the `jshell` tool supported rapid and exploratory programming.

1.2.9 High-Performance

> *While the performance of interpreted bytecodes is usually more than adequate, there are situations where higher performance is required. The bytecodes can be translated on the fly (at runtime) into machine code for the particular CPU the application is running on.*

In the early years of Java, many users disagreed with the statement that the performance was "more than adequate." Today, however, the just-in-time compilers have become so good that they are competitive with traditional compilers and, in some cases, even outperform them because they have more information available. For example, a just-in-time compiler can monitor which code is executed frequently and optimize just that code for speed. A more sophisticated optimization is the elimination (or “inlining”) of function calls. The just-in-time compiler knows which classes have been loaded. It can use inlining when, based upon the currently loaded collection of classes, a particular function is never overridden, and it can undo that optimization later if necessary.

1.2.10 Multithreaded

> *[The] benefits of multithreading are better interactive responsiveness and real-time behavior.*

Nowadays, we care about concurrency because Moore’s law has come to an end. Instead of faster processors, we just get more of them, and we have to keep them busy. Yet when you look at most programming languages, they show a shocking disregard for this problem.

Java was well ahead of its time. It was the first mainstream language to support concurrent programming. As you can see from the white paper, its motivation was a little different. At the time, multicore processors were exotic, but web programming had just started, and processors spent a lot of time waiting for a response from the server. Concurrent programming was needed to make sure the user interface didn’t freeze.

Concurrent programming is never easy, but Java has done a very good job making it manageable.

1.2.11 Dynamic

> *In a number of ways, Java is a more dynamic language than C or C++. It was designed to adapt to an evolving environment. Libraries can freely add new methods and instance variables without any effect on their clients. In Java, finding out runtime type information is straightforward.*

This is an important feature in situations where code needs to be added to a running program. A prime example is code that is downloaded from the

Internet to run in a browser. In C or C++, this is indeed a major challenge, but the Java designers were well aware of dynamic languages that made it easy to evolve a running program. Their achievement was to bring this feature to a mainstream programming language.

NOTE:

Shortly after the initial success of Java, Microsoft released a product called J++ with a programming language and virtual machine that were almost identical to Java. This effort failed to gain traction, and Microsoft followed through with another language called C# that also has many similarities to Java but runs on a different virtual machine. This book does not cover J++ or C#.

1.3 Java Applets and the Internet

The idea here is simple: Users will download Java bytecodes from the Internet and run them on their own machines. Java programs that work on web pages are called *applets*. To use an applet, you only need a Java-enabled web browser, which will execute the bytecodes for you. You need not install any software. You get the latest version of the program whenever you visit the web page containing the applet. Most importantly, thanks to the security of the virtual machine, you never need to worry about attacks from hostile code.

Inserting an applet into a web page works much like embedding an image. The applet becomes a part of the page, and the text flows around the space used for the applet. The point is, this image is *alive*. It reacts to user commands, changes its appearance, and exchanges data between the computer presenting the applet and the computer serving it.

Figure 1.1 shows the Jmol applet that displays molecular structures. By using the mouse, you can rotate and zoom each molecule to better understand its structure. At the time that applets were invented, this kind of direct manipulation was not achievable with web pages—there was only rudimentary JavaScript and no HTML canvas.

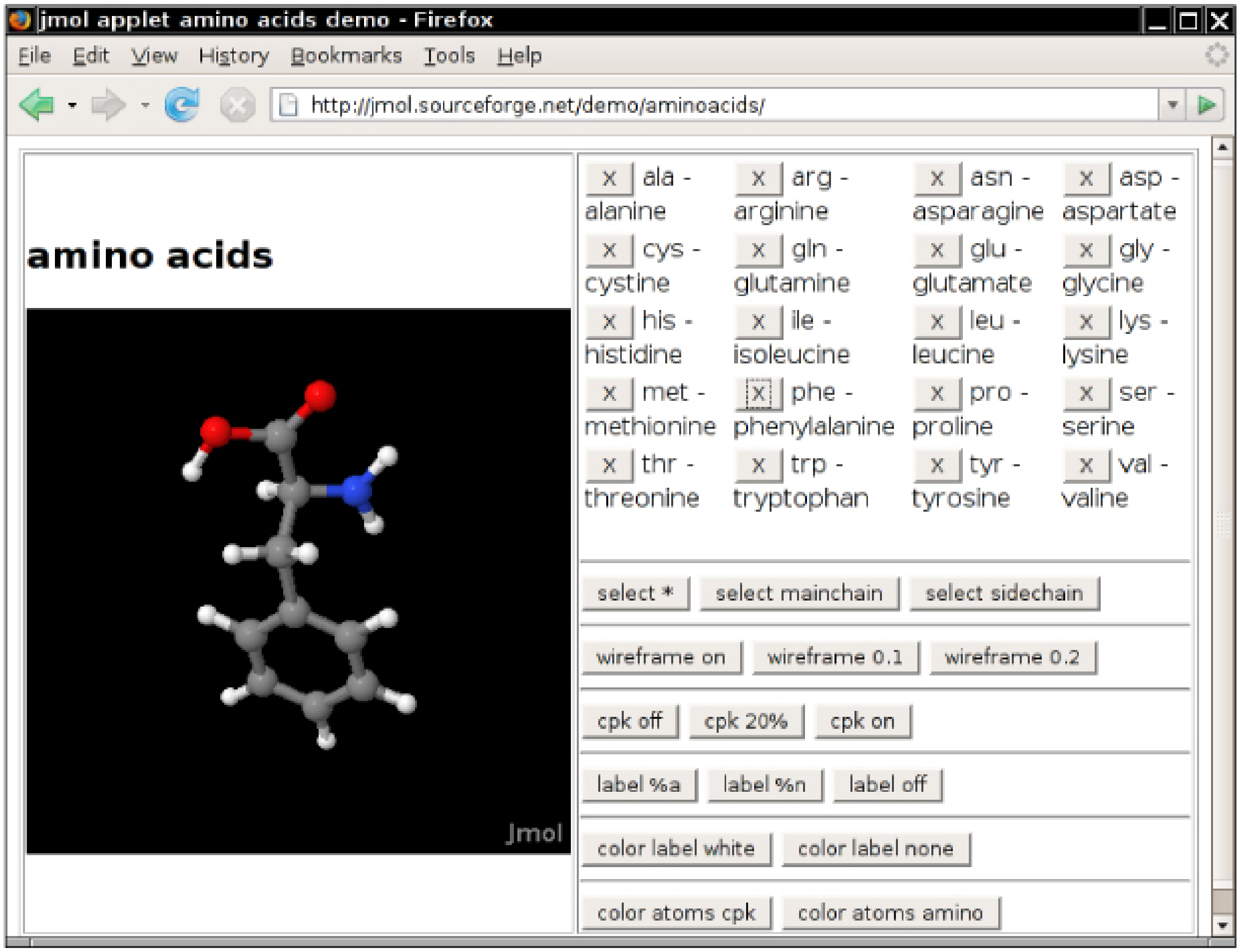


Figure 1.1 The Jmol applet

When applets first appeared, they created a huge amount of excitement. Many people believe that the lure of applets was responsible for the astonishing popularity of Java. However, the initial excitement soon turned into frustration. Various versions of the Netscape and Internet Explorer browsers ran different versions of Java, some of which were seriously outdated. This sorry situation made it increasingly difficult to develop applets that took advantage of the most current Java version. Instead, Adobe's Flash technology became popular for achieving dynamic effects in the browser. Later, when Java was dogged by serious security issues, browsers dropped applet support altogether. Of course, Flash fared no better.

1.4 A Short History of Java

This section gives a short history of Java's evolution. It is based on various published sources (most importantly an interview with Java's creators in the July 1995 issue of *SunWorld*'s online magazine).

Java goes back to 1991, when a group of Sun engineers, led by Patrick Naughton and James Gosling (a Sun Fellow and an all-around computer wizard), wanted to design a small computer language that could be used for consumer devices like cable TV switchboxes. Since these devices do not have a lot of power or memory, the language had to be small and generate very tight code. Also, as different manufacturers may choose different central processing units (CPUs), it was important that the language not be tied to any single architecture. The project was code-named "Green."

The requirements for small, tight, and platform-neutral code led the team to design a portable language that generated intermediate code for a virtual machine.

The Sun people came from a UNIX background, so they based their language on C++ rather than Lisp, Smalltalk, or Pascal. But, as Gosling says in the interview, "All along, the language was a tool, not the end." Gosling decided to call his language "Oak" (presumably because he liked the look of an oak tree that was right outside his window at Sun). The people at Sun later realized that Oak was the name of an existing computer language, so they changed the name to Java. This turned out to be an inspired choice.

In 1992, the Green project delivered its first product, called "*7." It was an extremely intelligent remote control. Unfortunately, no one was interested in producing this at Sun, and the Green people had to find other ways to market their technology. However, none of the standard consumer electronics companies were interested either. The group then bid on a project to design a cable TV box that could deal with emerging cable services such as video-on-demand. They did not get the contract. (Amusingly, the company that did was led by the same Jim Clark who started Netscape—a company that did much to make Java successful.)

The Green project (with a new name of “First Person, Inc.”) spent all of 1993 and half of 1994 looking for people to buy its technology. No one was found. (Patrick Naughton, one of the founders of the group and the person who ended up doing most of the marketing, claims to have accumulated 300,000 air miles in trying to sell the technology.) First Person was dissolved in 1994.

While all of this was going on at Sun, the World Wide Web part of the Internet was growing bigger and bigger. The key to the World Wide Web was the browser translating hypertext pages to the screen. In 1994, most people were using Mosaic, a noncommercial web browser that came out of the supercomputing center at the University of Illinois in 1993. (Mosaic was partially written by Marc Andreessen as an undergraduate student on a work-study project, for $6.85 an hour. He moved on to fame and fortune as one of the cofounders and the chief of technology at Netscape.)

In the *SunWorld* interview, Gosling says that in mid-1994, the language developers realized that “We could build a real cool browser. It was one of the few things in the client/server mainstream that needed some of the weird things we’d done: architecture-neutral, real-time, reliable, secure—issues that weren’t terribly important in the workstation world. So we built a browser.”

The actual browser was built by Patrick Naughton and Jonathan Payne and evolved into the HotJava browser, which was designed to show off the power of Java. The browser was capable of executing Java code inside web pages. This “proof of technology” was shown at SunWorld ’95 on May 23, 1995, and inspired the Java craze that continues today.

Sun released the first version of Java in early 1996. People quickly realized that Java 1.0 was not going to cut it for serious application development. Sure, you could use Java 1.0 to make a nervous text applet that moved text randomly around in a canvas. But you couldn’t even *print* in Java 1.0. To be blunt, Java 1.0 was not ready for prime time. Its successor, version 1.1, filled in the most obvious gaps, greatly improved the reflection capability, and added a new event model for GUI programming. It was still rather limited, though.

The big news of the 1998 JavaOne conference was the upcoming release of Java 1.2, which replaced the early toylike GUI and graphics toolkits with sophisticated scalable versions. Three days (!) after its release in December 1998, Sun's marketing department changed the name to the catchy *Java 2 Standard Edition Software Development Kit Version 1.2*.

Besides the Standard Edition, two other editions were introduced: the Micro Edition for embedded devices such as cell phones, and the Enterprise Edition for server-side processing. This book focuses on the Standard Edition.

Versions 1.3 and 1.4 of the Standard Edition were incremental improvements over the initial Java 2 release, with an ever-growing standard library, increased performance, and, of course, quite a few bug fixes. During this time, much of the initial hype about Java applets and client-side applications abated, but Java became the platform of choice for server-side applications.

Version 5.0 was the first release since version 1.1 that updated the Java *language* in significant ways. (This version was originally numbered 1.5, but the version number jumped to 5.0 at the 2004 JavaOne conference.) After many years of research, generic types (roughly comparable to C++ templates) have been added—the challenge was to add this feature without requiring changes in the virtual machine. Several other useful language features were inspired by C#: a "for each" loop, autoboxing, and annotations.

Version 6 (without the .0 suffix) was released at the end of 2006. Again, there were no language changes but additional performance improvements and library enhancements.

As datacenters increasingly relied on commodity hardware instead of specialized servers, Sun Microsystems fell on hard times and was purchased by Oracle in 2009. Development of Java stalled for a long time. In 2011, Oracle released a new version, with simple enhancements, as Java 7.

In 2014, the release of Java 8 followed, with the most significant changes to the Java language in almost two decades. Java 8 embraces a "functional" style of programming that makes it easy to express computations that can be executed concurrently. All programming languages must evolve to stay relevant, and Java has shown a remarkable capacity to do so.

The main feature of Java 9 goes all the way back to 2008. At that time, Mark Reinhold, the chief engineer of the Java platform, started an effort to break up the huge, monolithic Java platform. This was to be achieved by introducing *modules*, self-contained units of code that provide a specific functionality. It took eleven years to design and implement a module system that is a good fit for the Java platform, and it remains to be seen whether it is also a good fit for Java applications and libraries. Java 9, released in 2017, has other appealing features that are covered in this book.

Starting in 2018, Java versions are released every six months, to enable faster introduction of features. Ever so often, a version—so far Java 11 and Java 17— is designated as a long-term support version. Intermediate versions provide a mechanism for trying out experimental features.

Table 1.1 shows the evolution of the Java language and library. As you can see, the size of the application programming interface (API) has grown tremendously.

Table 1.1 Evolution of the Java Language

Version	Year	New Language Features	Number of Classes and Interfaces
1.0	1996	The language itself	211
1.1	1997	Inner classes	477
1.2	1998	The `strictfp` modifier	1,524
1.3	2000	None	1,840
1.4	2002	Assertions	2,723
5.0	2004	Generic classes, "for each" loop, varargs, autoboxing, metadata, enumerations, static import	3,279
6	2006	None	3,793
7	2011	Switch with strings, diamond operator, binary literals, exception handling enhancements	4,024
8	2014	Lambda expressions, interfaces with default methods, stream and date/time libraries	4,240
9	2017	Modules, miscellaneous language and library enhancements	6,005
11	2018	Local variable type inference (`var`), HTTP client, removal of Java FX, JNLP, Java EE overlap, and CORBA	4410
17	2021	Switch expressions, text blocks, `instanceof` pattern matching, records, sealed classes	4859

1.5 Common Misconceptions about Java

This chapter closes with a commented list of some common misconceptions about Java.

Java is an extension of HTML.

Java is a programming language; HTML is a way to describe the structure of a web page. They have nothing in common except that there once were HTML extensions for placing Java applets on a web page.

I use XML, so I don't need Java.

Java is a programming language; XML is a way to describe data. You can process XML data with any programming language, but the Java API contains excellent support for XML processing. In addition, many important XML tools are implemented in Java. See Volume II for more information.

Java is an easy programming language to learn.

No programming language as powerful as Java is easy. You always have to distinguish between how easy it is to write toy programs and how hard it is to do serious work. Also, consider that only seven chapters in this book discuss the Java language. The remaining chapters of both volumes show how to put the language to work, using the Java *libraries*. The Java libraries contain thousands of classes and interfaces and tens of thousands of functions. Luckily, you do not need to know every one of them, but you do need to know surprisingly many to use Java for anything realistic.

Java will become a universal programming language for all platforms.

This is possible in theory. But in practice, there are domains where other languages are entrenched. Objective C and its successor, Swift, are not going to be replaced on iOS devices. Anything that happens in a browser is controlled by JavaScript. Windows programs are written in C++ or C#. Java has the edge in server-side programming and in cross-platform client applications.

Java is just another programming language.

Java is a nice programming language; most programmers prefer it to C, C++, or C#. But there have been hundreds of nice programming languages that never gained widespread popularity, whereas languages with obvious flaws, such as C++ and Visual Basic, have been wildly successful.

Why? The success of a programming language is determined far more by the utility of the *support system* surrounding it than by the elegance of its syntax. Are there useful, convenient, and standard libraries for the features that you need to implement? Are there tool vendors that build great programming and debugging environments? Do the language and the toolset integrate with the rest of the computing infrastructure? Java is successful because its libraries let you easily do things such as networking, web applications, and concurrency. The fact that Java reduces pointer errors is a bonus, so programmers seem to be more productive with Java—but these factors are not the source of its success.

Java is proprietary, and should therefore be avoided.

When Java was first created, Sun Microsystems gave free licenses to distributors and end users. Although Sun had ultimate control over Java, they involved many other companies in the development of language revisions and the design of new libraries. Source code for the virtual machine and the libraries has always been freely available, but only for inspection, not for modification and redistribution. Java was "closed source, but playing nice."

This situation changed dramatically in 2007, when Sun announced that future versions of Java would be available under the General Public License (GPL), the same open source license that is used by Linux. Oracle has committed to keeping Java open source. There are now multiple providers of open Java implementations, with various levels of commitment and support.

Java is interpreted, so it is too slow for serious applications.

In the early days of Java, the language was interpreted. Nowadays, the Java virtual machine uses a just-in-time compiler. The "hot spots" of your code will run just as fast in Java as they would in C++, and in some cases even faster.

All Java programs run inside a web page.

There was a time when Java *applets* ran inside a web browser. Nowadays, Java programs are stand-alone applications that run outside of a web browser. In fact, most Java programs run on servers, producing code for web pages or computing business logic.

Java programs are a major security risk.

In the early days of Java, there were some well-publicized reports of failures in the Java security system. Researchers viewed it as a challenge to find chinks in the Java armor and to defy the strength and sophistication of the applet security model. The technical failures that they found had been quickly corrected. Later, there were more serious exploits, to which Sun, and later Oracle, responded slowly. Browser manufacturers discontinued support for Java applets. The security manager architecture that made applets possible is now deprecated. These days, Java applications are no less secure than other applications. Due to the protections of the virtual machine, they are far more secure than applications written in C or C++.

JavaScript is a simpler version of Java.

JavaScript, a scripting language that can be used inside web pages, was invented by Netscape and originally called LiveScript. JavaScript has a syntax that is reminiscent of Java, and the languages' names sound similar, but otherwise they are unrelated. In particularly, Java is *strongly typed*—the compiler catches many errors that arise from type misuse. In JavaScript, such errors are only found when the program runs, which makes their elimination far more laborious.

With Java, I can replace my desktop computer with a cheap "Internet appliance."

When Java was first released, some people bet big that this was going to happen. Companies produced prototypes of Java-powered network computers, but users were not ready to give up a powerful and convenient desktop for a limited machine with no local storage. Nowadays, of course, the world has changed, and for a large majority of end users, the platform that matters is a mobile phone or tablet. The majority of these devices are controlled by the Android platform. Learning Java programming will help you with Android programming as well.

Chapter 2. The Java Programming Environment

In this chapter

In this chapter, you will learn how to install the Java Development Kit (JDK) and how to compile and run Java programs. You can run the JDK tools by typing commands in a terminal window. However, many programmers prefer the comfort of an integrated development environment. You will learn how to use a freely available development environment to compile and run Java programs. Once you have mastered the techniques in this chapter and picked your development tools, you are ready to move on to Chapter 3, where you will begin exploring the Java programming language.

2.1 Installing the Java Development Kit

In days past, the most complete and up-to-date versions of the Java Development Kit (JDK) was available from Oracle. Nowadays many different companies, including Microsoft, Amazon, Red Hat, and Azul, provide up-to-date OpenJDK builds, some with better licensing conditions than Oracle. As I write this chapter, my favorite site is `https://adoptium.net`, run by a community of vendors, developers, and user groups. They provide free builds for Linux, Mac OS, and Windows.

2.1.1 Downloading the JDK

You can download the Java Development Kit from `https://adoptium.net`, or from Oracle at `www.oracle.com/technetwork/java/javase/downloads`, or from another provider. You should use the Java SE 17 (LTS) JDK. See Table 2.1 for a summary of the acronyms and jargon that you may encounter on the download site.

Table 2.1 Java Jargon

Name	Acronym	Explanation
Java Development Kit	JDK	The software for programmers who want to write Java programs
Java Runtime Environment	JRE	The software for running Java programs, without development tools. You do not want that.
Standard Edition	SE	The Java platform for use on desktops and simple server applications. You want that.
Micro Edition	ME	The Java platform for use on small devices.
OpenJDK	—	A free and open source implementation of Java SE.
Hotspot	—	The "just in time" compiler developed by Oracle. If asked, choose this one.
OpenJ9	—	Another "just in time" compiler developed by IBM.
Long Term Support	LTS	A release that is supported for multiple years, unlike the six-month releases that showcase new features. Choose the latest LTS release.

2.1.2 Setting up the JDK

After downloading the JDK, you need to install it and figure out where it was installed—you'll need that information later.

- Under Windows, launch the setup program. You will be asked where to install the JDK. It is best not to accept a default location with spaces in the path name, such as `c:\Program Files\Java\jdk-17.0.`*x*. Just take out the `Program Files` part of the path name.

- On the Mac, run the installer. It installs the software into `/Library/Java/JavaVirtualMachines/jdk-17.0.`*x*`.jdk/Contents/Home`. Locate it with the Finder.
- On Linux, simply uncompress the `.tar.gz` file to a location of your choice, such as your home directory or `/opt`. Or, if you installed from the RPM file, double-check that it is installed in `/usr/java/jdk-17.0.`*x*.

In this book, the installation directory is denoted as *jdk*. For example, when referring to the *jdk*`/bin` directory, I mean the directory with a name such as `/opt/jdk-17.0.4/bin` or `c:\Java\jdk-17.0.4\bin`.

Here is how you test whether you did it right. Start a terminal window. Type the line

```
javac --version
```

and press the Enter key. You should get a display such as this one:

```
javac 17.0.4
```

If instead you get a message such as "javac: command not found" or "The name specified is not recognized as an internal or external command, operable program or batch file," then you need to double-check your installation.

When you install the JDK on Windows or Linux, you may need to carry out one additional step: Add the *jdk*`/bin` directory to the executable path—the list of directories that the operating system traverses to locate executable files.

- On Linux, add a line such as the following to the end of your `~/.bashrc` or `~/.bash_profile` file:

```
export PATH=jdk/bin:$PATH
```

Be sure to use the correct path to the JDK, such as `/opt/jdk-17.0.4`.

- Under Windows 10, type "environment" into the search bar of the Windows Settings, and select "Edit environment variables for your account" (see Figure 2.1). An Environment Variables dialog should appear. (It may hide performance>behind the Windows Settings dialog. If you can't find it anywhere, try running `sysdm.cpl` from the Run dialog that you get by holding down the Windows and R key at the same time, and then select the Advanced tab and click the Environment Variables button.) Locate and select a variable named `Path` in the User Variables list. Click the Edit button, then the New button, and add an entry with the *jdk*`\bin` directory (see Figure 2.2).

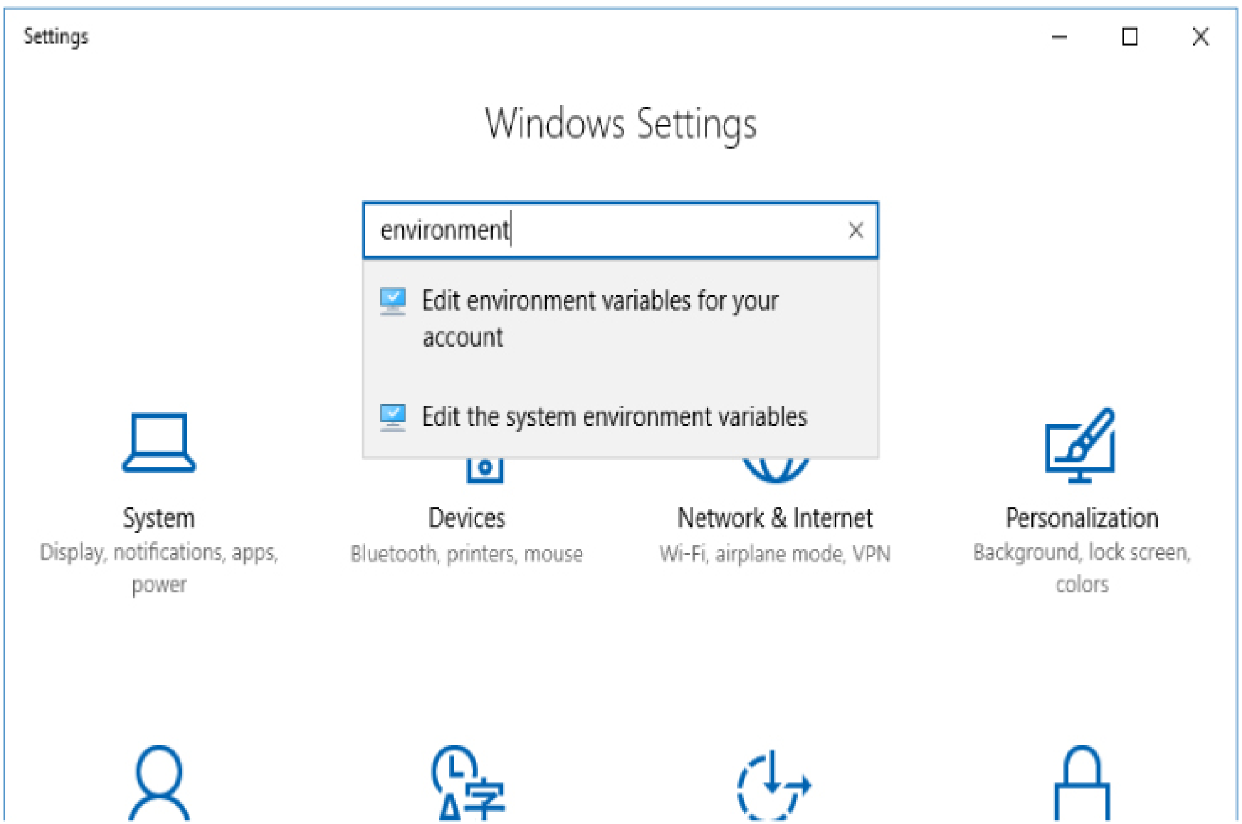


Figure 2.1 Setting system properties in Windows

Save your settings. Any new "Command Prompt" windows that you start will have the correct path.

2.1.3 Installing Source Files and Documentation

The library source files are delivered in the JDK as a compressed file `lib/src.zip`. Unpack that file to get access to the source code. Simply do the following:

1. Make sure the JDK is installed and the *jdk*`/bin` directory is on the executable path.
2. Make a directory `javasrc` in your home directory. If you like, you can do this from a terminal window.

   ```
   mkdir javasrc
   ```

3. Inside the *jdk*`/lib` directory, locate the file `src.zip`. 4. Unzip the `src.zip` file into the `javasrc` directory. In a terminal window, you can execute the commands

   ```
   cd javasrc
   jar xvf jdk/lib/src.zip
   cd ..
   ```

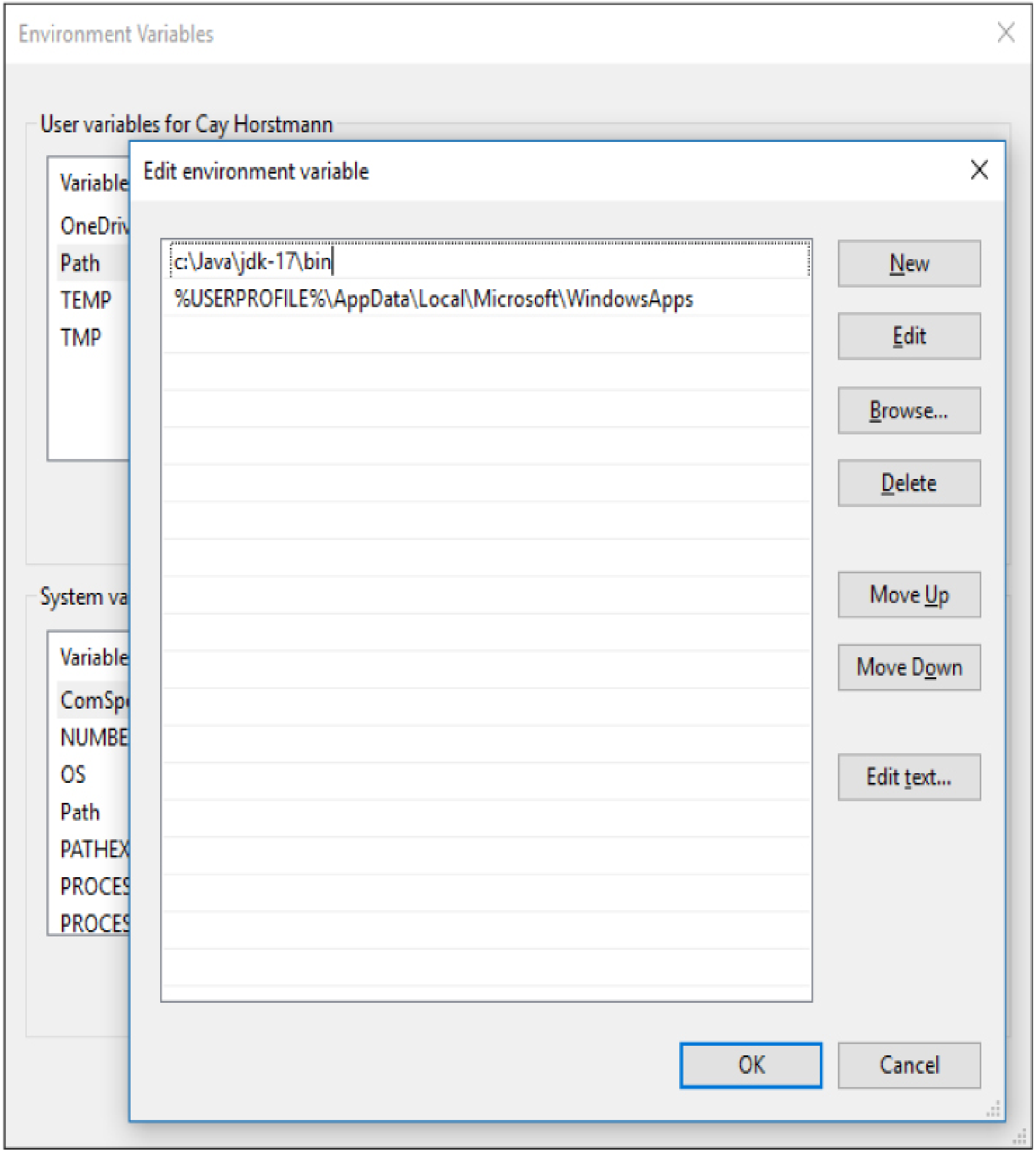


Figure 2.2 Setting the `Path` environment variable in Windows

✔ **TIP:**

The `src.zip` file contains the source code for all public libraries. To obtain even more source (for the compiler, the virtual machine, the native methods, and the private helper classes), go to `http://openjdk.java.net`.

The documentation is contained in a compressed file that is separate from the JDK. You can download the documentation from `www.oracle.com/technetwork/java/javase/downloads`. Follow these steps:

1. Download the documentation zip file. It is called `jdk-17.0.`*x*`_doc-all.zip`.
2. Unzip the file and rename the `doc` directory into something more descriptive, like `javadoc`. If you like, you can do this from the command line:

   ```
   jar xvf Downloads/jdk-17.0.x_doc-all.zip
   mv docs jdk-17-docs
   ```

3. In your browser, navigate to `jdk-17-docs/index.html` and add this page to your bookmarks.

You should also install the *Core Java* program examples. You can download them from `http://horstmann.com/corejava`. The programs are packaged into a zip file `corejava.zip`. Just unzip them into your home directory. They will be located in a directory `corejava`. If you like, you can do this from the command line:

```
jar xvf Downloads/corejava.zip
```

2.2 Using the Command-Line Tools

If your programming experience comes from a development environment such as Microsoft Visual Studio, you are accustomed to a system with a builtin text editor, menus to compile and launch a program, and a debugger. The JDK contains nothing even remotely similar. You do *everything* by typing in commands in a terminal window. This may sound cumbersome, but it is nevertheless an essential skill. When you first install Java, you will want to troubleshoot your installation before you install a development environment. Moreover, by executing the basic steps yourself, you gain a better understanding of what a development environment does behind your back.

However, after you have mastered the basic steps of compiling and running Java programs, you will want to use a professional development environment. You will see how to do that in the following section.

Let's get started the hard way: compiling and launching a Java program from the command line.

1. Open a terminal window.
2. Go to the `corejava/v1ch02/Welcome` directory. (The `corejava` directory is where you installed the source code for the book examples, as explained in Section 2.1.3, "Installing Source Files and Documentation," on p. 20.)
3. Enter the following commands:

   ```
   javac Welcome.java
   java Welcome
   ```

   You should see the output shown in Figure 2.3 in the terminal window.

Congratulations! You have just compiled and run your first Java program.

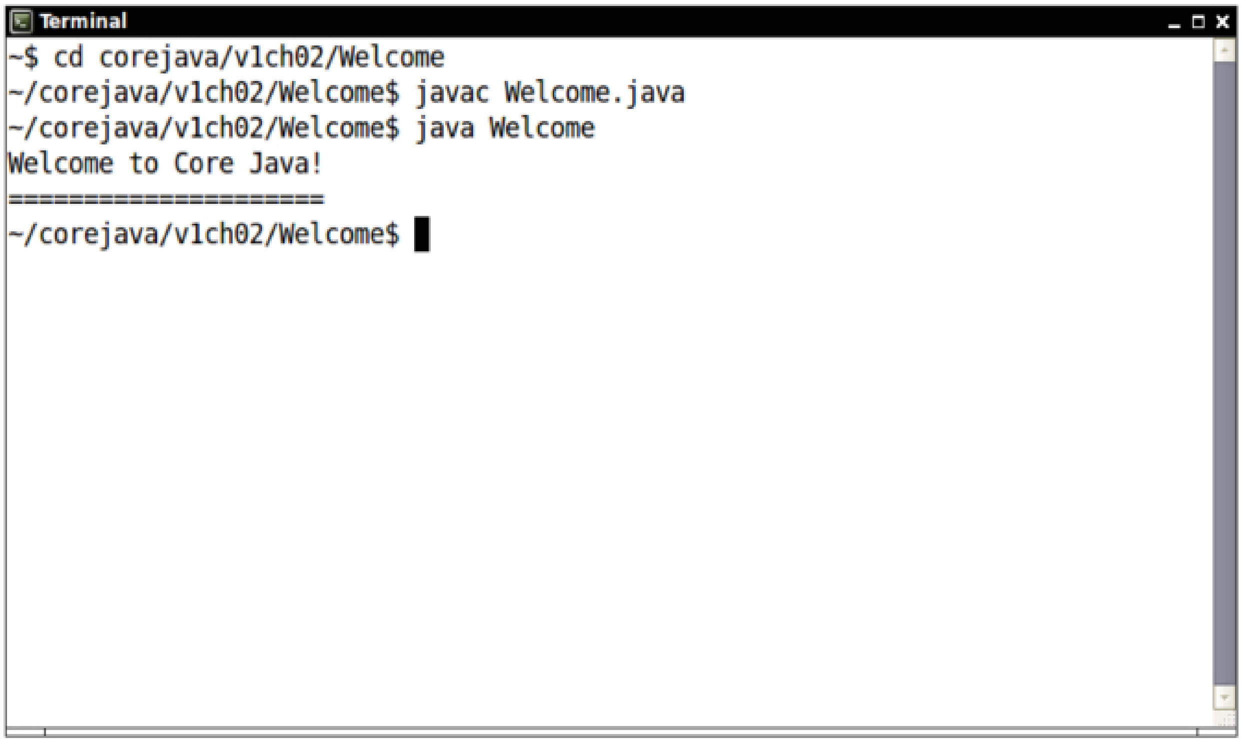


Figure 2.3 Compiling and running `Welcome.java`

What happened? The `javac` program is the Java compiler. It compiles the file

`Welcome.java` into the file `Welcome.class`. The `java` program launches the Java virtual machine. It executes the bytecodes that the compiler placed in the class file.

The `Welcome` program is extremely simple. It merely prints a message to the terminal. You may enjoy looking inside the program, shown in Listing 2.1. You will see how it works in the next chapter.

Listing 2.1 `Welcome/Welcome.java`

```
/**
 * This program displays a greeting for the reader.
 * @version 1.30 2014-02-27
 * @author Cay Horstmann
 */
public class Welcome
{
```

```
   public static void main(String[] args)
   {
      String greeting = "Welcome to Core Java!";
      System.out.println(greeting);
      for (int i = 0; i < greeting.length(); i++)
         System.out.print("=");
      System.out.println();
   }
}
```

In the age of integrated development environments, many programmers are unfamiliar with running programs in a terminal window. Any number of things can go wrong, leading to frustrating results.

Pay attention to the following points:

- If you type in the program by hand, make sure you correctly enter the uppercase and lowercase letters. In particular, the class name is `Welcome` and not `welcome` or `WELCOME`.
- The compiler requires a *file name* (`Welcome.java`). When you run the program, you specify a *class name* (`Welcome`) without a `.java` or `.class` extension.
- If you get a message such as “Bad command or file name” or “javac: command not found”, go back and double-check your installation, in particular the executable path setting.
- If `javac` reports that it cannot find the file `Welcome.java`, you should check whether that file is present in the directory.

  Under Linux, check that you used the correct capitalization for `Welcome.java`.

  Under Windows, use the `dir` command, *not* the graphical Explorer tool. Some text editors (in particular Notepad) insist on adding an extension `.txt` to every file’s name. If you use Notepad to edit `Welcome.java`, it will actually save it as `Welcome.java.txt`. Under the default Windows settings, Explorer conspires with Notepad and hides the `.txt` extension because it belongs to a “known file type.” In that case, you need to rename the file, using the `ren` command, or save it again, placing quotes around the file name: `"Welcome.java"`.

- If you launch your program and get an error message complaining about a `java.lang.NoClassDefFoundError`, then carefully check the name of the offending class.

  If you get a complaint about `welcome` (with a lowercase `w`), then you should reissue the `java Welcome` command with an uppercase `W`. As always, case matters in Java.

  If you get a complaint about `Welcome/java`, it means you accidentally typed `java Welcome.java`. Reissue the command as `java Welcome`.

- If you typed `java Welcome` and the virtual machine can't find the `Welcome` class, check if someone has set the `CLASSPATH` environment variable on your system. It is not a good idea to set this variable globally, but some poorly written software installers in Windows do just that. Follow the same procedure as for setting the `PATH` environment variable, but this time, remove the setting.

TIP:

The excellent tutorial at http://docs.oracle.com/javase/tutorial/getStarted/cupojava goes into much greater detail about the "gotchas" that beginners can run into.

NOTE:

You can skip the `javac` command if you have a single source file. This feature is intended for shell scripts (starting with a "shebang" line `#!/path/to/java`) and perhaps for simple student programs. Once your programs get more complex, you need to use `javac`.

The `Welcome` program was not terribly exciting. Next, try out a graphical application. This program is a simple image file viewer that loads and displays an image. As before, compile and run the program from the command line.

1. Open a terminal window.
2. Change to the directory `corejava/v1ch02/ImageViewer`.
3. Enter the following:

```
javac ImageViewer.java
java ImageViewer
```

A new program window pops up with the ImageViewer application. Now, select File → Open and look for an image file to open. (There are a couple of sample files in the same directory.) The image is displayed (see Figure 2.4). To close the program, click on the Close box in the title bar or select File → Exit from the menu.

Figure 2.4 Running the ImageViewer application

Have a quick look at the source code (Listing 2.2). The program is substantially longer than the first program, but it is not too complex if you consider how much code it would take in C or C++ to write a similar application. Of course, nowadays it is not common to write desktop applications with graphical user interfaces, but if you are interested, you can find more details in Chapter 10.

Listing 2.2 `ImageViewer/ImageViewer.java`

```
import java.awt.*;
import java.io.*;
import javax.swing.*;

/**
 * A program for viewing images.
 * @version 1.31 2018-04-10
 * @author Cay Horstmann
 */
public class ImageViewer
{
   public static void main(String[] args)
   {
      EventQueue.invokeLater(() ->
         {
            var frame = new ImageViewerFrame();
            frame.setTitle("ImageViewer");
            frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
            frame.setVisible(true);
         });
   }
}

/**
 * A frame with a label to show an image.
 */
class ImageViewerFrame extends JFrame
{
   private static final int DEFAULT_WIDTH = 300;
   private static final int DEFAULT_HEIGHT = 400;

   public ImageViewerFrame()
   {
```

```java
      setSize(DEFAULT_WIDTH, DEFAULT_HEIGHT);

      // use a label to display the images
      var label = new JLabel();
      add(label);

      // set up the file chooser
      var chooser = new JFileChooser();
      chooser.setCurrentDirectory(new File("."));

      // set up the menu bar
      var menuBar = new JMenuBar();
      setJMenuBar(menuBar);

      var menu = new JMenu("File");
      menuBar.add(menu);

      var openItem = new JMenuItem("Open");
      menu.add(openItem);
      openItem.addActionListener(event ->
         {
            // show file chooser dialog
            int result = chooser.showOpenDialog(null);

            // if file selected, set it as icon of the label
            if (result == JFileChooser.APPROVE_OPTION)
            {
                String name = chooser.getSelectedFile().getPath();
                label.setIcon(new ImageIcon(name));
         }
      });

    var exitItem = new JMenuItem("Exit");
    menu.add(exitItem);
    exitItem.addActionListener(event -> System.exit(0));
  }
}
```

2.3 Using an Integrated Development Environment

In the preceding section, you saw how to compile and run a Java program from the command line. That is a useful skill for troubleshooting, but for most day-to-day work, you should use an integrated development environment. These environments are so powerful and convenient that it simply doesn't make much sense to labor on without them. Excellent choices are the freely available Eclipse, IntelliJ IDEA, and NetBeans. In this chapter, you will learn how to get started with Eclipse. Of course, if you prefer a different development environment, you can certainly use it with this book.

Get started by downloading Eclipse from `http://eclipse.org/downloads`. Versions exist for Linux, Mac OS X, and Windows. Run the installation program and pick the installation set called "Eclipse IDE for Java Developers".

Here are the steps to write a program with Eclipse.

1. After starting Eclipse, select File → New → Project from the menu.
2. Select "Java Project" from the wizard dialog (see Figure 2.5).

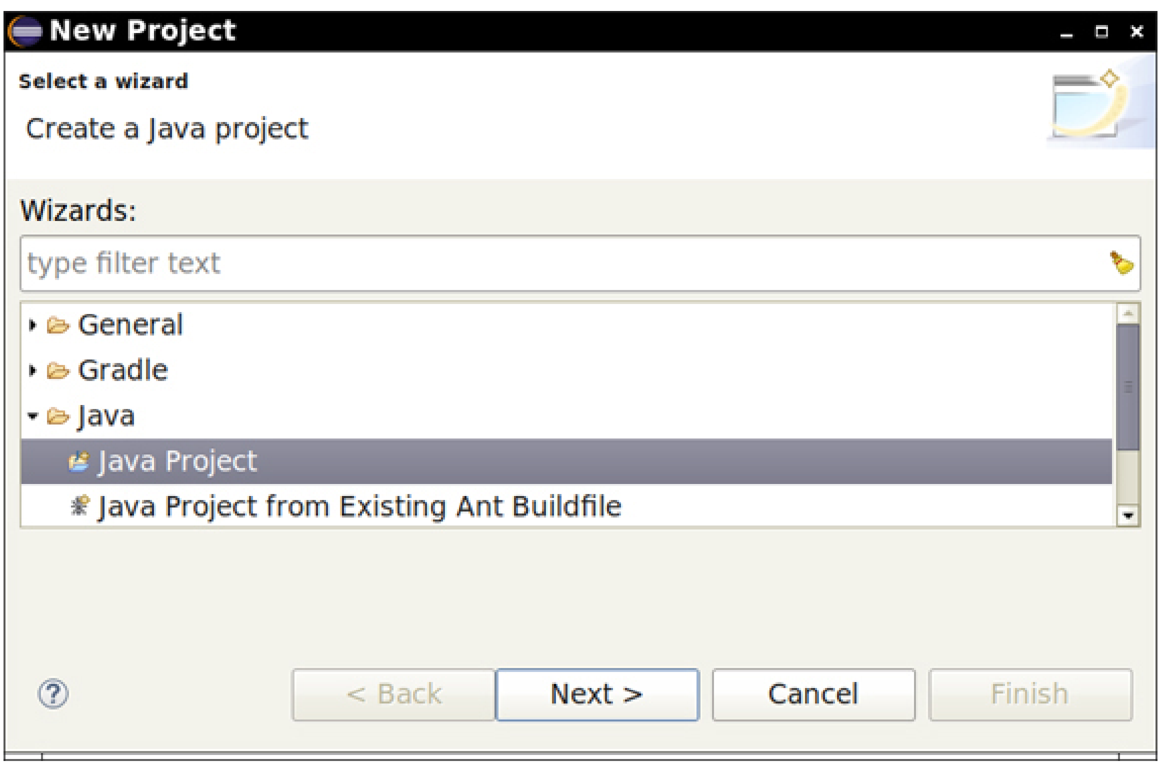


Figure 2.5 The New Project dialog in Eclipse

3. Click the Next button. *Uncheck* the "Use default location" checkbox. Click on Browse and navigate to the `corejava/v1ch02/Welcome` directory (Figure 2.6).

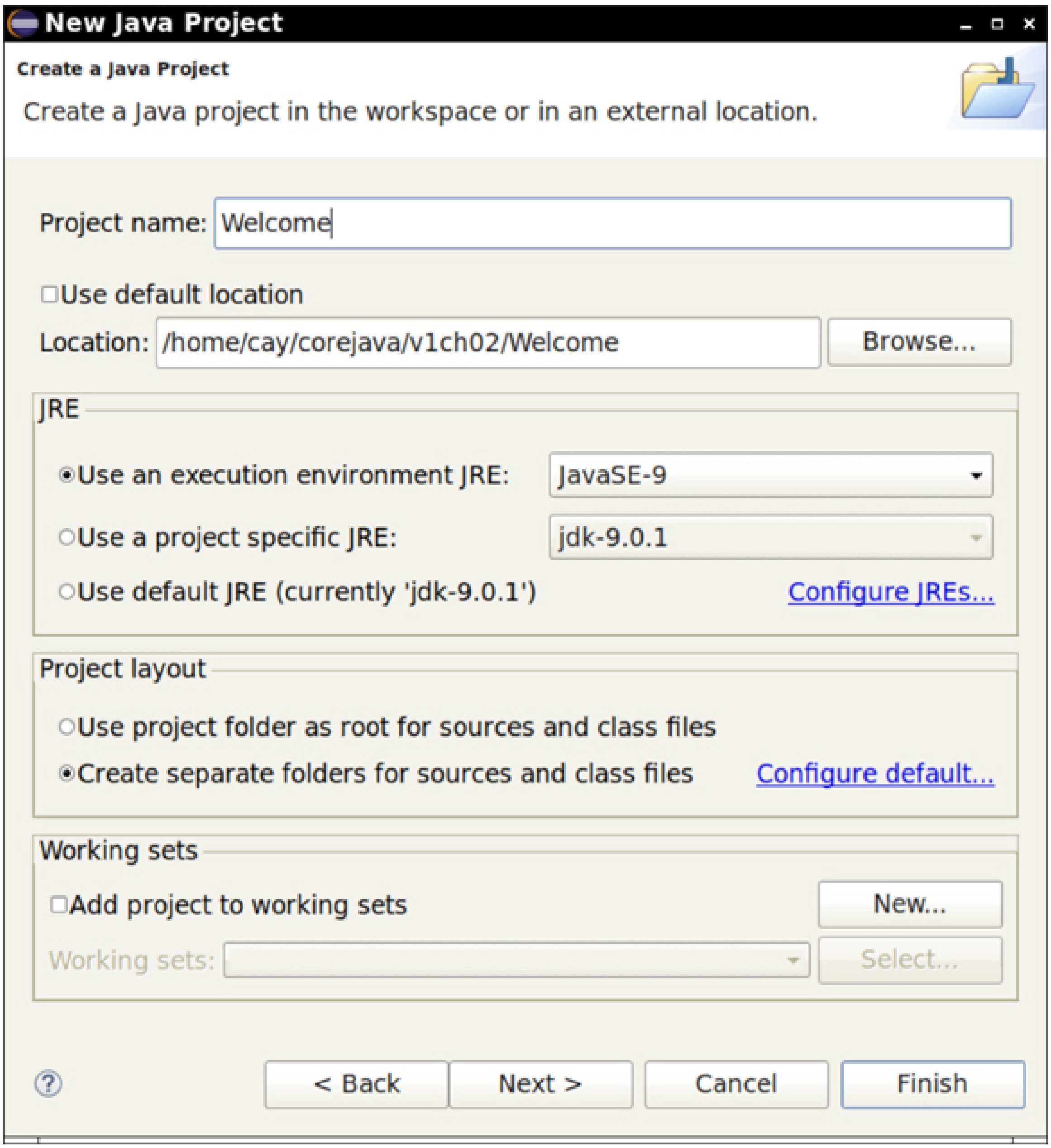


Figure 2.6 Configuring a project in Eclipse

4. Click the Finish button. The project is now created.

5. Click on the triangles in the left pane next to the project until you locate the file `Welcome.java`, and double-click on it. You should now see a pane with the program code (see Figure 2.7).

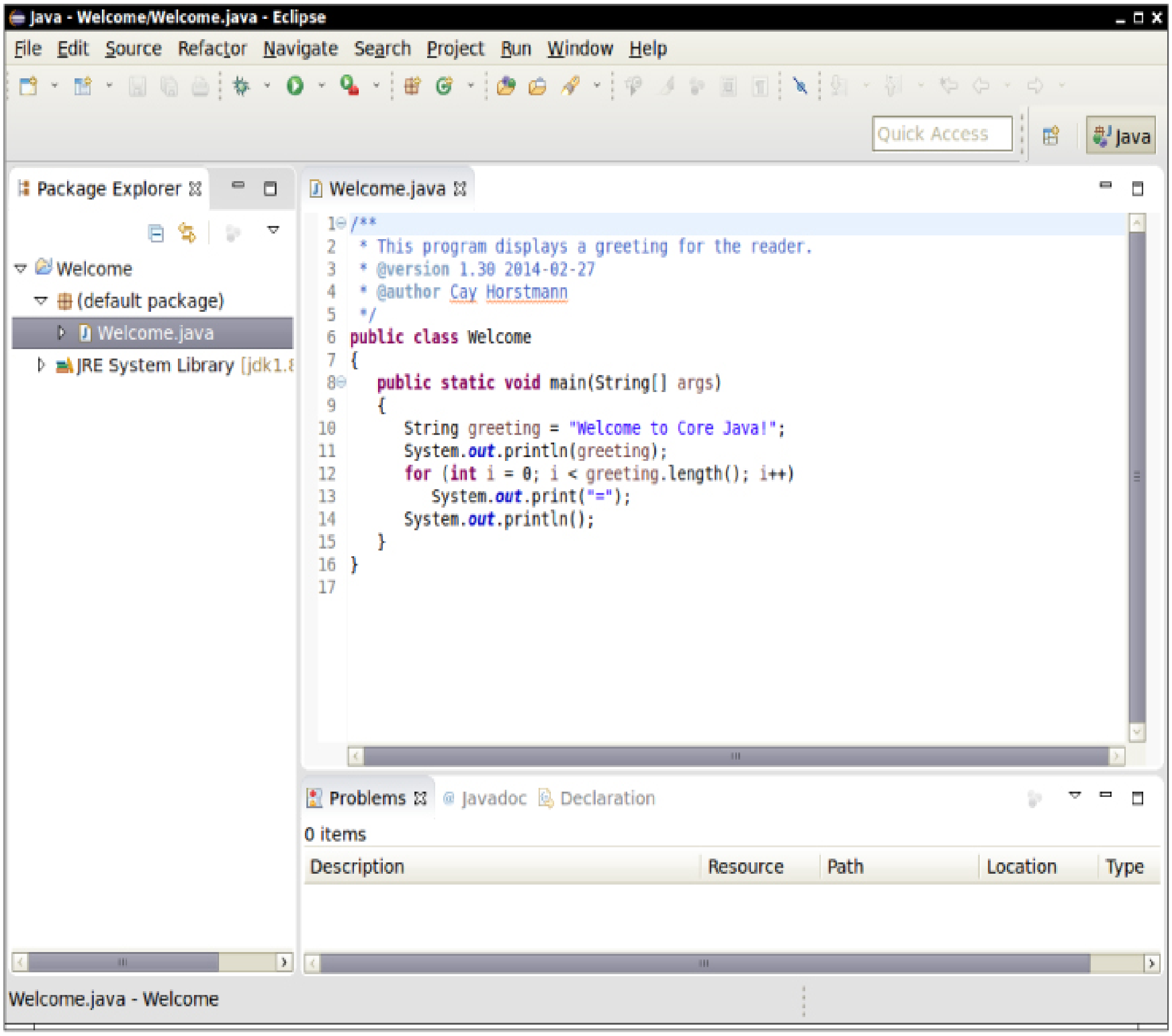


Figure 2.7 Editing a source file with Eclipse

6. With the right mouse button, click on the project name (Welcome) in the left pane. Select Run → Run As → Java Application. The program output is displayed in the console pane.

Presumably, this program does not have typos or bugs. (It was only a few lines of code, after all.) Let us suppose, for the sake of argument, that your code occasionally contains a typo (perhaps even a syntax error). Try it out.ruin your file, for example, by changing the capitalization of String as follows:

```
string greeting = "Welcome to Core Java!";
```

Note the wiggly line under `string`. In the tabs below the source code, click on Problems and expand the triangles until you see an error message that complains about an unknown `string` type (see Figure 2.8). Click on the error message. The cursor moves to the matching line in the edit pane, where you can correct your error. This allows you to fix your errors quickly.

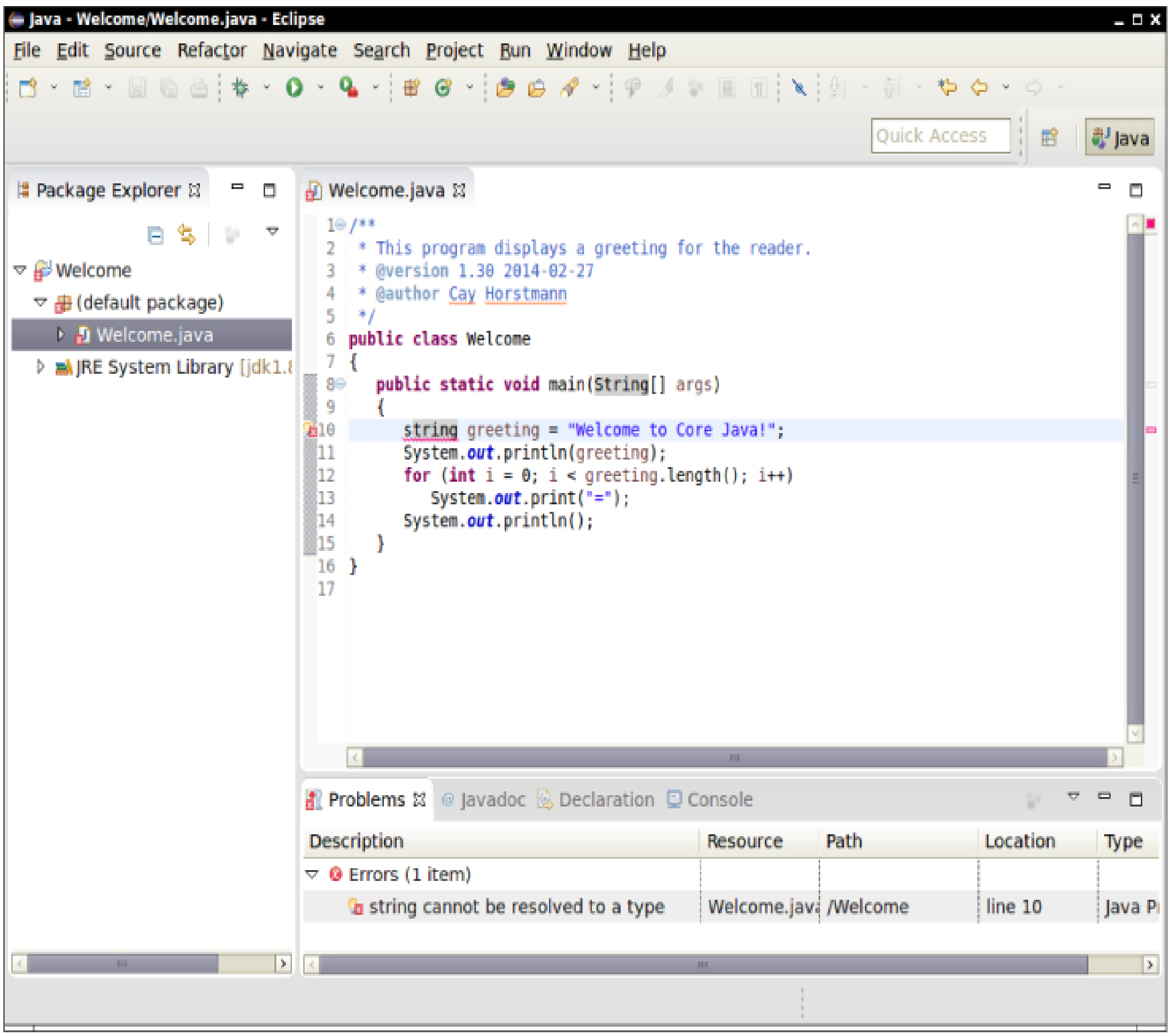


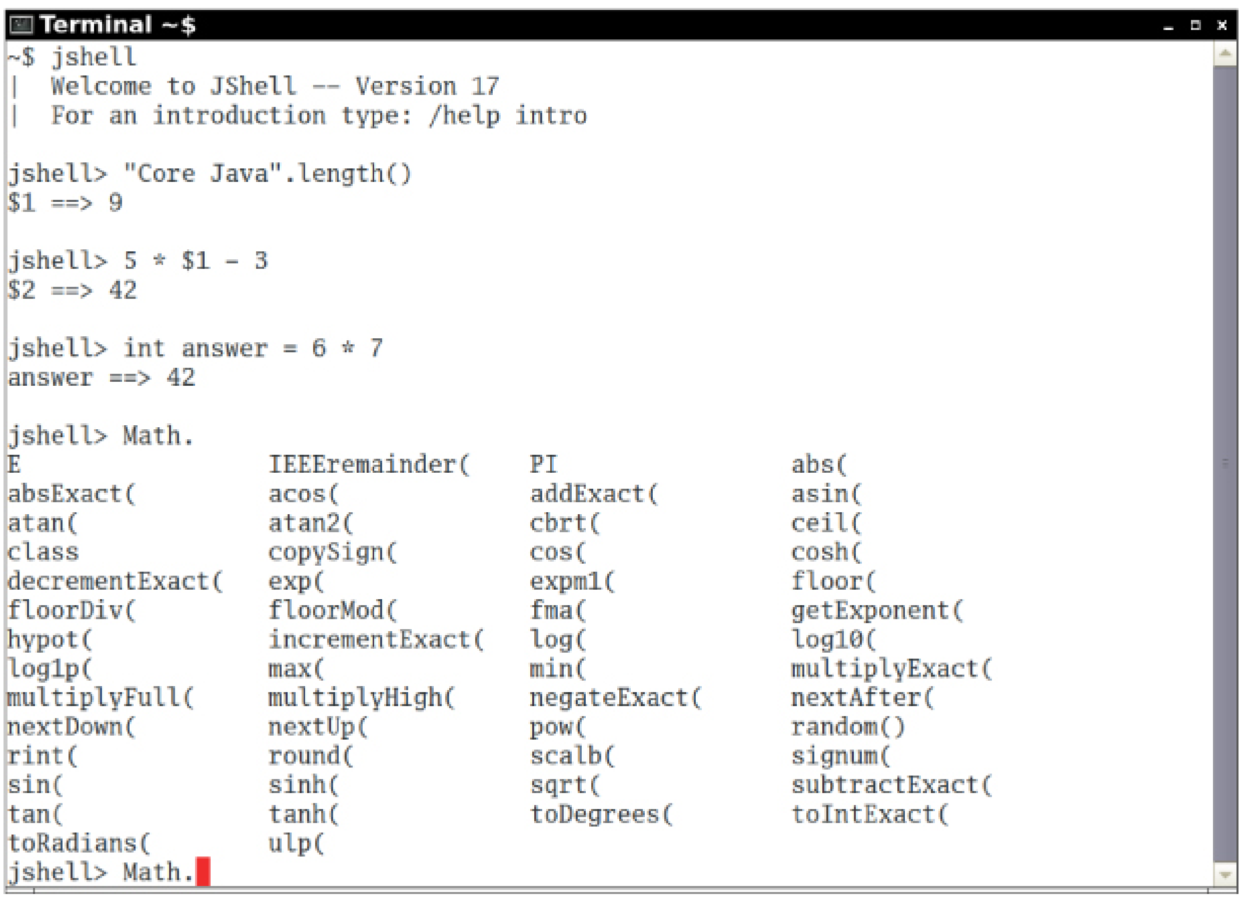
Figure 2.8 Error messages in Eclipse

TIP:

Often, an Eclipse error report is accompanied by a lightbulb icon. Click on the lightbulb to get a list of suggested fixes.

2.4 JShell

In the preceding section, you saw how to compile and run a Java program. Java 9 introduced another way of working with Java. The JShell program provides a “read-evaluate-print loop,” or REPL. You type a Java expression; JShell evaluates your input, prints the result, and waits for your next input. To start JShell, simply type `jshell` in a terminal window (see Figure 2.9).



```
Terminal ~$
~$ jshell
|  Welcome to JShell -- Version 17
|  For an introduction type: /help intro

jshell> "Core Java".length()
$1 ==> 9

jshell> 5 * $1 - 3
$2 ==> 42

jshell> int answer = 6 * 7
answer ==> 42

jshell> Math.
E                 IEEEremainder(    PI                abs(
absExact(         acos(             addExact(         asin(
atan(             atan2(            cbrt(             ceil(
class             copySign(         cos(              cosh(
decrementExact(   exp(              expm1(            floor(
floorDiv(         floorMod(         fma(              getExponent(
hypot(            incrementExact(   log(              log10(
log1p(            max(              min(              multiplyExact(
multiplyFull(     multiplyHigh(     negateExact(      nextAfter(
nextDown(         nextUp(           pow(              random()
rint(             round(            scalb(            signum(
sin(              sinh(             sqrt(             subtractExact(
tan(              tanh(             toDegrees(        toIntExact(
toRadians(        ulp(
jshell> Math.
```

Figure 2.9 Running JShell

JShell starts with a greeting, followed by a prompt:

```
|  Welcome to JShell -- Version 17.0.4
|  For an introduction type: /help intro

jshell>
```

Now type an expression, such as

```
"Core Java".length()
```

JShell responds with the result—in this case, the number of characters in the string “Core Java”.

```
$1 ==> 9
```

Note that you do *not* type `System.out.println`. JShell automatically prints the value of every expression that you enter.

The `$1` in the output indicates that the result is available in further calculations. For example, if you type

```
5 * $1 - 3
```

the response is

```
$2 ==> 42
```

If you need a variable many times, you can give it a more memorable name. You have to follow the Java syntax (explained in Chapter 3) and specify the type, followed by the name. For example,

```
jshell> int answer = 6 * 7
answer ==> 42
```

Another useful feature is tab completion. Type

```
Math.
```

followed by the Tab key. You get a list of all methods that you can invoke with the Math class:

```
jshell> Math.
E                  IEEEremainder(    PI abs(
absExact(          acos(             addExact(        asin(
atan(              atan2(            cbrt(            ceil(
class              copySign(         cos(             cosh(
decrementExact(    exp(              expm1(           floor(
floorDiv(          floorMod(         fma(             getExponent
(
hypot(             incrementExact(   log(             log10(
log1p(             max(              min(             multiplyExa
ct(
multiplyFull(      multiplyHigh(     negateExact(     nextAfter(
nextDown(          nextUp(           pow(             random()
rint(              round(            scalb(           signum(
sin(               sinh(             sqrt(            subtractExa
ct(
tan(               tanh(             toDegrees(       toIntExact(
toRadians(         ulp(
```

Now type `l` and hit the Tab key again. The method name is completed to `log`, and you get a shorter list:

```
jshell> Math.log
log(     log10(   log1p(
```

Now you can fill in the rest by hand:

```
jshell> Math.log10(0.001)
$3 ==> -3.0
```

To repeat a command, hit the ↑ key until you see the line that you want to reissue or edit. You can move the cursor in the line with the ← and → keys, and add or delete characters. Hit Enter when you are done. For example, hit and replace `0.001` with `1000`, then hit Enter:

```
jshell> Math.log10(1000)
$4 ==> 3.0
```

JShell makes it easy and fun to learn about the Java language and library without having to launch a heavy-duty development environment and without fussing with `public static void main`.

In this chapter, you learned about the mechanics of compiling and running Java programs. You are now ready to move on to Chapter 3 where you will start learning the Java language.

Chapter 3. Fundamental Programming Structures in Java

In this chapter

At this point, you should have successfully installed the JDK and executed the sample programs from Chapter 2. It's time to start programming. This chapter shows you how the basic programming concepts such as data types, branches, and loops are implemented in Java.

3.1 A Simple Java Program

Let's look more closely at one of the simplest Java programs you can have—one that merely prints a message to console:

```
public class FirstSample
{
  public static void main(String[] args)
  {
    System.out.println("We will not use 'Hello, World!'");
```

```
    }
}
```

It is worth spending all the time you need to become comfortable with the framework of this sample; the pieces will recur in all applications. First and foremost, *Java is case sensitive*. If you made any mistakes in capitalization (such as typing `Main` instead of `main`), the program will not run.

Now let's look at this source code line by line. The keyword `public` is called an *access modifier*; these modifiers control the level of access other parts of a program have to this code. For more about access modifiers, see Chapter 5. The keyword `class` reminds you that everything in a Java program lives inside a class. You will learn a lot more about classes in the next chapter. For now, think of a class as a container for the program logic that defines the behavior of an application. As mentioned in Chapter 1, classes are the building blocks with which all Java applications are built. *Everything* in a Java program must be inside a class.

Following the keyword `class` is the name of the class. The rules for class names in Java are quite generous. Names must begin with a letter, and after that, they can have any combination of letters and digits. The length is essentially unlimited. You cannot use a Java reserved word (such as `public` or `class`) for a class name. (See the appendix for a list of reserved words.)

The standard naming convention (used in the name `FirstSample`) is that class names are nouns that start with an uppercase letter. If a name consists of multiple words, use an initial uppercase letter in each of the words. This use of uppercase letters in the middle of a name is sometimes called "camel case" or, self-referentially, "CamelCase".

You need to make the file name for the source code the same as the name of the public class, with the extension `.java` appended. Thus, you must store this code in a file called `FirstSample.java`. (Again, case is important—don't use `firstsample.java`.)

If you have named the file correctly and not made any typos in the source code, then when you compile this source code, you end up with a file containing the bytecodes for this class. The Java compiler automatically names the bytecode file FirstSample.class and stores it in the same directory as the source file. Finally, launch the program by issuing the following command:

```
java FirstSample
```

(Remember to leave off the .class extension.) When the program executes, it simply displays the string We will not use 'Hello, World!' on the console.

When you use

```
java ClassName
```

to run a compiled program, the Java virtual machine always starts execution with the code in the main method in the class you indicate. (The term "method" is Java-speak for a function.) Thus, you *must* have a main method in the source of your class for your code to execute. You can, of course, add your own methods to a class and call them from the main method. (You will see in the next chapter how to write your own methods.)

NOTE:

According to the Java Language Specification, the main method must be declared public. (The Java Language Specification is the official document that describes the Java language. You can view or download it from http://docs.oracle.com/javase/specs.)

However, several versions of the Java launcher were willing to execute Java programs even when the main method was not public. A programmer filed a bug report. To see it, visit https://bugs.openjdk.java.net/browse/JDK-4252539. In 1999, that bug was marked as "closed, will not be fixed." A Sun engineer added an explanation that the Java Virtual Machine Specification does not mandate that main is public and that "fixing it will cause potential troubles." Fortunately, sanity prevailed. The Java launcher in Java 1.4 and beyond enforces that the `main` method is `public`.

Of course, it is frustrating to have quality assurance engineers, who are often overworked and not always experts in the fine points of Java, make questionable decisions about bug reports. But it is remarkable that the bug reports and their resolutions have been available for anyone to scrutinize, long before Java was open source.

Notice the braces `{ }` in the source code. In Java, as in C/C++, braces delineate the parts (usually called *blocks*) in your program. In Java, the code for any method must be started by an opening brace `{` and ended by a closing brace `}`.

Brace styles have inspired an inordinate amount of useless controversy. This book follows a style that lines up matching braces. As whitespace is irrelevant to the Java compiler, you can use whatever brace style you like.

For now, don't worry about the keywords `static void`—just think of them as part of what you need to get a Java program to compile. By the end of Chapter 4, you will understand this incantation completely. The point to remember for now is that every Java application must have a `main` method that is declared in the following way:

```
public class ClassName
{
  public static void main(String[] args)
  {
    program statements
  }
}
```

C++ NOTE:

As a C++ programmer, you know what a class is. Java classes are similar to C++ classes, but there are a few differences that can trap you. For example, in Java *all* functions are methods of some class. (The standard terminology refers to them as methods, not member functions.) Thus, in Java you must have a shell class for the `main` method. You may also be familiar with the idea of *static member functions* in C++. These are member functions defined inside a class that do not operate on objects. The `main` method in Java is always static. Finally, as in C/C++, the `void` keyword indicates that this method does not return a value. Unlike C/C++, the `main` method does not return an "exit code" to the operating system. If the `main` method exits normally, the Java program has the exit code `0`, indicating successful completion. To terminate the program with a different exit code, use the `System.exit` method.

Next, turn your attention to this fragment:

```
{
  System.out.println("We will not use 'Hello, World!'");
}
```

Braces mark the beginning and end of the *body* of the method. This method has only one statement in it. As with most programming languages, you can think of Java statements as sentences of the language. In Java, every statement must end with a semicolon. In particular, carriage returns do not mark the end of a statement, so statements can span multiple lines if need be.

The body of the `main` method contains a statement that outputs a single line of text to the console.

Here, we are using the `System.out` object and calling its `println` method. Notice the periods used to invoke a method. Java uses the general syntax

object`.`*method*`(`*parameters*`)`

as its equivalent of a function call.

In this case, the `println` method receives a string parameter. The method displays the string parameter on the console. It then terminates the output line, so that each call to `println` displays its output on a new line. Notice that Java, like C/C++, uses double quotes to delimit strings. (You can find more information about strings later in this chapter.)

Methods in Java, like functions in any programming language, can use zero, one, or more *parameters* (some programmers call them *arguments*). Even if a method takes no parameters, you must still use empty parentheses. For example, a variant of the `println` method with no parameters just prints a blank line. You invoke it with the call

```
System.out.println();
```

NOTE:

`System.out` also has a `print` method that doesn't add a newline character to the output. For example, `System.out.print("Hello")` prints `Hello` without a newline. The next output appears immediately after the letter `o`.

3.2 Comments

Comments in Java, as in most programming languages, do not show up in the executable program. Thus, you can add as many comments as needed without fear of bloating the code. Java has three ways of marking comments. The most common form is a `//`. Use this for a comment that runs from the `//` to the end of the line.

```
System.out.println("We will not use 'Hello, World!'"); // is
this too cute?
```

When longer comments are needed, you can mark each line with a `//`, or you can use the `/*` and `*/` comment delimiters that let you block off a longer comment.

Finally, a third kind of comment is used to generate documentation automatically. This comment uses a `/**` to start and a `*/` to end. You can see this type of comment in Listing 3.1. For more on this type of comment and on automatic documentation generation, see Chapter 4.

Listing 3.1 `FirstSample/FirstSample.java`

```
/**
 * This is the first sample program in Core Java Chapter 3
 * @version 1.01 1997-03-22
 * @author Gary Cornell
 */
public class FirstSample
{
   public static void main(String[] args)
   {
      System.out.println("We will not use 'Hello, World!'");
   }
}
```

CAUTION:

`/* */` comments do not nest in Java. That is, you might not be able to deactivate code simply by surrounding it with `/*` and `*/` because the code you want to deactivate might itself contain a `*/` delimiter.

3.3 Data Types

Java is a *strongly typed language*. This means that every variable must have a declared type. There are eight *primitive types* in Java. Four of them are integer types; two are floating-point number types; one is the character type `char`, used for code units in the Unicode encoding scheme (see Section 3.3.3, "The `char` Type," on p. 43); and one is a `boolean` type for truth values.

NOTE:

Java has an arbitrary-precision arithmetic package. However, “big numbers,” as they are called, are Java *objects* and not a primitive Java type. You will see how to use them later in this chapter.

3.3.1 Integer Types

The integer types are for numbers without fractional parts. Negative values are allowed. Java provides the four integer types shown in Table 3.1.

Table 3.1 Java Integer Types

Type	Storage Requirement	Range (Inclusive)
`int`	4 bytes	–2,147,483,648 to 2,147,483,647 (just over 2 billion)
`short`	2 bytes	–32,768 to 32,767
`long`	8 bytes	–9,223,372,036,854,775,808 to 9,223,372,036,854,775,807
`byte`	1 byte	–128 to 127

In most situations, the `int` type is the most practical. If you want to represent the number of inhabitants of our planet, you’ll need to resort to a `long`. The `byte` and `short` types are mainly intended for specialized applications, such as low-level file handling, or for large arrays when storage space is at a premium.

Under Java, the ranges of the integer types do not depend on the machine on which you will be running the Java code. This alleviates a major pain for the programmer who wants to move software from one platform to another, or even between operating systems on the same platform. In contrast, C and C++ programs use the most efficient integer type for each processor. As a result, a C program that runs well on a 32-bit processor may exhibit integer overflow on a 16-bit system. Since Java programs must run with the same results on all machines, the ranges for the various types are fixed.

Long integer numbers have a suffix `L` or `l` (for example, `4000000000L`). Hexadecimal numbers have a prefix `0x` or `0X` (for example, `0xCAFE)`. Octal numbers have a prefix `0` (for example, `010` is 8)—naturally, this can be confusing, and few programmers use octal constants.

You can write numbers in binary, with a prefix `0b` or `0B`. For example, `0b1001` is 9. You can add underscores to number literals, such as `1_000_000` (or `0b1111_0100_0010_0100_0000`) to denote one million. The underscores are for human eyes only. The Java compiler simply removes them.

C++ NOTE:

In C and C++, the sizes of types such as `int` and `long` depend on the target platform. On a 16-bit processor such as the 8086, integers are 2 bytes, but on a 32-bit processor like a Pentium or SPARC they are 4-byte quantities. Similarly, `long` values are 4-byte on 32-bit processors and 8-byte on 64-bit processors. These differences make it challenging to write cross-platform programs. In Java, the sizes of all numeric types are platform-independent.

Note that Java does not have any `unsigned` versions of the `int`, `long`, `short`, or `byte` types.

NOTE:

If you work with integer values that can never be negative and you really need an additional bit, you can, with some care, interpret signed integer values as unsigned. For example, instead of having a byte value b represent the range from –128 to 127, you may want a range from 0 to 255. You can store it in a `byte`. Due to the nature of binary arithmetic, addition, subtraction, and multiplication will work provided they don't overflow. For other operations, call `Byte.toUnsignedInt(b)` to get an int value between 0 and 255, then process the integer value and cast back to byte. The Integer and Long classes have methods for unsigned division and remainder.

3.3.2 Floating-Point Types

The floating-point types denote numbers with fractional parts. The two floating-point types are shown in Table 3.2.

Table 3.2 Floating-Point Types

Type	Storage Requirement	Range
`float`	4 bytes	Approximately $\pm 3.40282347 \times 10^{38}$ (6–7 significant decimal digits)
`double`	8 bytes	Approximately $\pm 1.79769313486231570 \times 10^{308}$ (15 significant decimal digits)

The name `double` refers to the fact that these numbers have twice the precision of the `float` type. (Some people call these *double-precision* numbers.) The limited precision of `float` (6–7 significant digits) is simply not sufficient for many situations. Use `float` values only when you work with a library that requires them, or when you need to store a very large number of them.

Numbers of type `float` have a suffix `F` or `f` (for example, `3.14F`). Floating-point numbers without an `F` suffix (such as 3.14) are always considered to be of type `double`. You can optionally supply the `D` or `d` suffix (for example, `3.14D`).

An `E` or e denotes a decimal exponent. For example, `1.729E3` is the same as `1729`.

NOTE:

You can specify floating-point literals in hexadecimal. For example, 0.125 = 2^{-3} can be written as `0x1.0p-3`. In hexadecimal notation, you use a `p`, not an `e`, to denote the exponent. (An `e` is a hexadecimal digit.) Note that the mantissa is written in hexadecimal and the exponent in decimal. The base of the exponent is 2, not 10.

All floating-point computations follow the IEEE 754 specification. In particular, there are three special floating-point values to denote overflows and errors:

- Positive infinity
- Negative infinity
- NaN (not a number)

For example, the result of dividing a positive number by 0 is positive infinity. Computing 0/0 or the square root of a negative number yields NaN.

NOTE:

The constants `Double.POSITIVE_INFINITY`, `Double.NEGATIVE_INFINITY`, and `Double.NaN` (as well as corresponding `Float` constants) represent these special values, but they are rarely used in practice. In particular, you cannot test

```
if (x == Double.NaN) // is never true
```

to check whether a particular result equals `Double.NaN`. All "not a number" values are considered distinct. However, you can use the `Double.isNaN` method:

```
if (Double.isNaN(x)) // check whether x is "not a number"
```

CAUTION:

Floating-point numbers are *not* suitable for financial calculations in which roundoff errors cannot be tolerated. For example, the command `System.out.println(2.0 - 1.1)` prints `0.8999999999999999`, not `0.9` as you would expect. Such roundoff errors are caused by the fact that floating-point numbers are represented in the binary number system. There is no precise binary representation of the fraction 1/10, just as there is no accurate representation of the fraction 1/3 in the decimal system. If you need precise numerical computations without roundoff errors, use the `BigDecimal` class, which is introduced later in this chapter.

3.3.3 The `char` Type

The `char` type was originally intended to describe individual characters. However, this is no longer the case. Nowadays, some Unicode characters can be described with one `char` value, and other Unicode characters require two `char`

values. Read the next section for the gory details.

Literal values of type `char` are enclosed in single quotes. For example, `'A'` is a character constant with value 65. It is different from `"A"`, a string containing a single character. Values of type `char` can be expressed as hexadecimal values that run from `\u0000` to `\uFFFF`. For example, `\u2122` is the trademark symbol (™) and `\u03C0` is the Greek letter pi (π).

Besides the `\u` escape sequences, there are several escape sequences for special characters, as shown in Table 3.3. You can use these escape sequences inside quoted character literals and strings, such as `'\u2122'` or `"Hello\n"`. The `\u` escape sequence (but none of the other escape sequences) can even be used *outside* quoted character constants and strings. For example,

```
public static void main(String\u005B\u005D args)
```

is perfectly legal—`\u005B` and `\u005D` are the encodings for `[` and `]`.

Table 3.3 Escape Sequences for Special Characters

Escape Sequence	Name	Unicode Value
`\b`	Backspace	`\u0008`
`\t`	Tab	`\u0009`
`\n`	Line feed	`\u000a`
`\r`	Carriage return	`\u000d`
`\f`	Form feed	`\u000c`
`\"`	Double quote	`\u0022`
`\'`	Single quote	`\u0027`
`\\`	Backslash	`\u005c`
`\s`	Space. Used in text blocks to retain trailing white space.	`\u0020`
`\`*newline*	In text blocks only: Join this line with the next	—

CAUTION:

Unicode escape sequences are processed before the code is parsed. For example, `"\u0022+\u0022"` is *not* a string consisting of a plus sign surrounded by quotation marks (U+0022). Instead, the `\u0022` are converted into `"` before parsing, yielding `""+""`, or an empty string.

Even more insidiously, you must beware of `\u` inside comments. The comment

```
// \u000A is a newline
```

yields a syntax error since `\u000A` is replaced with a newline when the program is read. Similarly, a comment

```
// look inside c:\users
```

yields a syntax error because the `\u` is not followed by four hex digits.

NOTE:

You can have any number of `u` in a Unicode escape sequence: `\uu0022` and `\uuu0022` also denote the quotation mark character. There is a reason for this oddity. Consider a programmer happily coding in Unicode who is forced, for some archaic reason, to check in code as ASCII only. A conversion tool can turn any character > U+007F into a Unicode escape and add a `u` to every existing Unicode escape. That makes the conversion reversible. For example, `\uD800 ™` is turned into `\uuD800 \u2122` and can be converted back to `\uD800 ™`.

3.3.4 Unicode and the `char` Type

To fully understand the `char` type, you have to know about the Unicode encoding scheme. Unicode was invented to overcome the limitations of traditional character encoding schemes. Before Unicode, there were many different standards: ASCII in the United States, ISO 8859–1 for Western European languages, KOI-8 for Russian, GB18030 and BIG-5 for Chinese, and so on. This caused two problems. First, a particular code value corresponds to different letters in the different encoding schemes. Second, the encodings for languages with large character sets have variable length: Some common characters are encoded as single bytes, others require two or more bytes.

Unicode was designed to solve these problems. When the unification effort started in the 1980s, a fixed 2-byte code was more than sufficient to encode all characters used in all languages in the world, with room to spare for future expansion—or so everyone thought at the time. In 1991, Unicode 1.0 was released, using slightly less than half of the available 65,536 code values. Java was designed from the ground up to use 16-bit Unicode characters, which was a major advance over other programming languages that used 8-bit characters.

Unfortunately, over time, the inevitable happened. Unicode grew beyond 65,536 characters, primarily due to the addition of a very large set of ideographs used for Chinese, Japanese, and Korean. Now, the 16-bit `char` type is insufficient to describe all Unicode characters.

We need a bit of terminology to explain how this problem is resolved in Java. A *code point* is a code value that is associated with a character in an encoding scheme. In the Unicode standard, code points are written in hexadecimal and prefixed with `U+`, such as `U+0041` for the code point of the Latin letter A. Unicode has code points that are grouped into 17 *code planes*. The first code plane, called the *basic multilingual plane*, consists of the "classic" Unicode characters with code points `U+0000` to `U+FFFF`. Sixteen additional planes, with code points `U+10000` to `U+10FFFF`, hold the *supplementary characters*.

The UTF-16 encoding represents all Unicode code points in a variable-length code. The characters in the basic multilingual plane are represented as 16-bit values, called *code units*. The supplementary characters are encoded as consecutive pairs of code units. Each of the values in such an encoding pair falls into a range of 2048 unused values of the basic multilingual plane, called the *surrogates area* (`U+D800` to `U+DBFF` for the first code unit, `U+DC00` to `U+DFFF` for the second code unit). This is rather clever, because you can immediately tell whether a code unit encodes a single character or it is the first or second part of a supplementary character. For example, (the mathematical symbol for the set of octonions, `http://math.ucr.edu/home/baez/octonions`) has code point `U+1D546` and is encoded by the two code units `U+D835` and `U+DD46`. (See `https://tools.ietf.org/html/rfc2781` for a description of the encoding algorithm.)

In Java, the `char` type describes a *code unit* in the UTF-16 encoding.

I strongly recommend against using the `char` type in your programs unless you are actually manipulating UTF-16 code units. You are almost always better off treating strings as abstract data types—see Section 3.6, "Strings," on p. 61.

3.3.5 The `boolean` Type

The `boolean` type has two values, `false` and `true`. It is used for evaluating logical conditions. You cannot convert between integers and `boolean` values.

C++ NOTE:

In C++, numbers and even pointers can be used in place of `boolean` values. The value `0` is equivalent to the `bool` value `false`, and a nonzero value is equivalent to `true`. This is *not* the case in Java. Thus, Java programmers are shielded from accidents such as

```
if (x = 0) // oops... meant x == 0
```

In C++, this test compiles and runs, always evaluating to `false`. In Java, the test does not compile because the integer expression `x = 0` cannot be converted to a `boolean` value.

3.4 Variables and Constants

As in every programming language, variables are used to store values. Constants are variables whose values don't change. In the following sections, you will learn how to declare variables and constants.

3.4.1 Declaring Variables

In Java, every variable has a *type*. You declare a variable by placing the type first, followed by the name of the variable. Here are some examples:

```
double salary;
int vacationDays;
long earthPopulation;
boolean done;
```

Notice the semicolon at the end of each declaration. The semicolon is necessary because a declaration is a complete Java statement, which must end in a semicolon.

The identifier for a variable name (as well as for other names) is made up of letters, digits, currency symbols, and “punctuation connectors”. The first character cannot be a digit.

Symbols like `'+'` or `'©'` cannot be used inside variable names, nor can spaces. Letter case is significant: `main` and `Main` are distinct identifiers. The length of an identifier is essentially unlimited.

The terms “letter,” “digit,” and “currency symbol” are much broader in Java than in most languages. A letter is *any* Unicode character that denotes a letter in a language. For example, German users can use umlauts such as `'ä'` in variable names; Greek speakers could use a π. Similarly, digits are `0–9` and *any* Unicode characters that denote a digit. Currency symbols are `$`, `€`, `¥`, and so on. Punctuation connectors include the underscore character _, a “wavy low line” , and a few others. In practice, most programmers stick to `A-Z`, `a-z`, `0-9`, and the underscore _.

TIP:

If you are really curious as to what Unicode characters can be used in identifiers, you can use the `isJavaIdentifierStart` and `isJavaIdentifierPart` methods in the `Character` class to check.

TIP:

Even though `$` is a valid character in an identifier, you should not use it in your own code. It is intended for names that are generated by the Java compiler and other tools.

You also cannot use a Java keyword such as `class` as a variable name.

As of Java 9, a single underscore _ is a reserved word. A future version of Java may use _ as a wildcard symbol.

You can declare multiple variables on a single line:

```
int i, j; // both are integers
```

However, I don't recommend this style. If you declare each variable separately, your programs are easier to read.

NOTE:

As you saw, names are case sensitive, for example, `hireday` and `hireDay` are two separate names. In general, you should not have two names that only differ in their letter case. However, sometimes it is difficult to come up with a good name for a variable. Many programmers then give the variable the same name as the type, for example

```
Box box; // "Box" is the type and "box" is the variable name
```

Other programmers prefer to use an "a" prefix for the variable:

```
Box aBox;
```

3.4.2 Initializing Variables

After you declare a variable, you must explicitly initialize it by means of an assignment statement—you can never use the value of an uninitialized variable. For example, the Java compiler flags the following sequence of statements as an error:

```
int vacationDays;
System.out.println(vacationDays); // ERROR--variable not
initialized
```

You assign to a previously declared variable by using the variable name on the left, an equal sign (=), and then some Java expression with an appropriate value on the right.

```
int vacationDays;
vacationDays = 12;
```

You can both declare and initialize a variable on the same line. For example:

```
int vacationDays = 12;
```

Finally, in Java you can put declarations anywhere in your code. For example, the following is valid code in Java:

```
double salary = 65000.0;
System.out.println(salary);
int vacationDays = 12; // OK to declare a variable here
```

In Java, it is considered good style to declare variables as closely as possible to the point where they are first used.

NOTE:

Starting with Java 10, you do not need to declare the types of local variables if they can be inferred from the initial value. Simply use the keyword `var` instead of the type:

```
var vacationDays = 12; // vacationDays is an int
var greeting = "Hello"; // greeting is a String
```

As you will see in the next chapter, this feature can make the declaration of objects less verbose.

C++ NOTE:

C and C++ distinguish between the *declaration* and *definition* of a variable. For example,

```
int i = 10;
```

is a definition, whereas

```
extern int i;
```

is a declaration. In Java, no declarations are separate from definitions.

3.4.3 Constants

In Java, you use the keyword `final` to denote a constant. For example:

```
public class Constants
{
   public static void main(String[] args)
   {
      final double CM_PER_INCH = 2.54;
```

```
        double paperWidth = 8.5;
        double paperHeight = 11;
        System.out.println("Paper size in centimeters: "
           + paperWidth * CM_PER_INCH + " by " + paperHeight *
CM_PER_INCH);
   }
}
```

The keyword `final` indicates that you can assign to the variable once, and then its value is set once and for all. It is customary to name constants in all uppercase.

It is probably more common in Java to create a constant so it's available to multiple methods inside a single class. These are usually called *class constants*.

Set up a class constant with the keywords `static final`. Here is an example of using a class constant:

```
public class Constants2
{
    public static final double CM_PER_INCH = 2.54;

    public static void main(String[] args)
    {
      double paperWidth = 8.5;
      double paperHeight = 11;
      System.out.println("Paper size in centimeters: "
         + paperWidth * CM_PER_INCH + " by " + paperHeight *
CM_PER_INCH);
    }
}
```

Note that the definition of the class constant appears *outside* the `main` method. Thus, the constant can also be used in other methods of the same class. Furthermore, if the constant is declared, as in this example, `public`, methods of other classes can also use it—in our example, as `Constants2.CM_PER_INCH`.

C++ NOTE:

`const` is a reserved Java keyword, but it is not currently used for anything. You must use `final` for a constant.

3.4.4 Enumerated Types

Sometimes, a variable should only hold a restricted set of values. For example, you may sell clothes or pizza in four sizes: small, medium, large, and extra large. Of course, you could encode these sizes as integers `1`, `2`, `3`, `4` or characters

`S`, `M`, `L`, and `X`. But that is an error-prone setup. It is too easy for a variable to hold a wrong value (such as `0` or `m`).

You can define your own *enumerated type* whenever such a situation arises. An enumerated type has a finite number of named values. For example,

```
enum Size { SMALL, MEDIUM, LARGE, EXTRA_LARGE };
```

Now you can declare variables of this type:

```
Size s = Size.MEDIUM;
```

A variable of type `Size` can hold only one of the values listed in the type declaration, or the special value `null` that indicates that the variable is not set to any value at all.

Enumerated types are discussed in greater detail in Chapter 5.

3.5 Operators

Operators are used to combine values. As you will see in the following sections, Java has a rich set of arithmetic and logical operators and mathematical functions.

3.5.1 Arithmetic Operators

The usual arithmetic operators `+`, `-`, `*`, `/` are used in Java for addition, subtraction, multiplication, and division. The `/` operator denotes integer division if both arguments are integers, and floating-point division otherwise. Integer remainder (sometimes called *modulus*) is denoted by `%`. For example, `15 / 2` is `7`, `15 % 2` is `1`, and `15.0 / 2` is `7.5`.

Note that integer division by 0 raises an exception, whereas floating-point division by 0 yields an infinite or NaN result.

NOTE:

One of the stated goals of the Java programming language is portability. A computation should yield the same results no matter which virtual machine executes it. For arithmetic computations with floating-point numbers, it can be surprisingly difficult to achieve this portability. The `double` type uses 64 bits to store a numeric value, but some processors use 80-bit floating-point registers. These registers yield added precision in intermediate steps of a computation.

But the result may be *different* from a computation that uses 64 bits throughout. For perfect portability, the initial specification of the Java virtual machine mandated that all intermediate computations must be truncated to 64 bit. The numeric community hated it. The computations were *slower* because the truncation operations took time on popular processors. For that reason, the Java programming language was updated to recognize the conflicting demands for optimum performance and perfect reproducibility. Virtual machine designers were permitted to use extended precision for intermediate computations. However, methods tagged with the `strictfp` keyword had to use strict floating-point operations that yield reproducible results.

Processors have become more flexible, and they can now carry out 64-bit arithmetic efficiently. As of Java 17, the virtual machine is again required to carry out strict 64-bit arithmetic, and the `strictfp` keyword is now obsolete.

3.5.2 Mathematical Functions and Constants

The `Math` class contains an assortment of mathematical functions that you may occasionally need, depending on the kind of programming that you do.

To take the square root of a number, use the `sqrt` method:

```
double x = 4;
double y = Math.sqrt(x);
System.out.println(y); // prints 2.0
```

NOTE:

There is a subtle difference between the `println` method and the `sqrt` method. The `println` method operates on the `System.out` object. But the `sqrt` method in the `Math` class does not operate on any object. Such a method is called a *static* method. You can learn more about static methods in Chapter 4.

The Java programming language has no operator for raising a quantity to a power: You must use the `pow` method in the `Math` class. The statement

```
double y = Math.pow(x, a);
```

sets `y` to be `x` raised to the power `a` (x^a). The `pow` method's parameters are both of type `double`, and it returns a `double` as well.

The `floorMod` method aims to solve a long-standing problem with integer remainders. Consider the expression `n % 2`. Everyone knows that this is `0` if `n` is even and `1` if `n` is odd. Except, of course, when `n` is odd and negative. Then it is `-1`. Why? When the first computers were built, someone had to make rules for how integer division and remainder should work for negative operands. Mathematicians had known the optimal (or “Euclidean”) rule for a few hundred years: always leave the remainder ≥ 0. But, rather than open a math textbook, those pioneers came up with rules that seemed reasonable but are actually inconvenient.

Consider this problem. You compute the position of the hour hand of a clock. An adjustment is applied, and you want to normalize to a number between `0` and `11`. That is easy: `(position + adjustment) % 12`. But what if the adjustment is negative? Then you might get a negative number. So you have to introduce a branch, or use `((position + adjustment) % 12 + 12) % 12`. Either way, it is a hassle.

The `floorMod` method makes it easier: `floorMod(position + adjustment, 12)` always yields a value between `0` and `11`. (Unfortunately, `floorMod` gives negative results for negative divisors, but that situation doesn’t often occur in practice.)

The `Math` class supplies the usual trigonometric functions:

```
Math.sin
Math.cos
Math.tan
Math.atan
Math.atan2
```

and the exponential function with its inverse, the natural logarithm, as well as the decimal logarithm:

```
Math.exp
Math.log
Math.log10
```

Finally, two constants denote the closest possible approximations to the mathematical constants π and *e*:

```
Math.PI
Math.E
```

TIP:

You can avoid the `Math` prefix for the mathematical methods and constants by adding the following line to the top of your source file:

```
import static java.lang.Math.*;
```

For example:

```
System.out.println("The square root of \u03C0 is " + sqrt(PI));
```

Static imports are covered in Chapter 4.

NOTE:

The methods in the `Math` class use the routines in the computer's floating-point unit for fastest performance. If completely predictable results are more important than performance, use the `StrictMath` class instead. It implements the algorithms from the "Freely Distributable Math Library" (`www.netlib.org/fdlibm`), guaranteeing identical results on all platforms.

NOTE:

The Math class provides several methods to make integer arithmetic safer. The mathematical operators quietly return wrong results when a computation overflows. For example, one billion times three (1000000000 * 3) evaluates to -1294967296 because the largest int value is just over two billion. If you call Math.multiplyExact(1000000000, 3) instead, an exception is generated. You can catch that exception or let the program terminate rather than quietly continue with a wrong result. There are also methods addExact, subtractExact, incrementExact, decrementExact, negateExact, and absExact, all with int and long parameters.

3.5.3 Conversions between Numeric Types

It is often necessary to convert from one numeric type to another. Figure 3.1 shows the legal conversions.

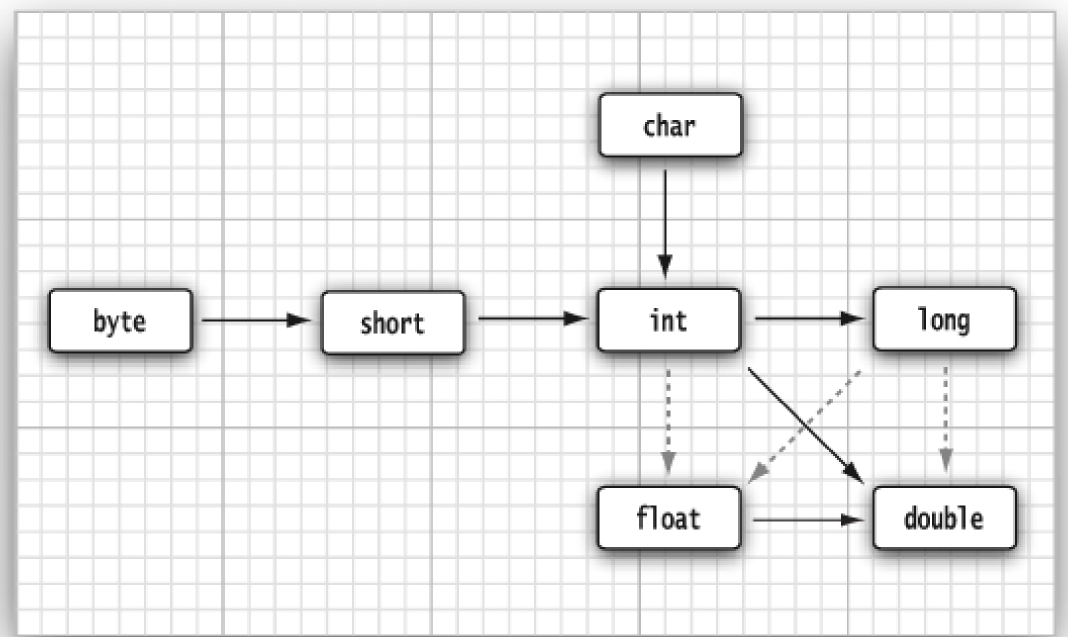


Figure 3.1 Legal conversions between numeric types

The six solid arrows in Figure 3.1 denote conversions without information loss. The three dotted arrows denote conversions that may lose precision.

For example, a large integer such as `123456789` has more digits than the `float`

type can represent. When the integer is converted to a `float`, the resulting value has the correct magnitude but loses some precision.

```
int n = 123456789;
float f = n; // f is 1.23456792E8
```

When two values are combined with a binary operator (such as `n + f` where `n` is an integer and `f` is a floating-point value), both operands are converted to a common type before the operation is carried out.

- If either of the operands is of type `double`, the other one will be converted to a `double`.
- Otherwise, if either of the operands is of type `float`, the other one will be converted to a `float`.
- Otherwise, if either of the operands is of type `long`, the other one will be converted to a `long`.
- Otherwise, both operands will be converted to an `int`.

3.5.4 Casts

In the preceding section, you saw that `int` values are automatically converted to `double` values when necessary. On the other hand, there are obviously times when you want to consider a `double` as an integer. Numeric conversions are possible in Java, but of course information may be lost. Conversions in which loss of information is possible are done by means of *casts*. The syntax for casting is to give the target type in parentheses, followed by the variable name. For example:

```
double x = 9.997;
int nx = (int) x;
```

Now, the variable `nx` has the value `9` because casting a floating-point value to an integer discards the fractional part.

If you want to *round* a floating-point number to the *nearest* integer (which in most cases is a more useful operation), use the `Math.round` method:

```
double x = 9.997;
int nx = (int) Math.round(x);
```

Now the variable `nx` has the value `10`. You still need to use the cast `(int)` when you call `round`. The reason is that the return value of the `round` method is a `long`, and a `long` can only be assigned to an `int` with an explicit cast because there is the possibility of information loss.

CAUTION:

If you try to cast a number of one type to another that is out of range for the target type, the result will be a truncated number that has a different value. For example, `(byte) 300` is actually `44`.

C++ NOTE:

You cannot cast between `boolean` values and any numeric type. This convention prevents common errors. In the rare case when you want to convert a `boolean` value to a number, you can use a conditional expression such as `b ? 1 : 0`.

3.5.5 Assignment

There is a convenient shortcut for using binary operators in an assignment. For example,

```
x += 4;
```

is equivalent to

```
x = x + 4;
```

(In general, place the operator to the left of the `=` sign, such as `*=` or `%=`.)

CAUTION:

If the operator yields a value whose type is different from that of the left-hand side, then it is coerced to fit. For example, if `x` is an `int`, then the statement

```
x += 3.5;
```

---

is valid, setting `x` to `(int)(x + 3.5)`.

Note that in Java, an assignment is an *expression*. That is, it has a value—namely, the value that is being assigned. You can use that value—for example, to assign it to another variable. Consider these statements:

```
int x = 1;
int y = x += 4;
```

The value of `x += 4` is 5, since that's the value that is being assigned to `x`. Next, that value is assigned to `y`.

Many programmers find such nested assignments confusing and prefer to write them more clearly, like this:

```
int x = 1;
x += 4;
```

```
int y = x;
```

3.5.6 Increment and Decrement Operators

Programmers, of course, know that one of the most common operations with a numeric variable is to add or subtract 1. Java, following in the footsteps of C and C++, has both increment and decrement operators: `n++` adds 1 to the current value of the variable `n`, and `n--` subtracts 1 from it. For example, the code

```
int n = 12;
n++;
```

changes `n` to `13`. Since these operators change the value of a variable, they cannot be applied to numbers themselves. For example, `4++` is not a legal statement.

There are two forms of these operators; you've just seen the postfix form of the operator that is placed after the operand. There is also a prefix form, `++n`. Both change the value of the variable by 1. The difference between the two appears only when they are used inside expressions. The prefix form does the addition first; the postfix form evaluates to the old value of the variable.

```
int m = 7;
int n = 7;
int a = 2 * ++m; // now a is 16, m is 8
int b = 2 * n++; // now b is 14, n is 8
```

Many programmers find this behavior confusing. In Java, using `++` inside expressions is uncommon.

3.5.7 Relational and `boolean` Operators

Java has the full complement of relational operators. To test for equality, use a double equal sign, `==`. For example, the value of

```
3 == 7
```

is `false`.

Use a `!=` for inequality. For example, the value of

```
3 != 7
```

is `true`.

Finally, you have the usual `<` (less than), `>` (greater than), `<=` (less than or equal), and `>=` (greater than or equal) operators. Java, following C++, uses `&&` for the logical "and" operator and `||` for the logical "or" operator. As you can easily remember from the `!=` operator, the exclamation point `!` is the logical negation operator. The `&&` and `||` operators are evaluated in "short circuit" fashion: The second argument is not evaluated if the first argument already determines the value. If you combine two expressions with the `&&` operator,

$expression_1$ **&&** $expression_2$

and the truth value of the first expression has been determined to be `false`, then it is impossible for the result to be `true`. Thus, the value for the second expression is *not* calculated. This behavior can be exploited to avoid errors. For example, in the expression

```
x != 0 && 1 / x > x + y // no division by 0
```

the second part is never evaluated if `x` equals zero. Thus, `1 / x` is not computed if `x` is zero, and no divide-by-zero error can occur.

Similarly, the value of $expression_1$ `||` $expression_2$ is automatically `true` if the first expression is `true`, without evaluating the second expression.

3.5.8 The Conditional Operator

Java provides the *conditional* `?:` operator that selects a value, depending on a Boolean expression. The expression *condition* `?` $expression_1$ `:` $expression_2$ evaluates to the first expression if the condition is `true`, to the second expression otherwise. For example,

```
x < y ? x : y
```

gives the smaller of `x` and `y`.

3.5.9 Switch Expressions

If you need to choose among more than two values, then you can use a `switch` expression (as of Java 14). It looks like this:

```
String seasonName = switch (seasonCode)
  {
     case 0 -> "Spring";
     case 1 -> "Summer";
     case 2 -> "Fall";
     case 3 -> "Winter";
     default -> "???";
  };
```

The `case` labels can also be strings or constants of an enumerated type.

NOTE:

The `switch` expression, like every expression, has a value. Note the -> arrow preceding the value in each branch.

NOTE:

As of Java 14, there are four (!) forms of `switch`. This section focuses on the most useful one. See Section 3.8.5, “Multiple Selections with `switch`,” on p. 98 for a thorough discussion of all forms of `switch` expressions and statements.

You can provide multiple labels for each `case`, separated by commas:

```
int numLetters = switch (seasonName)
   {
      case "Spring", "Summer", "Winter" -> 6;
      case "Fall" -> 4;
      default -> -1;
   };
```

When you use the `switch` expression with enumerated constants, you need not supply the name of the enumeration in each label—it is deduced from the

```
switch value. For example:
enum Size { SMALL, MEDIUM, LARGE, EXTRA_LARGE }; . . .
Size itemSize = . . .;
String label = switch (itemSize)
   {
      case SMALL -> "S"; // no need to use Size.SMALL
      case MEDIUM -> "M";
      case LARGE -> "L";
      case EXTRA_LARGE -> "XL";
   };
```

In the example, it was legal to omit the `default` since there was a case for each possible value.

CAUTION:

A switch expression with an integer or `String` operand must always have a `default` since it must yield a value, no matter what the operand value is.

CAUTION:

If the operand is `null`, a `NullPointerException` is thrown.

3.5.10 Bitwise Operators

For any of the integer types, you have operators that can work directly with the bits that make up the integers. This means that you can use masking techniques to get at individual bits in a number. The bitwise operators are

```
& ("and")  | ("or")  ^ ("xor")  ~ ("not")
```

These operators work on bit patterns. For example, if `n` is an integer variable, then

```
int fourthBitFromRight = (n & 0b1000) / 0b1000;
```

gives you a `1` if the fourth bit from the right in the binary representation of `n` is `1`, and `0` otherwise. Using `&` with the appropriate power of 2 lets you mask out all but a single bit.

NOTE:

When applied to `boolean` values, the `&` and `|` operators yield a `boolean` value. These operators are similar to the `&&` and `||` operators, except that the `&` and `|` operators are not evaluated in "short circuit" fashion—that is, both arguments are evaluated before the result is computed.

There are also >> and << operators which shift a bit pattern right or left. These operators are convenient when you need to build up bit patterns to do bit masking:

```
int fourthBitFromRight = (n & (1 << 3)) >> 3;
```

Finally, a >>> operator fills the top bits with zero, unlike >> which extends the sign bit into the top bits. There is no <<< operator.

CAUTION:

The right-hand argument of the shift operators is reduced modulo 32 (unless the left-hand argument is a `long`, in which case the right-hand argument is reduced modulo 64). For example, the value of `1 << 35` is the same as `1 << 3` or `8`.

C++ NOTE:

In C/C++, there is no guarantee as to whether >> performs an arithmetic shift (extending the sign bit) or a logical shift (filling in with zeroes). Implementors are free to choose whichever is more efficient. That means the C/C++ >> operator may yield implementation-dependent results for negative numbers. Java removes that uncertainty.

3.5.11 Parentheses and Operator Hierarchy

Table 3.4 shows the precedence of operators. If no parentheses are used, operations are performed in the hierarchical order indicated. Operators on the same level are processed from left to right, except for those that are right-associative, as indicated in the table. For example, `&&` has a higher precedence than `||`, so the expression

```
a && b || c
```

means

```
(a && b) || c
```

Since `+=` associates right to left, the expression

```
a += b += c
```

means

```
a += (b += c)
```

That is, the value of `b += c` (which is the value of `b` after the addition) is added to `a`.

Table 3.4 Operator Precedence

<table>
<tr><th>Operators</th><th>Associativity</th></tr>
<tr><td>[] . () (method call)</td><td>Left to right</td></tr>
<tr><td>! ~ ++ -- + (unary) - (unary) () (cast) new</td><td>Right to left</td></tr>
<tr><td>* / %</td><td>Left to right</td></tr>
<tr><td>+ -</td><td>Left to right</td></tr>
<tr><td><< >> >>></td><td>Left to right</td></tr>
<tr><td>< <= > >= instanceof</td><td>Left to right</td></tr>
<tr><td>== !=</td><td>Left to right</td></tr>
<tr><td>&</td><td>Left to right</td></tr>
<tr><td>^</td><td>Left to right</td></tr>
<tr><td>|</td><td>Left to right</td></tr>
<tr><td>&&</td><td>Left to right</td></tr>
<tr><td>||</td><td>Left to right</td></tr>
<tr><td>?:</td><td>Right to left</td></tr>
<tr><td>= += -= *= /= %= &= |= ^= <<= >>= >>>=</td><td>Right to left</td></tr>
</table>

C++ NOTE:

Unlike C or C++, Java does not have a comma operator. However, you can use a *comma-separated list of expressions* in the first and third slot of a `for` statement.

3.6 Strings

Conceptually, Java strings are sequences of Unicode characters. For example, the string `"Java\u2122"` consists of the five Unicode characters J, a, v, a, and ™ . Java does not have a built-in string type. Instead, the standard Java library contains a predefined class called, naturally enough, `String`. Each quoted string is an instance of the `String` class:

```
String e = ""; // an empty string
String greeting = "Hello";
```

3.6.1 Substrings

You can extract a substring from a larger string with the `substring` method of the `String` class. For example,

```
String greeting = "Hello";
String s = greeting.substring(0, 3);
```

creates a string consisting of the characters `"Hel"`.

NOTE:

Like C and C++, Java counts code units and code points in strings starting with `0`.

The second parameter of `substring` is the first position that you *do not* want to copy. In our case, we want to copy positions 0, 1, and 2 (from position 0 to position 2 inclusive). As `substring` counts it, this means from position 0 inclusive to position 3 *exclusive*.

There is one advantage to the way `substring` works: Computing the length of the substring is easy. The string `s.substring(a, b)` always has length `b` – `a`. For example, the substring `"Hel"` has length 3 – 0 = 3.

3.6.2 Concatenation

Java, like most programming languages, allows you to use `+` to join (concatenate) two strings.

```
String expletive = "Expletive";
String PG13 = "deleted";
String message = expletive + PG13;
```

The preceding code sets the variable `message` to the string `"Expletivedeleted"`. (Note the lack of a space between the words: The `+` operator joins two strings in the order received, *exactly* as they are given.)

When you concatenate a string with a value that is not a string, the latter is converted to a string. (As you will see in Chapter 5, every Java object can be converted to a string.) For example,

```
int age = 13;
String rating = "PG" + age;
```

sets `rating` to the string `"PG13"`.

This feature is commonly used in output statements. For example,

```
System.out.println("The answer is " + answer);
```

is perfectly acceptable and prints what you would expect (and with correct spacing because of the space after the word `is`).

If you need to put multiple strings together, separated by a delimiter, use the static `join` method:

```
String all = String.join(" / ", "S", "M", "L", "XL");
   // all is the string "S / M / L / XL"
```

As of Java 11, there is a `repeat` method:

```
String repeated = "Java".repeat(3); // repeated is
"JavaJavaJava"
```

3.6.3 Strings Are Immutable

The `String` class gives no methods that let you *change* a character in an existing string. If you want to turn `greeting` into `"Help!"`, you cannot directly change the last positions of `greeting` into `'p'` and `'!'`. If you are a C programmer, this can make you feel pretty helpless. How are we going to modify the string? In Java, it is quite easy: Concatenate the substring that you want to keep with the characters that you want to replace.

```
String greeting = "Hello";
greeting = greeting.substring(0, 3) + "p!";
```

This declaration changes the current value of the `greeting` variable to `"Help!"`.

Since you cannot change the individual characters in a Java string, the documentation refers to the objects of the `String` class as *immutable*. Just as the number `3` is always 3, the string `"Hello"` will always contain the code-unit sequence for the characters `H`, `e`, `l`, `l`, `o`. You cannot change these values. Yet you can, as you just saw, change the contents of the string *variable* `greeting` and make it refer to a different string, just as you can make a numeric variable currently holding the value `3` hold the value `4`.

Isn't that a lot less efficient? It would seem simpler to change the code units than to build up a whole new string from scratch. Well, yes and no. Indeed, it isn't efficient to generate a new string that holds the concatenation of `"Hel"` and `"p!"`. But immutable strings have one great advantage: The compiler can arrange that strings are *shared*.

To understand how this works, think of the various strings as sitting in a common pool. String variables then point to locations in the pool. If you copy a string variable, both the original and the copy share the same characters.

Overall, the designers of Java decided that the efficiency of sharing outweighs the inefficiency of string editing by extracting substrings and concatenating. Look at your own programs; most of the time, you probably don't change strings—you just compare them. (There is one common exception—assembling strings from individual characters or from shorter strings that come from the keyboard or a file. For these situations, Java provides a separate class—see Section 3.6.9, "Building Strings," on p. 73.)

C++ NOTE:

C programmers are generally bewildered when they see Java strings for the first time because they think of strings as arrays of characters:

```
char greeting[] = "Hello";
```

That is a wrong analogy: A Java string is roughly analogous to a `char*` pointer,

```
char* greeting = "Hello";
```

When you replace `greeting` with another string, the Java code does roughly the following:

```
char* temp = malloc(6);
strncpy(temp, greeting, 3);
strncpy(temp + 3, "p!", 3);
greeting = temp;
```

Sure, now `greeting` points to the string `"Help!"`. And even the most hardened C programmer must admit that the Java syntax is more pleasant than a sequence of `strncpy` calls. But what if we make another assignment to `greeting`?

```
greeting = "Howdy";
```

Don't we have a memory leak? After all, the original string was allocated on the heap. Fortunately, Java does automatic garbage collection. If a block of memory is no longer needed, it will eventually be recycled.

If you are a C++ programmer and use the `string` class defined by ANSI C++, you will be much more comfortable with the Java `String` type. C++ `string` objects also perform automatic allocation and deallocation of memory. The memory management is performed explicitly by constructors, assignment operators, and destructors. However, C++ strings are mutable—you can modify individual characters in a string.

3.6.4 Testing Strings for Equality

To test whether two strings are equal, use the `equals` method. The expression

```
s.equals(t)
```

returns `true` if the strings `s` and `t` are equal, `false` otherwise. Note that `s` and `t`

can be string variables or string literals. For example, the expression

```
"Hello".equals(greeting)
```

is perfectly legal. To test whether two strings are identical except for the upper/lowercase letter distinction, use the `equalsIgnoreCase` method.

```
"Hello".equalsIgnoreCase("hello")
```

Do *not* use the == operator to test whether two strings are equal! It only determines whether or not the strings are stored in the same location. Sure, if strings are in the same location, they must be equal. But it is entirely possible to store multiple copies of identical strings in different places.

```
String greeting = "Hello"; // initialize greeting to a string
if (greeting == "Hello") . . .
   // probably true
if (greeting.substring(0, 3) == "Hel") . . .
   // probably false
```

If the virtual machine always arranges for equal strings to be shared, then you could use the `==` operator for testing equality. But only string *literals* are shared, not strings that are the result of operations like `+` or `substring`. Therefore, *never* use `==` to compare strings lest you end up with a program with the worst kind of bug—an intermittent one that seems to occur randomly.

C++ NOTE:

If you are used to the C++ `string` class, you have to be particularly careful about equality testing. The C++ `string` class does overload the `==` operator to test for equality of the string contents. It is perhaps unfortunate that Java goes out of its way to give strings the same "look and feel" as numeric values but then makes strings behave like pointers for equality testing. The language designers could have redefined `==` for strings, just as they made a special arrangement for `+`. Oh well, every language has its share of inconsistencies.

C programmers never use `==` to compare strings but use `strcmp` instead. The Java method `compareTo` is the exact analog of `strcmp`. You can use

```
if (greeting.compareTo("Hello") == 0) . . .
```

but it seems clearer to use `equals` instead.

3.6.5 Empty and Null Strings

The empty string `""` is a string of length 0. You can test whether a string is empty by calling

```
if (str.length() == 0)
```

or

```
if (str.equals(""))
```

An empty string is a Java object which holds the string length (namely, `0`) and an empty contents. However, a `String` variable can also hold a special value, called `null`, that indicates that no object is currently associated with the variable. (See Chapter 4 for more information about `null`.) To test whether a string is `null`, use

```
if (str == null)
```

Sometimes, you need to test that a string is neither `null` nor empty. Then use

```
if (str != null && str.length() != 0)
```

You need to test that `str` is not `null` first. As you will see in Chapter 4, it is an error to invoke a method on a `null` value.

3.6.6 Code Points and Code Units

Java strings are sequences of `char` values. As you saw in Section 3.3.3, "The `char` Type," on p. 43, the `char` data type is a code unit for representing Unicode code points in the UTF-16 encoding. The most commonly used Unicode characters can be represented with a single code unit. The supplementary characters require a pair of code units.

The `length` method yields the number of code units required for a given string in the UTF-16 encoding. For example:

```
String greeting = "Hello";
int n = greeting.length(); // is 5
```

To get the true length—that is, the number of code points—call

```
int cpCount = greeting.codePointCount(0, greeting.length());
```

The call `s.charAt(n)` returns the code unit at position `n`, where `n` is between `0` and `s.length()` – 1. For example:

```
char first = greeting.charAt(0); // first is 'H'
char last = greeting.charAt(4); // last is 'o'
```

To get at the `i`th code point, use the statements

```
int index = greeting.offsetByCodePoints(0, i);
int cp = greeting.codePointAt(index);
```

What is the fuss about code units? Consider the sentence

𝕆 is the set of octonions.

The character (`U+1D546`) requires two code units in the UTF-16 encoding. Calling

```
char ch = sentence.charAt(1)
```

doesn't return a space but the second code unit of . To avoid this problem, you should not use the `char` type. It is too low-level.

NOTE:

Don't think that you can ignore exotic characters with code units above U+FFFF. Your emoji-loving users may put characters such as (U+1F37A, beer mug) into strings.

If your code traverses a string, and you want to look at each code point in turn, you can use these statements:

```
int cp = sentence.codePointAt(i);
if (Character.isSupplementaryCodePoint(cp)) i += 2;
else i++;
```

You can move backwards with the following statements:

```
i--;
if (Character.isSurrogate(sentence.charAt(i))) i--;
int cp = sentence.codePointAt(i);
```

Obviously, that is quite painful. An easier way is to use the `codePoints` method that yields a "stream" of `int` values, one for each code point. (Streams are covered in Volume II.) You can just turn the stream into an array (see Section 3.10, "Arrays," on p. 109) and traverse that.

```
int[] codePoints = str.codePoints().toArray();
```

Conversely, to turn an array of code points to a string, use a *constructor*. (Chapter 4 covers constructors and the `new` operator in detail.)

```
String str = new String(codePoints, 0, codePoints.length);
```

To turn a single code point into a string, use the `Character.toString(int)` method:

```
int codePoint = 0x1F37A;
str = Character.toString(codePoint);
```

NOTE:

The virtual machine does not have to implement strings as sequences of code units. A more compact representation is used as of Java 9. Strings that hold only single-byte code units use a `byte` array, and all others a `char` array.

3.6.7 The `String` API

The `String` class in Java contains close to 100 methods. The following API note summarizes the most useful ones.

These API notes, found throughout the book, will help you understand the Java Application Programming Interface (API). Each API note starts with the name of a class, such as `java.lang.String`. (The significance of the so-called *package* name `java.lang` is explained in Chapter 4.) The class name is followed by the names, explanations, and parameter descriptions of one or more methods.

The API notes do not list all methods of a particular class but present the most commonly used ones in a concise form. For a full listing, consult the online documentation (see Section 3.6.8, "Reading the Online API Documentation," on p. 70).

The number following the class name is the JDK version number in which it was introduced. If a method has been added later, it has a separate version number.

`java.lang.String` 1.0

- `char charAt(int index)`

  returns the code unit at the specified location. You probably don't want to call this method unless you are interested in low-level code units.

- `int codePointAt(int index)` 5

  returns the code point that starts at the specified location.

- `int offsetByCodePoints(int startIndex, int cpCount)` 5

  returns the index of the code point that is `cpCount` code points away from the code point at `startIndex`.

- `int compareTo(String other)`

  returns a negative value if the string comes before `other` in dictionary order, a positive value if the string comes after `other` in dictionary order, or `0` if the strings are equal.

- `IntStream codePoints()` 8

  returns the code points of this string as a stream. Call `toArray` to put them in an array.

- `new String(int[] codePoints, int offset, int count)` 5

  constructs a string with the `count` code points in the array starting at `offset`.

- `boolean isEmpty()`

  `boolean isBlank()` 11

  returns `true` if the string is empty or consists of whitespace.

- `boolean equals(Object other)`

  returns `true` if the string equals `other`.

- `boolean equalsIgnoreCase(String other)`

  returns `true` if the string equals `other`, except for upper/lowercase distinction.

- `boolean startsWith(String prefix)`
- `boolean endsWith(String suffix)`

  returns `true` if the string starts with `prefix` or ends with `suffix`.

- `int indexOf(String str)`
- `int indexOf(String str, int fromIndex)`

- `int indexOf(int cp)`
- `int indexOf(int cp, int fromIndex)`

  returns the start of the first substring equal to the string `str` or the code point `cp`, starting at index `0` or at `fromIndex`, or `-1` if `str` or `cp` does not occur in this string.

- `int lastIndexOf(String str)`
- `int lastIndexOf(String str, int fromIndex)`
- `int lastindexOf(int cp)`
- `int lastindexOf(int cp, int fromIndex)`

  returns the start of the last substring equal to the string `str` or the code point `cp`, starting at the end of the string or at `fromIndex`, or `-1` if `str` or `cp` does not occur.

- `int length()`

  returns the number of code units of the string.

- `int codePointCount(int startIndex, int endIndex)` 5

  returns the number of code points between `startIndex` and `endIndex` – 1.

- `String replace(CharSequence oldString, CharSequence newString)`

  returns a new string that is obtained by replacing all substrings matching `oldString` in the string with the string `newString`. You can supply `String` or `StringBuilder` objects for the `CharSequence` parameters.

- `String substring(int beginIndex)`
- `String substring(int beginIndex, int endIndex)`

  returns a new string consisting of all code units from `beginIndex` until the end of the string or until `endIndex` – 1.

- `String toLowerCase()`
- `String toUpperCase()`

returns a new string containing all characters in the original string, with uppercase characters converted to lowercase, or lowercase characters converted to uppercase.

- `String strip()` **11**

  `String stripLeading()` **11**

  `String stripTrailing()` **11**

  return a new string by eliminating leading and trailing, or just leading or traling whitespace in the original string. Use these methods instead of the archaic `trim` method that eliminates characters ≤ U+0020.

- `String join(CharSequence delimiter, CharSequence... elements)` **8**

  returns a new string joining all elements with the given delimiter.

- `String repeat(int count)` **11**

  returns a string that repeats this string `count` times.

NOTE:

In the API notes, there are a few parameters of type `CharSequence`. This is an *interface* type to which all strings belong. You will learn about interface types in Chapter 6. For now, you just need to know that you can pass arguments of type `String` whenever you see a `CharSequence` parameter.

3.6.8 Reading the Online API Documentation

As you just saw, the `String` class has lots of methods. Furthermore, there are thousands of classes in the standard libraries, with many more methods. It is plainly impossible to remember all useful classes and methods. Therefore, it is essential that you become familiar with the online API documentation that lets you look up all classes and methods in the standard library. You can download the API documentation from Oracle and save it locally, or you can point your browser to https://docs.oracle.com/en/java/javase/11/docs/api.

As of Java 9, the API documentation has a search box (see Figure 3.2). Older versions have frames with lists of packages and classes. You can still get those lists by clicking on the Frames menu item. For example, to get more information on the methods of the `String` class, type “String” into the search box and select the type `java.lang.String`, or locate the link in the frame with class names and click it. You get the class description, as shown in Figure 3.3.

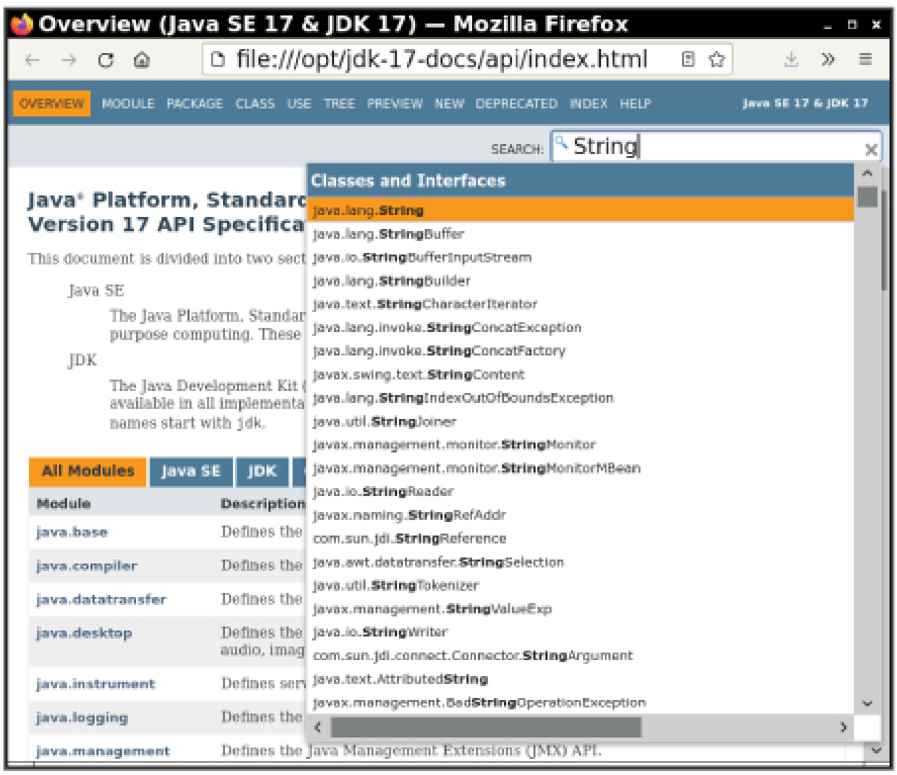


Figure 3.2 The Java API documentation

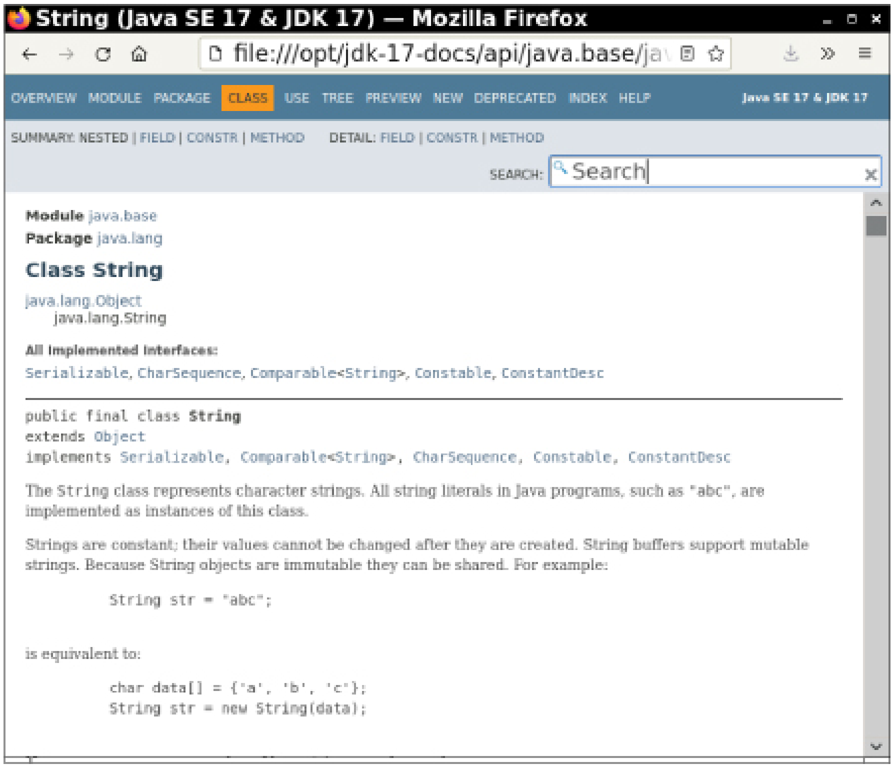


Figure 3.3 Class description for the `String` class

When you scroll down, you reach a summary of all methods, sorted in alphabetical order (see Figure 3.4). Click on any method name for a detailed description of that method (see Figure 3.5). For example, if you click on the compareToIgnoreCase link, you'll get the description of the `compareToIgnoreCase` method.

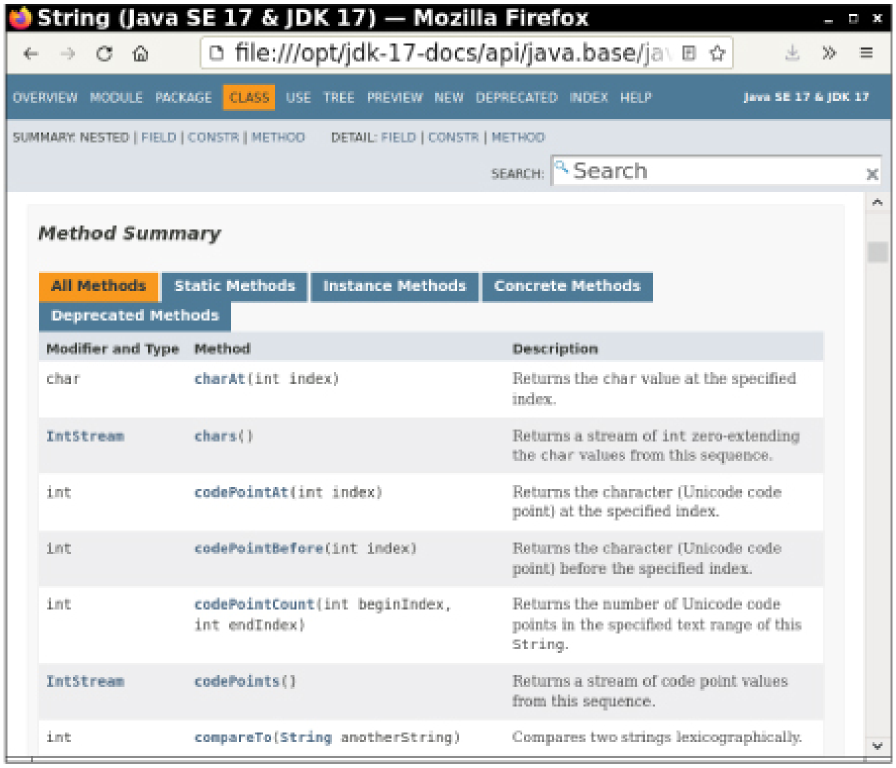


Figure 3.4 Method summary of the `String` class

Figure 3.5 Detailed description of a `String` method

TIP:

If you have not already done so, download the JDK documentation, as described in Chapter 2. Bookmark the `index.html` page of the documentation in your browser right now!

3.6.9 Building Strings

Occasionally, you need to build up strings from shorter strings, such as keystrokes or words from a file. It would be inefficient to use string concatenation for this purpose. Every time you concatenate strings, a new `String` object is constructed. This is time consuming and wastes memory. Using the `StringBuilder` class avoids this problem.

Follow these steps if you need to build a string from many small pieces. First, construct an empty string builder:

```
StringBuilder builder = new StringBuilder();
```

Each time you need to add another part, call the `append` method.

```
builder.append(ch); // appends a single character
builder.append(str); // appends a string
```

When you are done building the string, call the `toString` method. You will get a `String` object with the character sequence contained in the builder.

```
String completedString = builder.toString();
```

NOTE:

The `StringBuffer` class is less efficient than `StringBuilder`, but it allows multiple threads to add or remove characters. If all string editing happens in a single thread (which is usually the case), you should use `StringBuilder`. The APIs of both classes are identical.

The following API notes contain the most important methods for the `StringBuilder` class.

java.lang.StringBuilder 5

- `StringBuilder()`

  constructs an empty string builder.

- `int length()`

  returns the number of code units of the builder or buffer.

- `StringBuilder append(String str)`

  appends a string and returns `this`.

- `StringBuilder append(char c)`

  appends a code unit and returns `this`.

- `StringBuilder appendCodePoint(int cp)`

  appends a code point, converting it into one or two code units, and returns `this`.

- `void setCharAt(int i, char c)`

  sets the `i`th code unit to `c`.

- `StringBuilder insert(int offset, String str)`

  inserts a string at position `offset` and returns `this`.

- `StringBuilder insert(int offset, char c)` inserts a code unit at position `offset` and returns `this`.

- `StringBuilder delete(int startIndex, int endIndex)`

  deletes the code units with offsets `startIndex` to `endIndex` – 1 and returns `this`.

- `String toString()`

  returns a string with the same data as the builder or buffer contents.

3.6.10 Text Blocks

The text block feature, added in Java 15, makes it easy to provide string literals that span multiple lines. A text block starts with `"""`, followed by a line feed. The block ends with another `"""`:

```
String greeting = """
Hello
World
""";
```

A text block is easier to read and write than the equivalent string literal:

```
"Hello\nWorld\n"
```

This string contains two `\n`: one after `Hello` and one after `World`. The newline after the opening `"""` is not included in the string literal.

If you don't want a newline after the last line, put the closing `"""` immediately after the last character:

```
String prompt = """
Hello, my name is Hal.
Please enter your name: """;
```

Text blocks are particularly suited for including code in some other language, such as SQL or HTML. You can just paste it between the triple quotes:

```
String html = """
<div class="Warning">
   Beware of those who say "Hello" to the world
</div>
""";
```

Note that you don't have to escape the quotation marks. There are just two situations where you need to escape them:

- If the text block *ends* in a quotation mark
- If the text block contains a sequence of three or more quotation marks

Unfortunately, you still need to escape all backslashes.

All escape sequences from regular strings work the same way in text blocks.

There is one escape sequence that only works in text blocks. A `\` directly before the end of a line joins this line and the next. For example,

```
"""
Hello, my name is Hal. \
Please enter your name: """;
```

is the same as

```
"Hello, my name is Hal. Please enter your name: "
```

Line endings are normalized by removing trailing whitespace and changing any Windows line endings (`\r\n`) to simple newlines (`\n`). In the unlikely case that you need to preserve trailing spaces, turn the last one into a `\s` escape.

The story is more complex for leading white space. Consider a typical variable declaration that is indented from the left margin. You can indent the text block as well:

```
String html = """
   <div class="Warning">
      Beware of those who say "Hello" to the world
   </div>
""";
```

The indentation that is common to all lines in the text block is subtracted. The actual string is

```
"<div class=\"Warning\">\n  Beware of those who say \"Hello\"
to the world\n</div>\n"
```

Note that there are no indentations in the first and third line.

Your IDE may cheerfully offer to indent all text blocks, using only tabs, only spaces, or an appropriate mix.

Java wisely does not prescribe the width of a tab. The white space prefix has to match *exactly* for all lines in the text block.

Entirely blank lines are not considered in the indentation removal process. However, the white space before the closing `"""` is significant. Be sure to indent to the end of the white space that you want to have stripped.

CAUTION:

Be careful about mixed tabs and spaces in the common prefix of an indented text block. An overlooked space can easily yield a wrongly indented string.

TIP:

If a text block contains code that isn't Java, you may actually prefer to place it at the left margin. It stands out from the Java code, and you have more room for long lines.

3.7 Input and Output

To make our example programs more interesting, we want to accept input and properly format the program output. Of course, modern programs use a GUI for collecting user input. However, programming such an interface requires more tools and techniques than we have at our disposal at this time. Our first order of business is to become more familiar with the Java programming language, so we use the humble console for input and output.

3.7.1 Reading Input

You saw that it is easy to print output to the "standard output stream" (that is, the console window) just by calling `System.out.println`. Reading from the "standard input stream" `System.in` isn't quite as simple. To read console input, you first construct a `Scanner` that is attached to `System.in`:

```
Scanner in = new Scanner(System.in);
```

(Constructors and the `new` operator are discussed in detail in Chapter 4.)

Now you can use the various methods of the `Scanner` class to read input. For example, the `nextLine` method reads a line of input.

```
System.out.print("What is your name? ");
String name = in.nextLine();
```

Here, we use the `nextLine` method because the input might contain spaces. To read a single word (delimited by whitespace), call

```
String firstName = in.next();
```

To read an integer, use the `nextInt` method.

```
System.out.print("How old are you? ");
int age = in.nextInt();
```

Similarly, the `nextDouble` method reads the next floating-point number.

The program in Listing 3.2 asks for the user's name and age and then prints a message like

```
Hello, Cay. Next year, you'll be 57
```

Finally, note the line

```
import java.util.*;
```

at the beginning of the program. The `Scanner` class is defined in the `java.util` package. Whenever you use a class that is not defined in the basic `java.lang` package, you need to use an `import` directive. Packages and `import` directives are covered in more detail in Chapter 4.

Listing 3.2 `InputTest/InputTest.java`

```
import java.util.*;

/**
 * This program demonstrates console input.
 * @version 1.10 2004-02-10
 * @author Cay Horstmann
 */
public class InputTest
{
   public static void main(String[] args)
   {
```

```
        Scanner in = new Scanner(System.in);

        // get first input
        System.out.print("What is your name? ");
        String name = in.nextLine();

        // get second input
        System.out.print("How old are you? ");
        int age = in.nextInt();

        // display output on console
        System.out.println("Hello, " + name + ". Next year, you'll be " + (age + 1));
    }
}
```

NOTE:

The `Scanner` class is not suitable for reading a password from a console since the input is plainly visible to anyone. Use the `Console` class for this purpose. To read a password, use the following code:

```
Console cons = System.console();
String username = cons.readLine("User name: ");
char[] passwd = cons.readPassword("Password: ");
```

For security reasons, the password is returned in an array of characters rather than a string. After you are done processing the password, you should immediately overwrite the array elements with a filler value. (Array processing is discussed in Section 3.10, "Arrays," on p. 109.)

Input processing with a `Console` object is not as convenient as with a `Scanner`. You must read the input a line at a time. There are no methods for reading individual words or numbers.

java.util.Scanner 5

- `Scanner(InputStream in)`

  constructs a `Scanner` object from the given input stream.

- `String nextLine()`

  reads the next line of input.

- `String next()`

  reads the next word of input (delimited by whitespace).

- `int nextInt()`
- `double nextDouble()`

  reads and converts the next character sequence that represents an integer or floating-point number.

- `boolean hasNext()`

  tests whether there is another word in the input.

- `boolean hasNextInt()`
- `boolean hasNextDouble()`

  tests whether the next character sequence represents an integer or floating-point number.

java.lang.System 1.0

- `static Console console()` 6

  returns a `Console` object for interacting with the user through a console window if such interaction is possible, `null` otherwise. A `Console` object is available for any program that is launched in a console window. Otherwise, the availability is system-dependent.

java.io.Console 6

- `static char[] readPassword(String prompt, Object... args)`
- `static String readLine(String prompt, Object... args)`

  displays the prompt and reads the user input until the end of the input line. The optional `args` parameters are used to supply formatting arguments, as described in the next section.

3.7.2 Formatting Output

You can print a number `x` to the console with the statement `System.out.print(x)`. That command will print `x` with the maximum number of nonzero digits for that type. For example,

```
double x = 10000.0 / 3.0;
System.out.print(x);
```

prints

```
3333.3333333333335
```

That is a problem if you want to display, for example, dollars and cents.

The remedy is the `printf` method, which follows the venerable conventions from the C library. For example, the call

```
System.out.printf("%8.2f", x);
```

prints `x` with a *field width* of 8 characters and a *precision* of 2 characters. That is, the printout contains a leading space and the seven characters

```
3333.33
```

You can supply multiple parameters to `printf`. For example:

```
System.out.printf("Hello, %s. Next year, you'll be %d", name,
age);
```

Each of the *format specifiers* that start with a `%` character is replaced with the corresponding argument. The *conversion character* that ends a format specifier indicates the type of the value to be formatted: `f` is a floating-point number, `s` a string, and `d` a decimal integer. Table 3.5 shows all conversion characters.

The uppercase variants produce uppercase letters. For example, `"%8.2E"` formats 3333.33 as `3.33E+03`, with an uppercase `E`.

Table 3.5 Conversions for `printf`

Conversion Character	Type	Example
d	Decimal integer	159
x or X	Hexadecimal integer. For more control over hexadecimal formatting, use the HexFormat class.	9f
o	Octal integer	237
f or F	Fixed-point floating-point	15.9
e or E	Exponential floating-point	1.59e+01
g or G	General floating-point (the shorter of e and f)	—
a or A	Hexadecimal floating-point	0x1.fccdp3
s or S	String	Hello
c or C	Character	H
b or B	boolean	true
h or H	Hash code	42628b2
tx or Tx	Legacy date and time formatting. Use the java.time classes instead—see Chapter 6 of Volume II.	—
%	The percent symbol	%
n	The platform-dependent line separator	—

NOTE:

You can use the `s` conversion to format arbitrary objects. If an arbitrary object implements the `Formattable` interface, the object's `formatTo` method is invoked. Otherwise, the `toString` method is invoked to turn the object into a string. The `toString` method is discussed in Chapter 5 and interfaces in Chapter 6.

In addition, you can specify *flags* that control the appearance of the formatted output. Table 3.6 shows all flags. For example, the comma flag adds group separators. That is,

```
System.out.printf("%,.2f", 10000.0 / 3.0);
```

prints

```
3,333.33
```

You can use multiple flags, for example `"%,(.2f"` to use group separators and enclose negative numbers in parentheses.

Table 3.6 Flags for `printf`

Flag	Purpose	Example
+	Prints sign for positive and negative numbers.	+3333.33
space	Adds a space before positive numbers.	| 3333.33|
0	Adds leading zeroes.	003333.33
-	Left-justifies field.	|3333.33 |
(	Encloses negative numbers in parentheses.	(3333.33)
,	Adds group separators.	3,333.33
# (for `f` format)	Always includes a decimal point.	3,333.
# (for `x` or `o` format)	Adds `0x` or `0` prefix.	0xcafe
$	Specifies the index of the argument to be formatted; for example, `%1$d %1$x` prints the first argument in decimal and hexadecimal.	159 9F
<	Formats the same value as the previous specification; for example, `%d %<x` prints the same number in decimal and hexadecimal.	159 9F

You can use the static `String.format` method to create a formatted string without printing it:

```
String message = String.format("Hello, %s. Next year, you'll be
%d", name, age + 1);
```

NOTE:

As of Java 15, you can use the `formatted` method instead, saving you five characters:

```
String message = "Hello, %s. Next year, you'll be %d".formatted(name, age + 1);
```

You have now seen all features of the `printf` method. Figure 3.6 shows a syntax diagram for format specifiers.

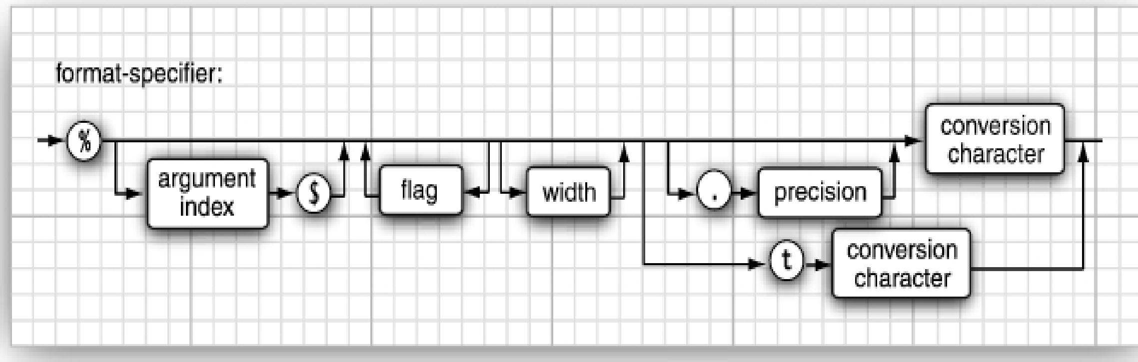


Figure 3.6 Format specifier syntax

NOTE:

Formatting is *locale-specific*. For example, in Germany, the group separator is a period, not a comma. Chapter 7 of Volume II shows how to control the international behavior of your applications.

3.7.3 File Input and Output

To read from a file, construct a `Scanner` object like this:

```
Scanner in = new Scanner(Path.of("myfile.txt"),
StandardCharsets.UTF_8);
```

If the file name contains backslashes, remember to escape each of them with an additional backslash: `"c:\\mydirectory\\myfile.txt"`.

Now you can read from the file, using any of the `Scanner` methods that you already encountered.

NOTE:

Here, we specify the UTF-8 character encoding, which is common (but not universal) for files on the Internet. You need to know the character encoding when you read a text file (see Volume II, Chapter 2 for more information). If you omit the character encoding, then the "default encoding" of the computer running the Java program is used. That is not a good idea—the program might act differently depending on where it is run.

CAUTION:

You can construct a `Scanner` with a string parameter, but the scanner interprets the string as data, not a file name. For example, if you call

---

```
Scanner in = new Scanner("myfile.txt"); // ERROR?
```

then the scanner will see ten characters of data: `'m'`, `'y'`, `'f'`, and so on. That is probably not what was intended in this case.

To write to a file, construct a `PrintWriter` object. In the constructor, supply the file name and the character encoding:

```
PrintWriter out = new PrintWriter("myfile.txt",
StandardCharsets.UTF_8);
```

If the file does not exist, it is created. You can use the `print`, `println`, and `printf`

commands as you did when printing to `System.out`.

NOTE:

When you specify a relative file name, such as `"myfile.txt"`, `"mydirectory/myfile.txt"`, or `"../myfile.txt"`, the file is located relative to the directory in which the Java virtual machine was started. If you launched your program from a command shell, by executing

```
java MyProg
```

then the starting directory is the current directory of the command shell. However, if you use an integrated development environment, it controls the starting directory. You can find the directory location with this call:

```
String dir = System.getProperty("user.dir");
```

If you run into grief with locating files, consider using absolute path names such as `"c:\\mydirectory\\myfile.txt"` or `"/home/me/mydirectory/myfile.txt"`.

As you saw, you can access files just as easily as you can use `System.in` and `System.out`. There is just one catch: If you construct a `Scanner` with a file that does not exist or a `PrintWriter` with a file name that cannot be created, an exception occurs. The Java compiler considers these exceptions to be more serious than a "divide by zero" exception, for example. In Chapter 7, you will learn various ways of handling exceptions. For now, you should simply tell the compiler that you are aware of the possibility of an "input/output" exception. You do this by tagging the `main` method with a `throws` clause, like this:

```
public static void main(String[] args) throws IOException
{
   Scanner in = new Scanner(Path.of("myfile.txt"),
StandardCharsets.UTF_8);
   . . .
}
```

You have now seen how to read and write files that contain textual data. For more advanced topics, such as dealing with different character encodings, processing binary data, reading directories, and writing zip files, turn to Chapter 2 of Volume II.

NOTE:

When you launch a program from a command shell, you can use the redirection syntax of your shell and attach any file to `System.in` and `System.out`:

```
java MyProg < myfile.txt > output.txt
```

Then, you need not worry about handling the `IOException`.

`java.util.Scanner` 5

- `Scanner(Path p, String encoding)`

  constructs a `Scanner` that reads data from the given path, using the given character encoding.

- `Scanner(String data)`

  constructs a `Scanner` that reads data from the given string.

java.io.PrintWriter 1.1

- `PrintWriter(String fileName)`

  constructs a `PrintWriter` that writes data to the file with the given file name.

java.nio.file.Path

- `static Path of(String pathname)` 11

  constructs a `Path` from the given path name.

3.8 Control Flow

Java, like any programming language, supports both conditional statements and loops to determine control flow. I will start with the conditional statements, then move on to loops, to end with the `switch` statement that you can use to test for many values of a single expression.

C++ NOTE:

The Java control flow constructs are identical to those in C and C++, with a few exceptions. There is no `goto`, but there is a "labeled" version of `break` that you can use to break out of a nested loop (where, in C, you perhaps would have used a `goto`). Finally, there is a variant of the `for` loop that is similar to the range-based `for` loop in C++ and the `foreach` loop in C#.

3.8.1 Block Scope

Before learning about control structures, you need to know more about *blocks*.

A block, or compound statement, consists of a number of Java statements, surrounded by a pair of braces. Blocks define the scope of your variables. A block can be *nested* inside another block. Here is a block that is nested inside the block of the `main` method:

```
public static void main(String[] args)
{
  int n;
  . . .
  {
    int k;
    . . .
  } // k is only defined up to here
}
```

You may not declare identically named local variables in two nested blocks. For example, the following is an error and will not compile:

```
public static void main(String[] args)
{
  int n;
  . . .
  {
    int k;
    int n; // ERROR--can't redeclare n in inner block
    . . .
  }
}
```

C++ NOTE:

In C++, it is possible to redefine a variable inside a nested block. The inner definition then shadows the outer one. This can be a source of programming errors; hence, Java does not allow it.

3.8.2 Conditional Statements

The conditional statement in Java has the form

```
if (condition) statement
```

The condition must be surrounded by parentheses.

In Java, as in most programming languages, you will often want to execute multiple statements when a single condition is true. In this case, use a *block statement* that takes the form

```
{
   statement1
   statement2
   . . .
}
```

For example:

```
if (yourSales >= target)
{
   performance = "Satisfactory";
   bonus = 100;
}
```

In this code all the statements surrounded by the braces will be executed when `yourSales` is greater than or equal to `target` (see Figure 3.7).

NOTE:

A block (sometimes called a *compound statement*) enables you to have more than one (simple) statement in any Java programming structure that otherwise allows for a single (simple) statement.

The more general conditional in Java looks like this (see Figure 3.8):

`if (`*condition*`)` *statement*$_1$ `else` *statement*$_2$

For example:

```
if (yourSales >= target)
{
   performance = "Satisfactory";
   bonus = 100 + 0.01 * (yourSales - target);
}
```

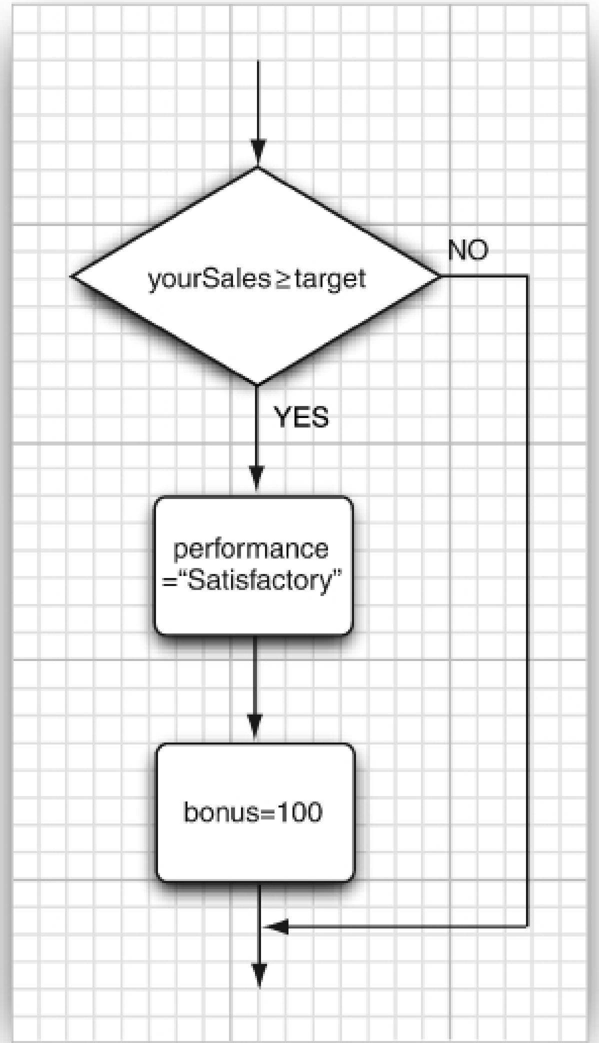


Figure 3.7 Flowchart for the `if` statement

```
else
{
   performance = "Unsatisfactory";
   bonus = 0;
}
```

The `else` part is always optional. An `else` groups with the closest `if`. Thus, in the statement

```
if (x <= 0) if (x == 0) sign = 0; else sign = -1;
```

the `else` belongs to the second `if`. Of course, it is a good idea to use braces to clarify this code:

```
if (x <= 0) { if (x == 0) sign = 0; else sign = -1; }
```

Repeated `if . . . else if . . .` alternatives are common (see Figure 3.9). For example:

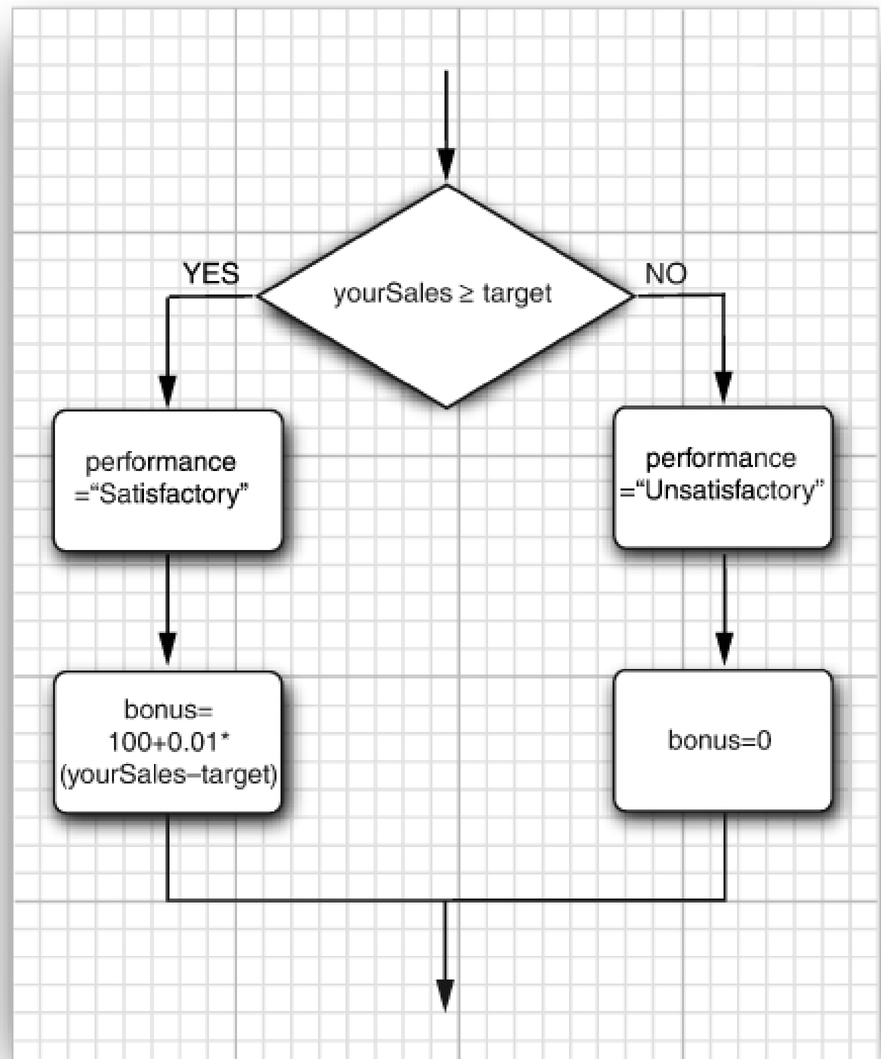


Figure 3.8 Flowchart for the `if/else` statement

```
if (yourSales >= 2 * target)
{
   performance = "Excellent";
   bonus = 1000;
}
else if (yourSales >= 1.5 * target)
{
   performance = "Fine";
   bonus = 500;
}
else if (yourSales >= target)
{
   performance = "Satisfactory";
   bonus = 100;
}
else
{
   System.out.println("You're fired");
}
```

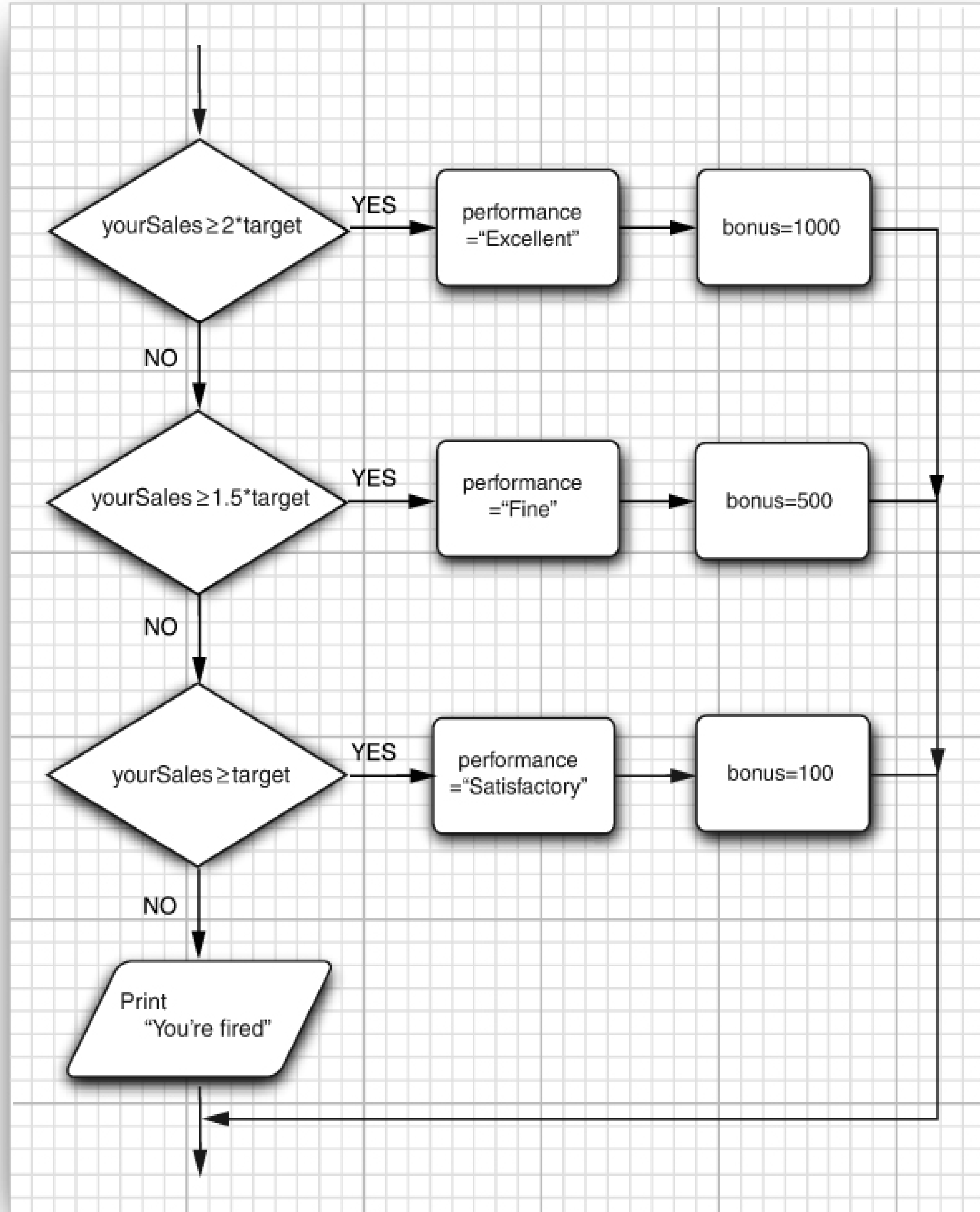


Figure 3.9 Flowchart for the `if/else if` (multiple branches)

3.8.3 Loops

The `while` loop executes a statement (which may be a block statement) while a condition is `true`. The general form is

`while (`*condition*`)` *statement*

The `while` loop will never execute if the condition is `false` at the outset (see Figure 3.10).

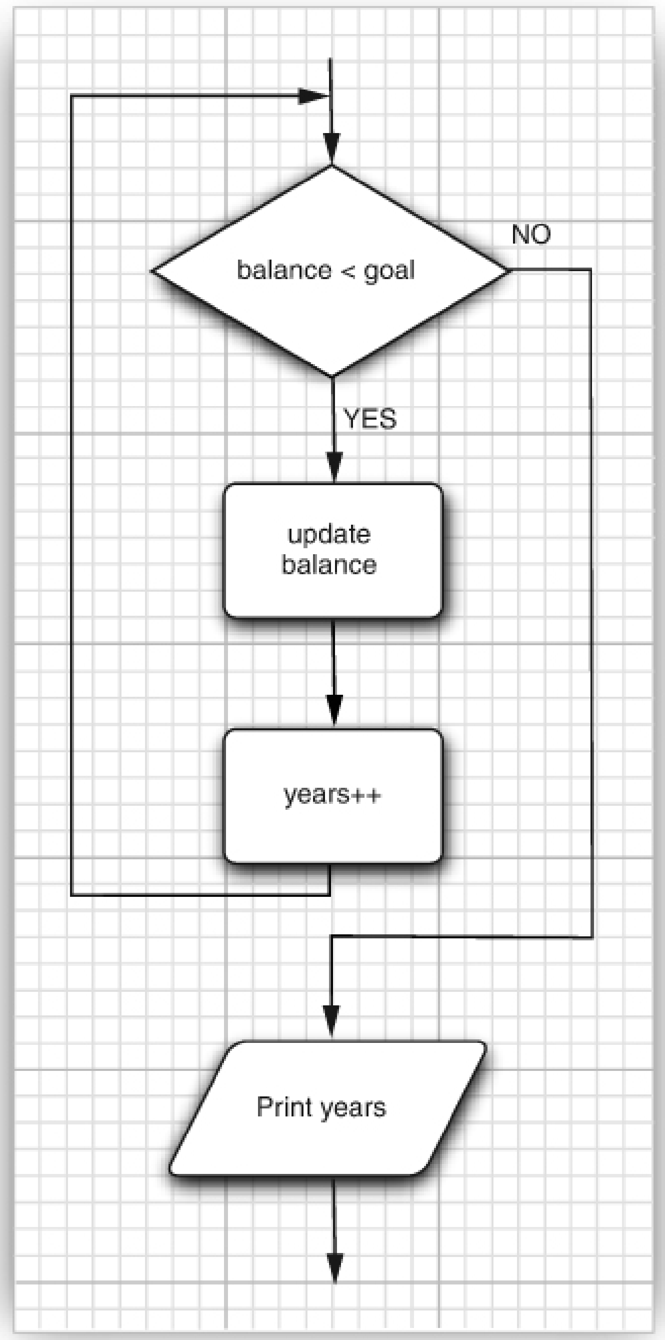


Figure 3.10 Flowchart for the `while` statement

The program in Listing 3.3 determines how long it will take to save a specific amount of money for your well-earned retirement, assuming you deposit the same amount of money per year and the money earns a specified interest rate. In the example, we are incrementing a counter and updating the amount currently accumulated in the body of the loop until the total exceeds the targeted amount.

```
while (balance < goal)
{
   balance += payment;
   double interest = balance * interestRate / 100;
   balance += interest;
   years++;
}
System.out.println(years + " years.");
```

(Don't rely on this program to plan for your retirement. It lacks a few niceties such as inflation and your life expectancy.)

A `while` loop tests at the top. Therefore, the code in the block might never be executed. If you want to make sure a block is executed at least once, you need to move the test to the bottom, using the `do/while` loop. Its syntax looks like this:

`do` *statement* `while (`*condition*`);`

This loop executes the statement (which is typically a block) and only then tests the condition. If it's `true`, it repeats the statement and retests the condition, and so on. The code in Listing 3.4 computes the new balance in your retirement account and then asks if you are ready to retire:

```
do
{
   balance += payment;
   double interest = balance * interestRate / 100;
   balance += interest;
   years++;
   // print current balance
   . . .
   // ask if ready to retire and get input
   . . .
```

```
}
while (input.equals("N"));
```

As long as the user answers `"N"`, the loop is repeated (see Figure 3.11). This program is a good example of a loop that needs to be entered at least once, because the user needs to see the balance before deciding whether it is sufficient for retirement.

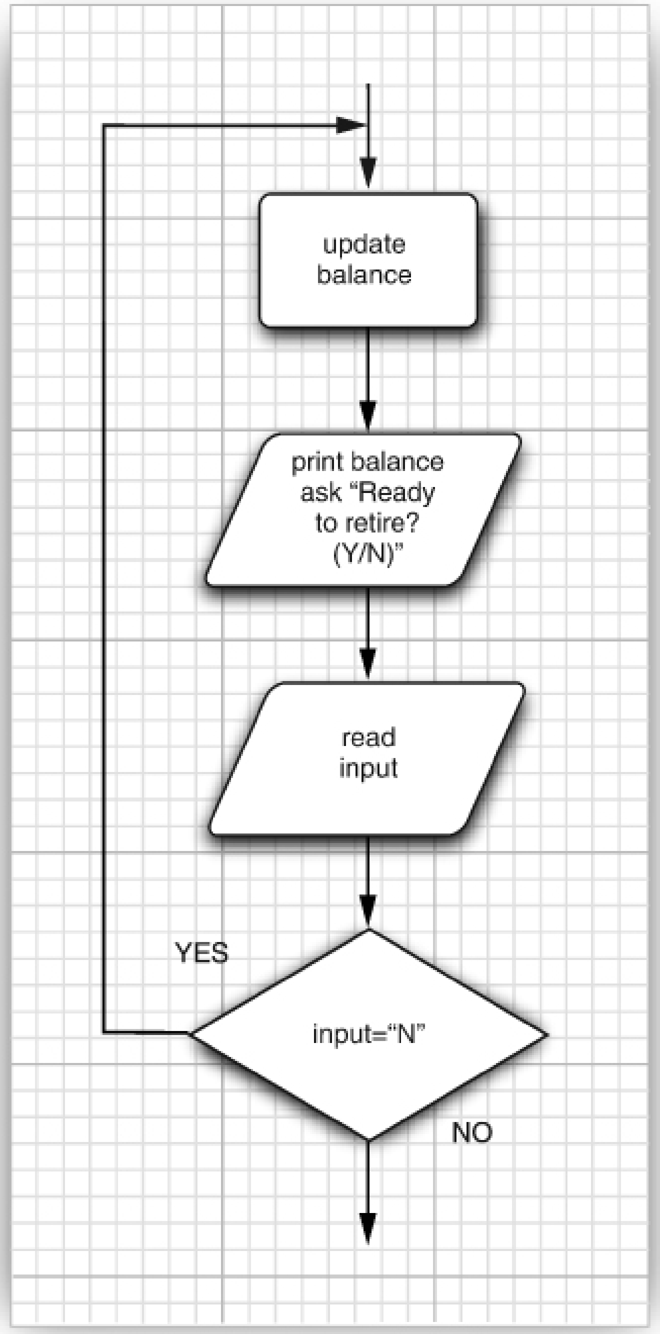


Figure 3.11 Flowchart for the `do/while` statement

Listing 3.3 `Retirement/Retirement.java`

```java
import java.util.*;

/**
 * This program demonstrates a <code>while</code> loop.
 * @version 1.20 2004-02-10
 * @author Cay Horstmann
 */
public class Retirement
{
   public static void main(String[] args)
   {
      // read inputs
      Scanner in = new Scanner(System.in);

      System.out.print("How much money do you need to retire? ");
      double goal = in.nextDouble();

      System.out.print("How much money will you contribute every year? ");
      double payment = in.nextDouble();

      System.out.print("Interest rate in %: ");
      double interestRate = in.nextDouble();

      double balance = 0;
      int years = 0;

      // update account balance while goal isn't reached
      while (balance < goal)
      {
         // add this year's payment and interest
         balance += payment;
         double interest = balance * interestRate / 100;
         balance += interest;
         years++;
      }

      System.out.println("You can retire in " + years + " years.");
```

```
   }
}
```

Listing 3.4 `Retirement2/Retirement2.java`

```
import java.util.*;

/**
 * This program demonstrates a <code>do/while</code> loop.
 * @version 1.20 2004-02-10
 * @author Cay Horstmann
 */
public class Retirement2
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);

      System.out.print("How much money will you contribute every year? ");
      double payment = in.nextDouble();

      System.out.print("Interest rate in %: ");
      double interestRate = in.nextDouble();

      double balance = 0;
      int year = 0;

      String input;

      // update account balance while user isn't ready to retire
      do
      {
         // add this year's payment and interest
         balance += payment;
         double interest = balance * interestRate / 100;
         balance += interest;
```

```
            year++;

            // print current balance
            System.out.printf("After year %d, your balance is %,.2f%n", year, balance);

            // ask if ready to retire and get input
            System.out.print("Ready to retire? (Y/N) ");
            input = in.next();
         }
         while (input.equals("N"));
      }
   }
```

3.8.4 Determinate Loops

The `for` loop is a general construct to support iteration controlled by a counter or similar variable that is updated after every iteration. As Figure 3.12 shows, the following loop prints the numbers from 1 to 10 on the screen:

```
for (int i = 1; i <= 10; i++)
   System.out.println(i);
```

The first slot of the `for` statement usually holds the counter initialization. The second slot gives the condition that will be tested before each new pass through the loop, and the third slot specifies how to update the counter.

Although Java, like C++, allows almost any expression in the various slots of a `for` loop, it is an unwritten rule of good taste that the three slots should only initialize, test, and update the same counter variable. One can write very obscure loops by disregarding this rule.

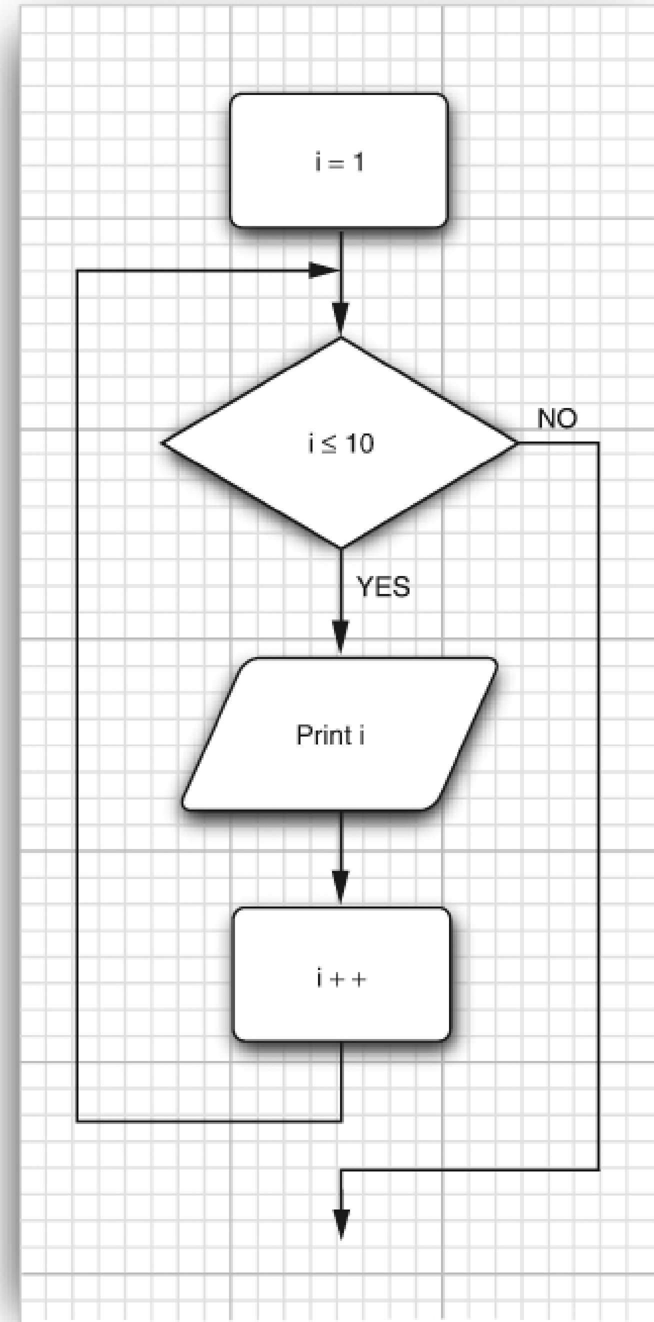


Figure 3.12 Flowchart for the `for` statement

Even within the bounds of good taste, much is possible. For example, you can have loops that count down:

```
for (int i = 10; i > 0; i--)
   System.out.println("Counting down . . . " + i);
System.out.println("Blastoff!");
```

CAUTION:

Be careful with testing for equality of floating-point numbers in loops. A `for` loop like this one

```
for (double x = 0; x != 10; x += 0.1) . . .
```

might never end. Because of roundoff errors, the final value might not be reached exactly. In this example, `x` jumps from `9.99999999999998` to `10.09999999999998` because there is no exact binary representation for 0.1.

When you declare a variable in the first slot of the `for` statement, the scope of that variable extends until the end of the body of the `for` loop.

```
for (int i = 1; i <= 10; i++)
{
   . . .
}
// i no longer defined here
```

In particular, if you define a variable inside a `for` statement, you cannot use its value outside the loop. Therefore, if you wish to use the final value of a loop counter outside the `for` loop, be sure to declare it outside the loop header.

```
int i;
for (i = 1; i <= 10; i++)
{
   . . .
```

```
}
// i is still defined here
```

On the other hand, you can define variables with the same name in separate `for` loops:

```
for (int i = 1; i <= 10; i++)
{
   . . .
} . . .
for (int i = 11; i <= 20; i++) // OK to define another variable
named i
{
   . . .
}
```

A `for` loop is merely a convenient shortcut for a `while` loop. For example,

```
for (int i = 10; i > 0; i--)
   System.out.println("Counting down . . . " + i);
int i = 10;
while (i > 0)
{
   System.out.println("Counting down . . . " + i);
   i--;
}
```

Listing 3.5 shows a typical example of a `for` loop.

The program computes the odds of winning a lottery. For example, if you must pick six numbers from the numbers 1 to 50 to win, then there are (50 × 49 × 48 × 47 × 46 × 45)/(1 × 2 × 3 × 4 × 5 × 6) possible outcomes, so your chance is 1 in 15,890,700. Good luck!

In general, if you pick k numbers out of n, there are

$$\frac{n \times (n-1) \times (n-2) \times \cdots \times (n-k+1)}{1 \times 2 \times 3 \times 4 \times \cdots \times k}$$

possible outcomes. The following `for` loop computes this value:

```
int lotteryOdds = 1;
for (int i = 1; i <= k; i++)
   lotteryOdds = lotteryOdds * (n - i + 1) / i;
```

NOTE:

Section 3.10.3, "The 'for each' Loop," on p. 112 describes the "generalized `for` loop" (also called "for each" loop) that makes it convenient to visit all elements of an array or collection.

Listing 3.5 `LotteryOdds/LotteryOdds.java`

```
import java.util.*;

/**
 * This program demonstrates a <code>for</code> loop.
 * @version 1.20 2004-02-10
 * @author Cay Horstmann
 */
public class LotteryOdds
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);

      System.out.print("How many numbers do you need to draw? ");
      int k = in.nextInt();

      System.out.print("What is the highest number you can draw? ");
```

```
        int n = in.nextInt();

        /*
         * compute binomial coefficient n*(n-1)*(n-2)*...*(n-k+1)/(1*2*3*...*k)
         */

        int lotteryOdds = 1;
        for (int i = 1; i <= k; i++)
           lotteryOdds = lotteryOdds * (n - i + 1) / i;

        System.out.println("Your odds are 1 in " + lotteryOdds + ". Good luck!");
    }
}
```

3.8.5 Multiple Selections with `switch`

The `if/else` construct can be cumbersome when you have to deal with multiple alternatives for the same expression. The `switch` statement makes this easier, particularly with the form that has been introduced in Java 14.

For example, if you set up a menu system with four alternatives like that in Figure 3.13, you could use code that looks like this:

```
Scanner in = new Scanner(System.in);
System.out.print("Select an option (1, 2, 3, 4) ");
int choice = in.nextInt();
switch (choice)
{
   case 1 ->
      . . .
   case 2 ->
      . . .
   case 3 ->
      . . .
   case 4 ->
      . . .
```

```
    default ->
        System.out.println("Bad input");
}
```

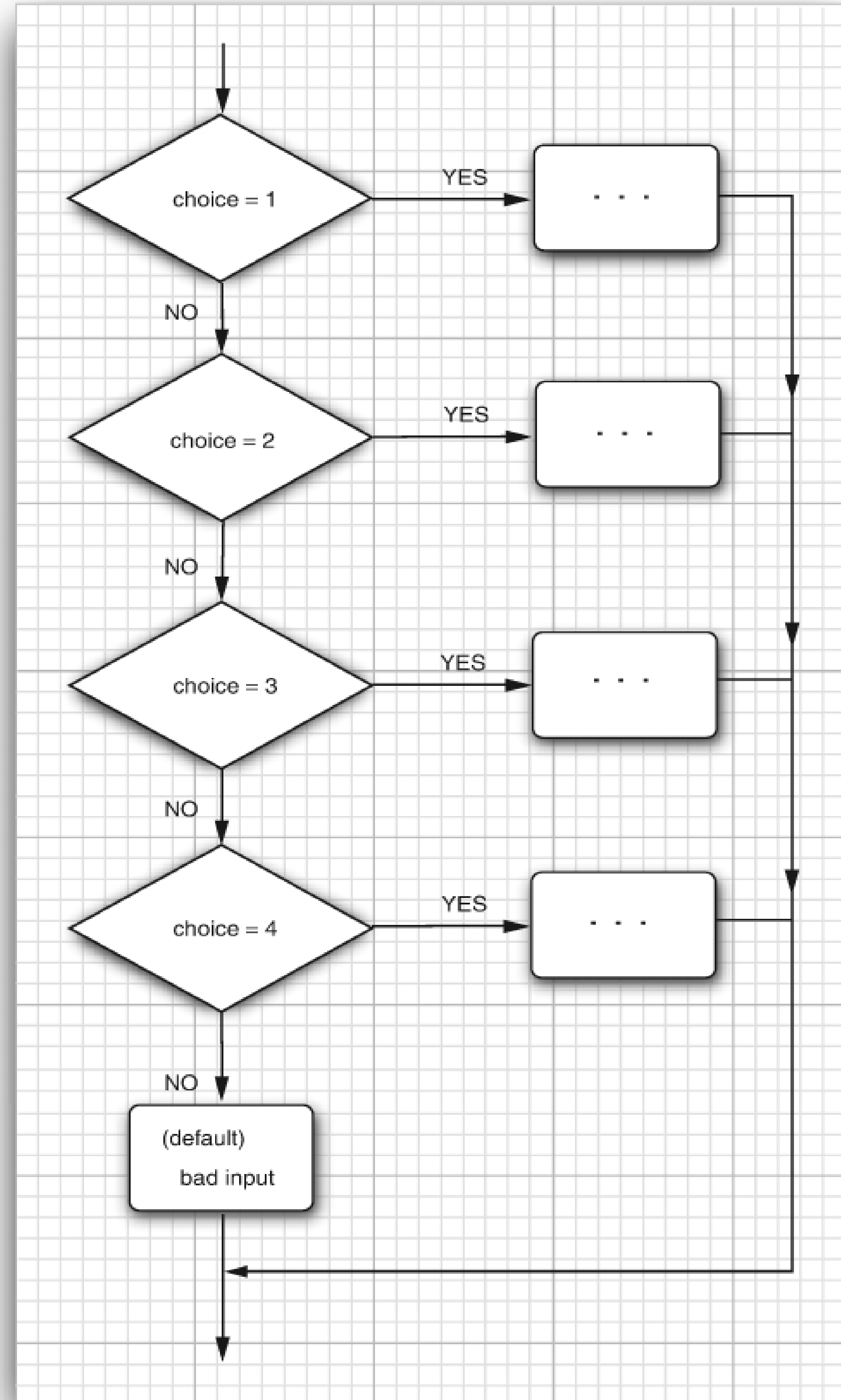

choice = 1
YES
. . .
NO
choice = 2
YES
. . .
NO
choice = 3
YES
. . .
NO
choice = 4
YES
. . .
NO
(default)
bad input

Figure 3.13 Flowchart for the `switch` statement

A `case` label can be

- A constant expression of type `char`, `byte`, `short`, or `int`
- An enumerated constant
- A string literal
- More than one of these, separated by commas

For example,

```
String input = . . .;
switch (input.toLowerCase())
{
   case "yes", "y" ->
      . . .
   case "no", "n" ->
      . . .
   default ->
      . . .
}
```

The "classic" form of the `switch` statement, which dates all the way back to the C language, has been supported since Java 1.0. It has the form:

```
int choice = . . .;
switch (choice)
{
   case 1:
      . . .
   break;
   case 2:
      . . .
   break;
   case 3:
      . . .
   break;
```

```
        case 4:
           . . .
        break;
        default:
           // bad input
           . . .
        break;
    }
```

Execution starts at the `case` label that matches the value on which the selection is performed and continues until the next `break` or the end of the switch. If none of the case labels match, then the `default` clause is executed, if it is present.

CAUTION:

It is possible for multiple alternatives to be triggered. If you forget to add a `break` at the end of an alternative, execution falls through to the next alternative! This behavior is plainly dangerous and a common cause for errors.

To detect such problems, compile your code with the `-Xlint:fallthrough` option, like this:

```
javac -Xlint:fallthrough Test.java
```

Then the compiler will issue a warning whenever an alternative does not end with a `break` statement.

If you actually want to use the fallthrough behavior, tag the surrounding method with the annotation `@SuppressWarnings("fallthrough")`. Then no warnings will be generated for that method. (An annotation is a mechanism for supplying information to the compiler or a tool that processes Java source or class files. Volume II has an in-depth coverage of annotations.)

These two forms of `switch` are *statements*. In Section 3.5.9, "Switch Expressions," on p. 58, you saw a `switch` *expression*, which yields a value. It doesn't have the fallthrough behavior.

For symmetry, Java 14 also introduces a `switch` expression with fallthrough, for a total of four forms of `switch`. Table 3.7 shows them all.

In the fallthrough variants, each case ends with a colon. If the cases end with arrows `->`, then there is no fallthrough. You can't mix colons and arrows in a single `switch` statement.

Note the `yield` keyword with switch expressions. Like `break`, it terminates execution. Unlike `break`, it also yields a value—the value of the expression.

To use statements in a branch of a `switch` expression without fallthrough, you must use braces and `yield`, as in the example in the table that adds a logging statement to a branch:

```
case "Spring" ->
   {
      System.out.println("spring time!");
      yield 6;
   }
```

Each branch of a switch *expression* must yield a value. Most commonly, each value follows an `->` arrow:

```
case "Summer", "Winter" -> 6;
```

If that is not possible, use a `yield` statement.

Table 3.7 The four forms of `switch`

	Expression	Statement

No fallthrough	`int numLetters = switch (seasonName)`
	`{`
	`   case "Spring" ->`
	`      {`
	`         System.out.println(`
	`            "spring time!");`
	`         yield 6;`
	`      }`
	`   case "Summer", "Winter" -> 6;`
	`   case "Fall" -> 4;`
	`   default -> -1;`
	`};`
		`switch (seasonName)`
		`{`
		`   case "Spring" ->`
		`      {`
		`         System.out.println(`
		`            "spring time!");`
		`         numLetters = 6;`
		`      }`
		`   case "Summer", "Winter" ->`
		`      numLetters = 6;`
		`   case "Fall" ->`
		`      numLetters = 4;`
		`   default ->`
		`      numLetters = -1;`
		`}`

Fallthrough	`int numLetters = switch (seasonName)`
	`{`
	`   case "Spring":`
	`      System.out.println(`
	`         "spring time!");`
	`   case "Summer", "Winter":`
	`      yield 6;`
	`   case "Fall":`
	`      yield 4;`
	`   default:`
	`      yield -1;`
	`};`
		`switch (seasonName)`
		`{`
		`   case "Spring":`
		`      System.out.println(`
		`         "spring time!");`
		`   case "Summer", "Winter":`
		`      numLetters = 6;`
		`   case "Fall":`
		`      numLetters = 4;`
		`   default:`
		`      numLetters = -1;`
		`}`

NOTE:

It is legal to throw an exception in a branch of a switch expression. For example:

```
default -> throw new IllegalArgumentException("Not a valid season");
```

Exceptions are covered in detail in Chapter 7.

CAUTION:

The point of a switch expression is to produce a value (or to fail with an exception). You are not allowed to “jump out”:

```
default -> { return -1; } // ERROR
```

Specifically, you cannot use `return`, `break`, or `continue` statements in a switch expression. (See Section 3.8.6, “Statements That Break Control Flow,” on p. 103 for the latter two.)

With so many variations of `switch`, which one should you choose?

Prefer `switch` expressions over statements. If each branch computes the value for a variable assignment or method call, yield the value with an expression, and then use it. For example,

```
numLetters = switch (seasonName)
   {
      case "Spring", "Summer", "Winter" -> 6
      case "Fall" -> 4
      default -> -1
   };
```

is better than

```
switch (seasonName)
{
   case "Spring", "Summer", "Winter" ->
      numLetters = 6;
   case "Fall" ->
```

```
        numLetters = 4;
    default ->
        numLetters = -1;
}
```

Only use `break` or `yield` if you actually need fallthrough, or if you must add statements into a `switch` expression. These situations are exceedingly rare.

3.8.6 Statements That Break Control Flow

Although the designers of Java kept `goto` as a reserved word, they decided not to include it in the language. In general, `goto` statements are considered poor style. Some programmers feel the anti-`goto` forces have gone too far (see, for example, the famous article of Donald Knuth called "Structured Programming with goto statements"). They argue that unrestricted use of `goto` is error-prone but that an occasional jump *out of a loop* is beneficial. The Java designers agreed and even added a new statement, the labeled break, to support this programming style.

Let us first look at the unlabeled `break` statement. The same `break` statement that you use to exit a `switch` statement can also be used to break out of a loop. For example:

```
while (years <= 100)
{
    balance += payment;
    double interest = balance * interestRate / 100;
    balance += interest;
    if (balance >= goal) break;   years++;
}
```

Now the loop is exited if either `years > 100` occurs at the top of the loop or `balance >= goal` occurs in the middle of the loop. Of course, you could have computed the same value for `years` without a `break`, like this:

```
while (years <= 100 && balance < goal)
{
```

```
    balance += payment;
    double interest = balance * interestRate / 100;
    balance += interest;

    if (balance < goal)
       years++;
 }
```

But note that the test `balance < goal` is repeated twice in this version. To avoid this repeated test, some programmers prefer the `break` statement.

Unlike C++, Java also offers a *labeled break* statement that lets you break out of multiple nested loops. Occasionally something weird happens inside a deeply nested loop. In that case, you may want to break completely out of all the nested loops. It is inconvenient to program that simply by adding extra conditions to the various loop tests.

Here's an example that shows the break statement at work. Notice that the label must precede the outermost loop out of which you want to break. It also must be followed by a colon.

```
Scanner in = new Scanner(System.in);
int n;
read_data:
while (. . .) // this loop statement is tagged with the label
{
   . . .
   for (. . .) // this inner loop is not labeled
   {
      System.out.print("Enter a number >= 0: ");
      n = in.nextInt();
      if (n < 0) // should never happen—can't go on
         break read_data;
         // break out of read_data loop
      . . .
   }
}
// this statement is executed immediately after the labeled
```

```
breakif (n < 0) // check for bad situation
{
   // deal with bad situation
}
else
{
   // carry out normal processing
}
```

If there is a bad input, the labeled break moves past the end of the labeled block. As with any use of the `break` statement, you then need to test whether the loop exited normally or as a result of a break.

NOTE:

Curiously, you can apply a label to any statement, even an `if` statement or a block statement, like this:

```
label:
{
   . . .
   if (condition) break label; // exits block
   . . .
}
// jumps here when the break statement executes
```

Thus, if you are lusting after a `goto` and you can place a block that ends just before the place to which you want to jump, you can use a `break` statement! Naturally, I don't recommend this approach. Note, however, that you can only jump *out of* a block, never *into* a block.

Finally, there is a `continue` statement that, like the `break` statement, breaks the regular flow of control. The `continue` statement transfers control to the header of the innermost enclosing loop. Here is an example:

```
Scanner in = new Scanner(System.in);
while (sum < goal)
{
   System.out.print("Enter a number: ");
   n = in.nextInt();
   if (n < 0) continue;
   sum += n; // not executed if n < 0
}
```

If `n < 0`, then the `continue` statement jumps immediately to the loop header, skipping the remainder of the current iteration.

If the `continue` statement is used in a `for` loop, it jumps to the "update" part of the `for` loop. For example:

```
for (count = 1; count <= 100; count++)
{
   System.out.print("Enter a number, -1 to quit: ");
   n = in.nextInt();
   if (n < 0) continue;
   sum += n; // not executed if n < 0
}
```

If `n < 0`, then the `continue` statement jumps to the `count++` statement.

There is also a labeled form of the `continue` statement that jumps to the header of the loop with the matching label.

TIP:

Many programmers find the `break` and `continue` statements confusing. These statements are entirely optional—you can always express the same logic without them. None of the programs in this book use `break` or `continue`.

3.9 Big Numbers

If the precision of the basic integer and floating-point types is not sufficient, you can turn to a couple of handy classes in the `java.math` package: `BigInteger` and `BigDecimal`. These are classes for manipulating numbers with an arbitrarily long sequence of digits. The `BigInteger` class implements arbitrary-precision integer arithmetic, and `BigDecimal` does the same for floating-point numbers.

Use the static `valueOf` method to turn an ordinary number into a big number:

```
BigInteger a = BigInteger.valueOf(100);
```

For longer numbers, use a constructor with a string parameter:

```
BigInteger reallyBig
   = new
BigInteger("22223224462942044552973989346190996720666693909649976499097960О");
```

There are also constants `BigInteger.ZERO`, `BigInteger.ONE`, `BigInteger.TEN`, and, since Java 9, `BigInteger.TWO`.

CAUTION:

With the `BigDecimal` class, you should always use the constructor with a string parameter. There is a constructor `BigDecimal(double)` that is inherently prone to roundoff: `new BigDecimal(0.1)` has digits `0.1000000000000000055511151231257827021181583404541015625`.

Unfortunately, you cannot use the familiar mathematical operators such as `+` and `*` to combine big numbers. Instead, you must use methods such as `add` and `multiply` in the big number classes.

```
BigInteger c = a.add(b); // c = a + b
BigInteger d = c.multiply(b.add(BigInteger.valueOf(2))); // d =
c * (b + 2)
```

C++ NOTE:

Unlike C++, Java has no programmable operator overloading. There was no way for the programmers of the `BigInteger` class to redefine the `+` and `*` operators to give the `add` and `multiply` operations of the `BigInteger` classes. The language designers did overload the `+` operator to denote concatenation of strings. They chose not to overload other operators, and they did not give Java programmers the opportunity to overload operators in their own classes.

Listing 3.6 shows a modification of the lottery odds program of Listing 3.5, updated to work with big numbers. For example, if you are invited to participate in a lottery in which you need to pick 60 numbers out of a possible 490 numbers, you can use this program to tell you your odds of winning. They are 1 in `7163958434619955574151162225400929334117176127892634934933510134594811046688 48`. Good luck!

The program in Listing 3.5 computed the statement

```
lotteryOdds = lotteryOdds * (n - i + 1) / i;
```

When big integers are used for `lotteryOdds` and `n`, the equivalent statement becomes

```
lotteryOdds = lotteryOdds
   .multiply(n.subtract(BigInteger.valueOf(i - 1)))
   .divide(BigInteger.valueOf(i));
```

Listing 3.6 `BigIntegerTest/BigIntegerTest.java`

```java
import java.math.*;
import java.util.*;

/**
 * This program uses big numbers to compute the odds of winning the grand prize in a lottery.
 * @version 1.20 2004-02-10
 * @author Cay Horstmann
 */
public class BigIntegerTest
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);

      System.out.print("How many numbers do you need to draw? ");
      int k = in.nextInt();

      System.out.print("What is the highest number you can draw? ");
      BigInteger n = in.nextBigInteger();

      /*
       * compute binomial coefficient n*(n-1)*(n-2)*...*(n-k+1)/(1*2*3*...*k)
       */

      BigInteger lotteryOdds = BigInteger.ONE;

      for (int i = 1; i <= k; i++)
         lotteryOdds = lotteryOdds
            .multiply(n.subtract(BigInteger.valueOf(i - 1)))
            .divide(BigInteger.valueOf(i));

      System.out.printf("Your odds are 1 in %s. Good luck!%n", lotteryOdds);
```

```
    }
}
```

java.math.BigInteger 1.1

- `BigInteger add(BigInteger other)`
- `BigInteger subtract(BigInteger other)`
- `BigInteger multiply(BigInteger other)`
- `BigInteger divide(BigInteger other)`
- `BigInteger mod(BigInteger other)`

  returns the sum, difference, product, quotient, and remainder of this big integer and `other`.

- `BigInteger sqrt()` 9

  yields the square root of this `BigInteger`.

- `int compareTo(BigInteger other)`

  returns `0` if this big integer equals `other`, a negative result if this big integer is less than `other`, and a positive result otherwise.

- `static BigInteger valueOf(long x)`

  returns a big integer whose value equals `x`.

java.math.BigDecimal 1.1

- `BigDecimal(String digits)`

  constructs a big decimal with the given digits.

- `BigDecimal add(BigDecimal other)`
- `BigDecimal subtract(BigDecimal other)`
- `BigDecimal multiply(BigDecimal other)`

- `BigDecimal divide(BigDecimal other)`
- `BigDecimal divide(BigDecimal other, RoundingMode mode)` 5

  returns the sum, difference, product, or quotient of this big decimal and `other`. The first `divide` method throws an exception if the quotient does not have a finite decimal expansion. To obtain a rounded result, use the second method. The mode `RoundingMode.HALF_UP` is the rounding mode that you learned in school: round down the digits 0 to 4, round up the digits 5 to 9. It is appropriate for routine calculations. See the API documentation for other rounding modes.

- `int compareTo(BigDecimal other)`

  returns `0` if this big decimal equals `other`, a negative result if this big decimal is less than `other`, and a positive result otherwise.

3.10 Arrays

Arrays hold sequences of values of the same type. In the following sections, you will see how to work with arrays in Java.

3.10.1 Declaring Arrays

An array is a data structure that stores a collection of values of the same type. You access each individual value through an integer *index*. For example, if `a` is an array of integers, then `a[i]` is the `i`th integer in the array.

Declare an array variable by specifying the array type—which is the element type followed by `[]`—and the array variable name. For example, here is the declaration of an array `a` of integers:

```
int[] a;
```

However, this statement only declares the variable `a`. It does not yet initialize `a` with an actual array. Use the `new` operator to create the array.

```
int[] a = new int[100]; // or var a = new int[100];
```

This statement declares and initializes an array of 100 integers.

The array length need not be a constant: `new int[n]` creates an array of length `n`.

Once you create an array, you cannot change its length (although you can, of course, change an individual array element). If you frequently need to expand the length of arrays while your program is running, you should use *array lists*, which are covered in Chapter 5.

NOTE:

You can define an array variable either as

```
int[] a;
```

or as

```
int a[];
```

Most Java programmers prefer the former style because it neatly separates the type `int[]` (integer array) from the variable name.

Java has a shortcut for creating an array object and supplying initial values:

```
int[] smallPrimes = { 2, 3, 5, 7, 11, 13 };
```

Notice that you do not use `new` with this syntax, and you don't specify the length.

A comma after the last value is allowed, which can be convenient for an array to which you keep adding values over time:

```
String[] authors =
   {
      "James Gosling",
      "Bill Joy",
      "Guy Steele",
   // add more names here and put a comma after each name
   };
```

You can declare an *anonymous array*:

```
new int[] { 17, 19, 23, 29, 31, 37 }
```

This expression allocates a new array and fills it with the values inside the braces. It counts the number of initial values and sets the array length accordingly. You can use this syntax to reinitialize an array without creating a new variable. For example,

```
smallPrimes = new int[] { 17, 19, 23, 29, 31, 37 };
```

is shorthand for

```
int[] anonymous = { 17, 19, 23, 29, 31, 37 };
smallPrimes = anonymous;
```

NOTE:

It is legal to have arrays of length 0. Such an array can be useful if you write a method that computes an array result and the result happens to be empty. Construct an array of length 0 as

new *elementType*[0]

or

```
new elementType[] {}
```

Note that an array of length 0 is not the same as `null`.

3.10.2 Accessing Array Elements

The array elements are *numbered starting from 0*. The last valid index is one less than the length. In the example below, the index values range from 0 to 99. Once the array is created, you can fill the elements in an array, for example, by using a loop:

```
int[] a = new int[100];
for (int i = 0; i < 100; i++)
   a[i] = i; // fills the array with numbers 0 to 99
```

When you create an array of numbers, all elements are initialized with zero. Arrays of `boolean` are initialized with `false`. Arrays of objects are initialized with the special value `null`, which indicates that they do not (yet) hold any objects. This can be surprising for beginners. For example,

```
String[] names = new String[10];
```

creates an array of ten strings, all of which are `null`. If you want the array to hold empty strings, you must supply them:

```
for (int i = 0; i < 10; i++) names[i] = "";
```

CAUTION:

If you construct an array with 100 elements and then try to access the element `a[100]` (or any other index outside the range from 0 to 99), an "array index out of bounds" exception will occur.

To find the number of elements of an array, use *array*`.length`. For example:

```
for (int i = 0; i < a.length; i++)
   System.out.println(a[i]);
```

3.10.3 The "for each" Loop

Java has a powerful looping construct that allows you to loop through each element in an array (or any other collection of elements) without having to fuss with index values.

The *enhanced* `for` loop

```
for (variable : collection) statement
```

sets the given variable to each element of the collection and then executes the statement (which, of course, may be a block). The *collection* expression must be an array or an object of a class that implements the `Iterable` interface, such as `ArrayList`. Array lists are covered in Chapter 5 and the `Iterable` interface in Chapter 9.

For example,

```
for (int element : a)
   System.out.println(element);
```

prints each element of the array `a` on a separate line.

You should read this loop as "for each `element` in `a`". The designers of the Java language considered using keywords, such as `foreach` and `in`. But this loop was a late addition to the Java language, and in the end nobody wanted to break the old code that already contained methods or variables with these names (such as `System.in`).

Of course, you could achieve the same effect with a traditional `for` loop:

```
for (int i = 0; i < a.length; i++)
   System.out.println(a[i]);
```

However, the “for each” loop is more concise and less error-prone, as you don’t have to worry about those pesky start and end index values.

NOTE:

The loop variable of the “for each” loop traverses the *elements* of the array, not the index values.

The “for each” loop is a pleasant improvement over the traditional loop if you need to process all elements in a collection. However, there are still plenty of opportunities to use the traditional `for` loop. For example, you might not want to traverse the entire collection, or you may need the index value inside the loop.

TIP:

There is an even easier way to print all values of an array, using the `toString` method of the `Arrays` class. The call `Arrays.toString(a)` returns a string containing the array elements, enclosed in brackets and separated by commas, such as `"[2, 3, 5, 7, 11, 13]"`. To print the array, simply call

```
System.out.println(Arrays.toString(a));
```

3.10.4 Array Copying

You can copy one array variable into another, but then *both variables refer to the same array*:

```
int[] luckyNumbers = smallPrimes;
luckyNumbers[5] = 12; // now smallPrimes[5] is also 12
```

Figure 3.14 shows the result. If you actually want to copy all values of one array into a new array, use the `copyOf` method in the `Arrays` class:

```
int[] copiedLuckyNumbers = Arrays.copyOf(luckyNumbers,
luckyNumbers.length);
```

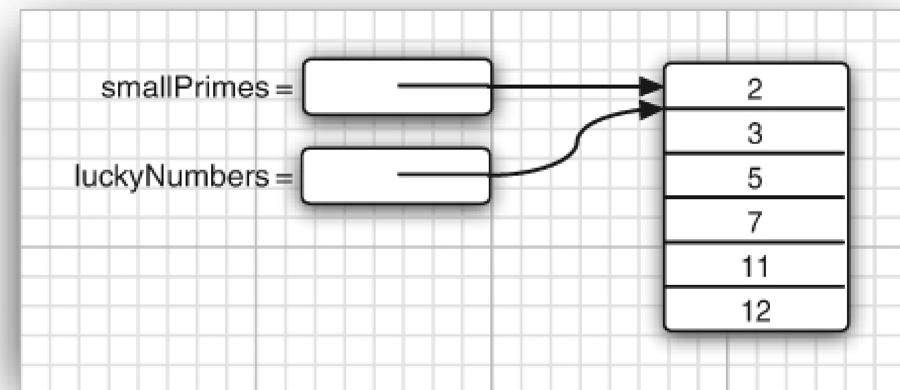


Figure 3.14 Copying an array variable

The second parameter is the length of the new array. A common use of this method is to increase the length of an array:

```
luckyNumbers = Arrays.copyOf(luckyNumbers, 2 *
luckyNumbers.length);
```

The additional elements are filled with `0` if the array contains numbers, `false` if the array contains `boolean` values. Conversely, if the length is less than the length of the original array, only the initial values are copied.

C++ NOTE:

A Java array is quite different from a C++ array on the stack. It is, however, essentially the same as a pointer to an array allocated on the *heap*. That is,

```
int[] a = new int[100]; // Java
```

is not the same as

```
int a[100]; // C++
```

but rather

```
int* a = new int[100]; // C++
```

In Java, the `[]` operator is predefined to perform *bounds checking*. Furthermore, there is no pointer arithmetic—you can't increment `a` to point to the next element in the array.

3.10.5 Command-Line Parameters

You have already seen one example of a Java array repeated quite a few times. Every Java program has a `main` method with a `String[] args` parameter. This parameter indicates that the `main` method receives an array of strings— namely, the arguments specified on the command line.

For example, consider this program:

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

```
   {
      if (args.length == 0 || args[0].equals("-h"))
         System.out.print("Hello,");
      else if (args[0].equals("-g"))
         System.out.print("Goodbye,");
      // print the other command-line arguments
      for (int i = 1; i < args.length; i++)
         System.out.print(" " + args[i]);
      System.out.println("!");
   }
}
```

If the program is called as

```
java Message -g cruel world
```

then the `args` array has the following contents:

```
args[0]: "-g"
args[1]: "cruel"
args[2]: "world"
```

The program prints the message

```
Goodbye, cruel world!
```

C++ NOTE:

In the `main` method of a Java program, the name of the program is not stored in the `args` array. For example, when you start up a program as

```
java Message -h world
```

from the command line, then `args[0]` will be `"-h"` and not `"Message"` or `"java"`.

3.10.6 Array Sorting

To sort an array of numbers, you can use one of the `sort` methods in the `Arrays`

class:

```
int[] a = new int[10000];
. . .
Arrays.sort(a)
```

This method uses a tuned version of the QuickSort algorithm that is claimed to be very efficient on most data sets. The `Arrays` class provides several other convenience methods for arrays that are included in the API notes at the end of this section.

The program in Listing 3.7 puts arrays to work. This program draws a random combination of numbers for a lottery game. For example, if you play a "choose 6 numbers from 49" lottery, the program might print this:

```
Bet the following combination. It'll make you rich!
   4
   7
   8
   19
   30
   44
```

To select such a random set of numbers, first fill an array `numbers` with the values `1`, `2`, . . ., `n`:

```
int[] numbers = new int[n];
for (int i = 0; i < numbers.length; i++)
   numbers[i] = i + 1;
```

A second array holds the numbers to be drawn:

```
int[] result = new int[k];
```

Now draw `k` numbers. The `Math.random` method returns a random floating-point number that is between `0` (inclusive) and `1` (exclusive). Multiplying the result with `n` yields a random number between `0` and `n` – 1.

```
int r = (int) (Math.random() * n);
```

Set the `i`th result to be the number at that index. Initially, that is just `r` + 1, but as you'll see presently, the contents of the `numbers` array are changed after each draw.

```
result[i] = numbers[r];
```

Now, you must be sure never to draw that number again—all lottery numbers must be distinct. Therefore, overwrite `numbers[r]` with the *last* number in the array and reduce `n` by 1.

```
numbers[r] = numbers[n - 1];
n--;
```

The point is that in each draw we pick an *index,* not the actual value. The index points into an array that contains the values that have not yet been drawn.

After drawing `k` lottery numbers, sort the `result` array for a more pleasing output:

```
Arrays.sort(result);
for (int r : result)
   System.out.println(r);
```

Listing 3.7 `LotteryDrawing/LotteryDrawing.java`

```
import java.util.*;

/**
 * This program demonstrates array manipulation.
 * @version 1.20 2004-02-10
 * @author Cay Horstmann
 */
public class LotteryDrawing
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);

      System.out.print("How many numbers do you need to draw? ");
      int k = in.nextInt();

      System.out.print("What is the highest number you can draw? ");
      int n = in.nextInt();

      // fill an array with numbers 1 2 3 . . . n
      int[] numbers = new int[n];
      for (int i = 0; i < numbers.length; i++)
      numbers[i] = i + 1;

      // draw k numbers and put them into a second array
      int[] result = new int[k];
      for (int i = 0; i < result.length; i++)
      {
        // make a random index between 0 and n - 1
        int r = (int) (Math.random() * n);
```

```

        // pick the element at the random location
        result[i] = numbers[r];

        // move the last element into the random location
        numbers[r] = numbers[n - 1];
        n--;
     }

     // print the sorted array
     Arrays.sort(result);
     System.out.println("Bet the following combination. It'll make you rich!");
     for (int r : result)
       System.out.println(r);
  }
}
```

---

java.util.Arrays 1.2

- `static String toString(`*xxx*`[] a)` 5

  returns a string with the elements of `a`, enclosed in brackets and delimited by commas. In this and the following methods, the component type *xxx* of the array can be `int`, `long`, `short`, `char`, `byte`, `boolean`, `float`, or `double`.

- `static` *xxx*`[] copyOf(`*xxx*`[] a, int end)` 6
- `static` *xxx*`[] copyOfRange(`*xxx*`[] a, int start, int end)` 6

  returns an array of the same type as `a`, of length either `end` or `end – start`, filled with the values of `a`. If `end` is larger than `a.length`, the result is padded with `0` or `false` values.

- `static void sort(`*xxx*`[] a)`

  sorts the array, using a tuned QuickSort algorithm.

- `static int binarySearch(`*xxx*`[] a,` *xxx* `v)`

- `static int binarySearch(xxx[] a, int start, int end, xxx v)` 6

  uses the binary search algorithm to search for the value `v` in the sorted array `a`. If `v` is found, its index is returned. Otherwise, a negative value `r` is returned; –`r` – 1 is the spot at which `v` should be inserted to keep `a` sorted.

- `static void fill(xxx[] a, xxx v)`

  sets all elements of the array to `v`.

- `static boolean equals(xxx[] a, xxx[] b)`

  returns `true` if the arrays have the same length and if the elements at corresponding indexes match.

3.10.7 Multidimensional Arrays

Multidimensional arrays use more than one index to access array elements. They are used for tables and other more complex arrangements. You can safely skip this section until you have a need for this storage mechanism.

Suppose you want to make a table of numbers that shows how much an investment of $10,000 will grow under different interest rate scenarios in which interest is paid annually and reinvested (Table 3.8).

Table 3.8 Growth of an Investment at Different Interest Rates

10%	11%	12%	13%	14%	15%
10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00
11,000.00	11,100.00	11,200.00	11,300.00	11,400.00	11,500.00
12,100.00	12,321.00	12,544.00	12,769.00	12,996.00	13,225.00
13,310.00	13,676.31	14,049.28	14,428.97	14,815.44	15,208.75
14,641.00	15,180.70	15,735.19	16,304.74	16,889.60	17,490.06
16,105.10	16,850.58	17,623.42	18,424.35	19,254.15	20,113.57
17,715.61	18,704.15	19,738.23	20,819.52	21,949.73	23,130.61
19,487.17	20,761.60	22,106.81	23,526.05	25,022.69	26,600.20
21,435.89	23,045.38	24,759.63	26,584.44	28,525.86	30,590.23
23,579.48	25,580.37	27,730.79	30,040.42	32,519.49	35,178.76

You can store this information in a two-dimensional array (matrix) named `balances`.

Declaring a two-dimensional array in Java is simple enough. For example:

```
double[][] balances;
```

You cannot use the array until you initialize it. In this case, you can do the initialization as follows:

```
balances = new double[NYEARS][NRATES];
```

In other cases, if you know the array elements, you can use a shorthand notation for initializing a multidimensional array without a call to `new`. For example:

```
int[][] magicSquare =
   {
```

```
        {16, 3, 2, 13},
        {5, 10, 11, 8},
        {9, 6, 7, 12},
        {4, 15, 14, 1}
    };
```

Once the array is initialized, you can access individual elements by supplying two pairs of brackets—for example, `balances[i][j]`.

The example program stores a one-dimensional array `interest` of interest rates and a two-dimensional array `balances` of account balances, one for each year and interest rate. Initialize the first row of the array with the initial balance:

```
for (int j = 0; j < balances[0].length; j++)
   balances[0][j] = 10000;
```

Then compute the other rows, as follows:

```
for (int i = 1; i < balances.length; i++)
{
   for (int j = 0; j < balances[i].length; j++)
   {
      double oldBalance = balances[i - 1][j];
      double interest = . . .;
      balances[i][j] = oldBalance + interest;
   }
}
```

Listing 3.8 shows the full program.

NOTE:

A “for each” loop does not automatically loop through all elements in a two-dimensional array. Instead, it loops through the rows, which are themselves one-dimensional arrays. To visit all elements of a two-dimensional array `a`, nest two loops, like this:

```
for (double[] row : a)
   for (double value : row)
      do something with value
```

TIP:

To print out a quick-and-dirty list of the elements of a two-dimensional array, call

```
System.out.println(Arrays.deepToString(a));
```

The output is formatted like this:

```
[[16, 3, 2, 13], [5, 10, 11, 8], [9, 6, 7, 12], [4, 15, 14, 1]]
```

Listing 3.8 `CompoundInterest/CompoundInterest.java`

```
/**
 * This program shows how to store tabular data in a 2D array.
 * @version 1.40 2004-02-10
 * @author Cay Horstmann
 */
public class CompoundInterest
{
   public static void main(String[] args)
   {
      final double STARTRATE = 10;
      final int NRATES = 6;
      final int NYEARS = 10;

```

```java
         // set interest rates to 10 . . . 15%
         double[] interestRate = new double[NRATES];
         for (int j = 0; j < interestRate.length; j++)
            interestRate[j] = (STARTRATE + j) / 100.0;

         double[][] balances = new double[NYEARS][NRATES];

         // set initial balances to 10000
         for (int j = 0; j < balances[0].length; j++)
            balances[0][j] = 10000;

         // compute interest for future years
         for (int i = 1; i < balances.length; i++)
         {
         for (int j = 0; j < balances[i].length; j++)
         {
            // get last year's balances from previous row
            double oldBalance = balances[i - 1][j];

            // compute interest
            double interest = oldBalance * interestRate[j];

            // compute this year's balances
            balances[i][j] = oldBalance + interest;
         }
      }

      // print one row of interest rates
      for (int j = 0; j < interestRate.length; j++)
         System.out.printf("%9.0f%%", 100 * interestRate[j]);

      System.out.println();

      // print balance table
      for (double[] row : balances)
      {
         // print table row
         for (double b : row)
            System.out.printf("%10.2f", b);
```

```
            System.out.println();
        }
    }
}
```

3.10.8 Ragged Arrays

So far, what you have seen is not too different from other programming languages. But there is actually something subtle going on behind the scenes that you can sometimes turn to your advantage: Java has *no* multidimensional arrays at all, only one-dimensional arrays. Multidimensional arrays are faked as “arrays of arrays.”

For example, the `balances` array in the preceding example is actually an array that contains ten elements, each of which is an array of six floating-point numbers (Figure 3.15).

The expression `balances[i]` refers to the `i`th subarray—that is, the `i`th row of the table. It is itself an array, and `balances[i][j]` refers to the `j`th element of that array.

Since rows of arrays are individually accessible, you can actually swap them!

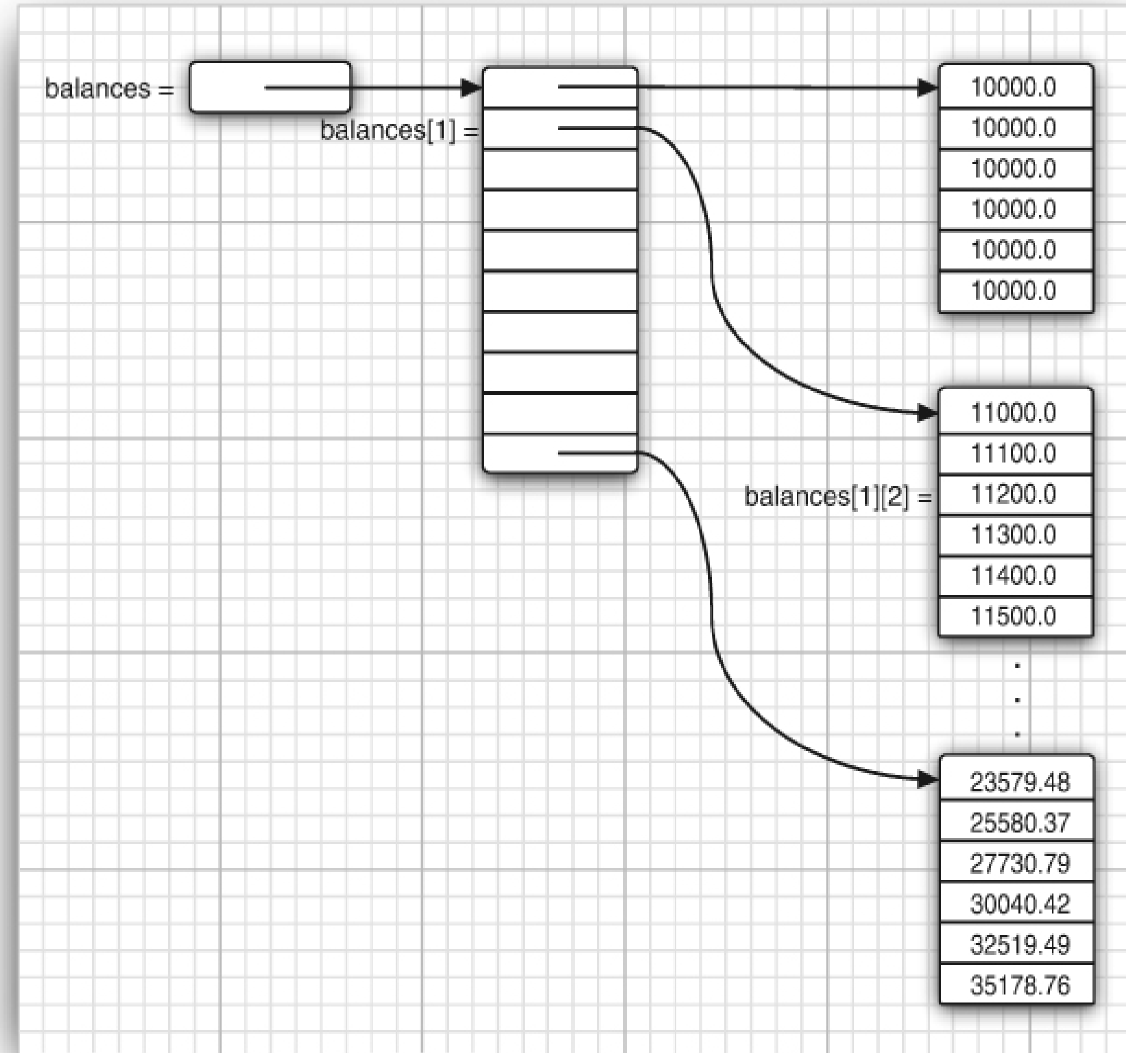


Figure 3.15 A two-dimensional array

```
double[] temp = balances[i];
balances[i] = balances[i + 1];
balances[i + 1] = temp;
```

It is also easy to make “ragged” arrays—that is, arrays in which different rows have different lengths. Here is the standard example. Let us make an array in which the element at row `i` and column `j` equals the number of possible outcomes of a “choose `j` numbers from `i` numbers” lottery.

```
1
1   1
1   2   1
1   3   3   1
1   4   6   4   1
1   5  10  10   5  1
1   6  15  20  15  6  1
```

As `j` can never be larger than `i`, the matrix is triangular. The `i`th row has `i` + 1 elements. (It is OK to choose 0 elements; there is one way to make such a choice.) To build this ragged array, first allocate the array holding the rows:

```
final int NMAX = 10;
int[][] odds = new int[NMAX + 1][];
```

Next, allocate the rows:

```
for (int n = 0; n <= NMAX; n++)
   odds[n] = new int[n + 1];
```

Now that the array is allocated, you can access the elements in the normal way, provided you do not overstep the bounds:

```
for (int n = 0; n < odds.length; n++)
   for (int k = 0; k < odds[n].length; k++)
   {
      // compute lotteryOdds
      . . .
      odds[n][k] = lotteryOdds;
   }
```

Listing 3.9 gives the complete program.

C++ NOTE:

In C++, the Java declaration

```
double[][] balances = new double[10][6]; // Java
```

is not the same as

```
double balances[10][6]; // C++
```

or even

```
double (*balances)[6] = new double[10][6]; // C++
```

Instead, an array of ten pointers is allocated:

```
double** balances = new double*[10]; // C++
```

Then, each element in the pointer array is filled with an array of six numbers:

```
for (i = 0; i < 10; i++)
   balances[i] = new double[6];
```

Mercifully, this loop is automatic when you ask for a `new double[10][6]`. When you want ragged arrays, you allocate the row arrays separately.

Listing 3.9 `LotteryArray/LotteryArray.java`

```
/**
 * This program demonstrates a triangular array.
 * @version 1.20 2004-02-10
 * @author Cay Horstmann
 */
public class LotteryArray
{
```

```
   public static void main(String[] args)
   {
      final int NMAX = 10;

      // allocate triangular array
      int[][] odds = new int[NMAX + 1][];
      for (int n = 0; n <= NMAX; n++)
         odds[n] = new int[n + 1];

      // fill triangular array
      for (int n = 0; n < odds.length; n++)
         for (int k = 0; k < odds[n].length; k++)
         {
            /*
             * compute binomial coefficient n*(n-1)*(n-2)*...*(n-k+1)/(1*2*3*...*k)
             */
            int lotteryOdds = 1;
            for (int i = 1; i <= k; i++)
               lotteryOdds = lotteryOdds * (n - i + 1) / i;

            odds[n][k] = lotteryOdds;
         }

      // print triangular array
      for (int[] row : odds)
      {
         for (int odd : row)
            System.out.printf("%4d", odd);
         System.out.println();
      }
   }
}
```

You have now seen the fundamental programming structures of the Java language. The next chapter covers object-oriented programming in Java.

Chapter 4. Objects and Classes

In this chapter

In this chapter, I

- Introduce you to object-oriented programming;
- Show you how you can create objects that belong to classes from the standard Java library; and
- Show you how to write your own classes.

If you do not have a background in object-oriented programming, you will want to read this chapter carefully. Object-oriented programming requires a different way of thinking than procedural languages. The transition is not always easy, but you do need some familiarity with object concepts to go further with Java.

For experienced C++ programmers, this chapter, like the previous chapter, presents familiar information; however, there are enough differences between the two languages that you should read the later sections of this chapter carefully. You'll find the C++ notes helpful for making the transition.

4.1 Introduction to Object-Oriented Programming

Object-oriented programming, or OOP for short, is the dominant programming paradigm these days, having replaced the "structured" or procedural programming techniques that were developed in the 1970s. Since Java is object-oriented, you have to be familiar with OOP to become productive with Java.

An object-oriented program is made of objects. Each object has a specific functionality, exposed to its users, and a hidden implementation. Many objects in your programs will be taken "off-the-shelf" from a library; others will be custom-designed. Whether you build an object or buy it might depend on your budget or time. But, basically, as long as an object satisfies your specifications, you don't care how the functionality is implemented.

Traditional structured programming consists of designing a set of procedures (or *algorithms*) to solve a problem. Once the procedures are determined, the traditional next step was to find appropriate ways to store the data. This is why the designer of the Pascal language, Niklaus Wirth, called his famous book on programming *Algorithms + Data Structures = Programs* (Prentice Hall, 1976). Notice that in Wirth's title, algorithms come first, and data structures second. This reflects the way programmers worked at that time. First, they decided on the procedures for manipulating the data; then, they decided what structure to impose on the data to make the manipulations easier. OOP reverses the order: puts the data first, then looks at the algorithms to operate on the data.

For small problems, the breakdown into procedures works very well. But objects are more appropriate for larger problems. Consider a simple web browser. It might require 2,000 procedures for its implementation, all of which manipulate a set of global data. In the object-oriented style, there might be 100 classes with an average of 20 methods per class (see Figure 4.1). This structure is much easier for a programmer to grasp. It is also much easier to find bugs in. Suppose the data of a particular object is in an incorrect state. It is far easier to search for the culprit among the 20 methods that had access to that data item than among 2,000 procedures.

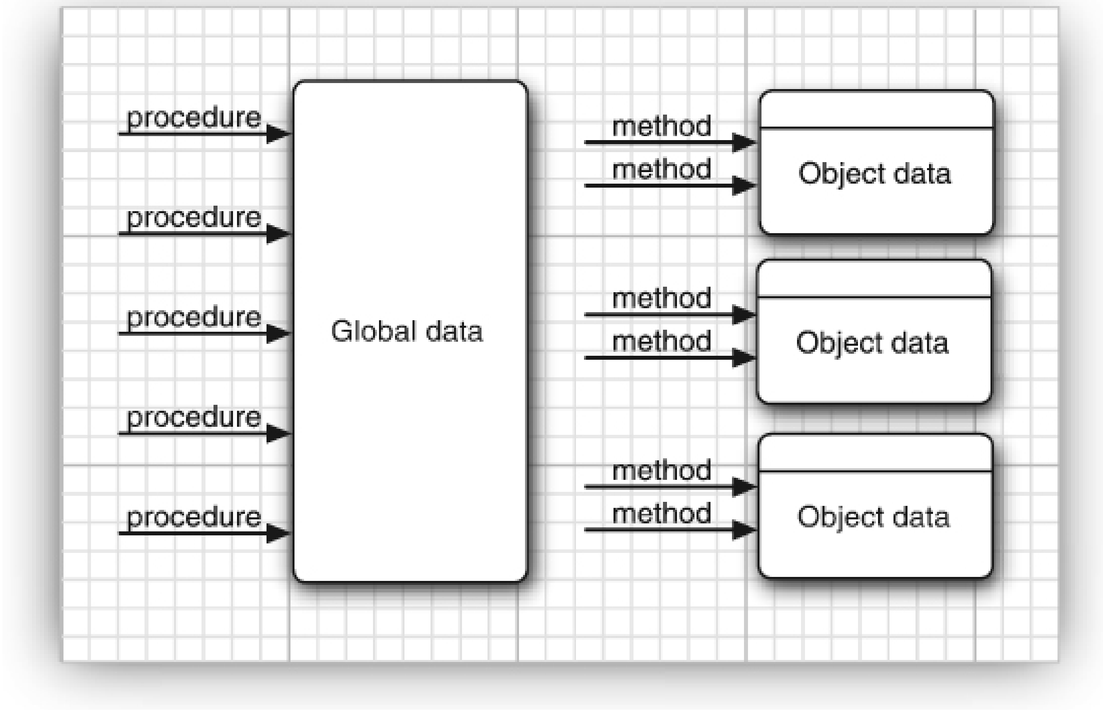


Figure 4.1 Procedural vs. OO programming

4.1.1 Classes

A *class* specifies how objects are made. Think of classes as cookie cutters; objects are the cookies themselves. When you *construct* an object from a class, you are said to have created an *instance* of the class.

As you have seen, all code that you write in Java is inside a class. The standard Java library supplies several thousand classes for such diverse purposes as user interface design, dates and calendars, and network programming. Nonetheless, in Java you still have to create your own classes to describe the objects of your application's problem domain.

Encapsulation (sometimes called *information hiding*) is a key concept in working with objects. Formally, encapsulation is simply combining data and behavior in one package and hiding the implementation details from the users of the object. The bits of data in an object are called its *instance fields*, and the procedures that operate on the data are called its *methods*. A specific object that is an instance of a class will have specific values of its instance fields. The set of those values is the current *state* of the object. Whenever you invoke a method on an object, its state may change.

The key to making encapsulation work is to have methods *never* directly access instance fields in a class other than their own. Programs should interact with object data *only* through the object's methods. Encapsulation is the way to give an object its "black box" behavior, which is the key to reuse and reliability. This means a class may totally change how it stores its data, but as long as it continues to use the same methods to manipulate the data, no other object will know or care.

When you start writing your own classes in Java, another tenet of OOP will make this easier: Classes can be built by *extending* other classes. Java, in fact, comes with a "cosmic superclass" called `Object`. All other classes extend this class. You will learn more about the `Object` class in the next chapter.

When you extend an existing class, the new class has all the properties and methods of the class that you extend. You then supply new methods and instance fields that apply to your new class only. The concept of extending a class to obtain another class is called *inheritance*. See the next chapter for more on inheritance.

4.1.2 Objects

To work with OOP, you should be able to identify three key characteristics of objects:

- The object's *behavior*—what can you do with this object, or what methods can you apply to it?
- The object's *state*—how does the object react when you invoke those methods?

- The object's *identity*—how is the object distinguished from others that may have the same behavior and state?

All objects that are instances of the same class share a family resemblance by supporting the same *behavior*. The behavior of an object is defined by the methods that you can call.

Next, each object stores information about what it currently looks like. This is the object's *state*. An object's state may change over time, but not spontaneously. A change in the state of an object must be a consequence of method calls. (If an object's state changed without a method call on that object, someone broke encapsulation.)

However, the state of an object does not completely describe it, because each object has a distinct *identity*. For example, in an order processing system, two orders are distinct even if they request identical items. Notice that the individual objects that are instances of a class *always* differ in their identity and *usually* differ in their state.

These key characteristics can influence each other. For example, the state of an object can influence its behavior. (If an order is "shipped" or "paid," it may reject a method call that asks it to add or remove items. Conversely, if an order is "empty"—that is, no items have yet been ordered—it should not allow itself to be shipped.)

4.1.3 Identifying Classes

In a traditional procedural program, you start the process at the top, with the `main` function. When designing an object-oriented system, there is no "top," and newcomers to OOP often wonder where to begin. The answer is: Identify your classes and then add methods to each class.

A simple rule of thumb in identifying classes is to look for nouns in the problem analysis. Methods, on the other hand, correspond to verbs.

For example, in an order-processing system, some of the nouns are

- Item

• Order

• Shipping address

• Payment

• Account

These nouns may lead to the classes `Item`, `Order`, and so on.

Next, look for verbs. Items are *added* to orders. Orders are *shipped* or *canceled*. Payments are *applied* to orders. With each verb, such as “add,” “ship,” “cancel,” or “apply,” you identify the object that has the major responsibility for carrying it out. For example, when a new item is added to an order, the order object should be the one in charge because it knows how it stores and sorts items. That is, `add` should be a method of the `Order` class that takes an `Item` object as a parameter.

Of course, the “noun and verb” is but a rule of thumb; only experience can help you decide which nouns and verbs are the important ones when building your classes.

4.1.4 Relationships between Classes

The most common relationships between classes are

• *Dependence* (“uses–a”)

• *Aggregation* (“has–a”)

• *Inheritance* (“is–a”)

The *dependence*, or “uses–a” relationship, is the most obvious and also the most general. For example, the `Order` class uses the `Account` class because `Order` objects need to access `Account` objects to check for credit status. But the `Item` class does not depend on the `Account` class, because `Item` objects never need to worry about customer accounts. Thus, a class depends on another class if its methods use or manipulate objects of that class.

Try to minimize the number of classes that depend on each other. The point is, if a class `A` is unaware of the existence of a class `B`, it is also unconcerned about any changes to `B`. (And this means that changes to `B` do not introduce bugs into `A`.) In software engineering terminology, you want to minimize the *coupling* between classes.

The *aggregation*, or "has–a" relationship, is easy to understand because it is concrete; for example, an `Order` object contains `Item` objects. Containment means that objects of class `A` contain objects of class `B`.

NOTE:

Some methodologists view the concept of aggregation with disdain and prefer to use a more general "association" relationship. From the point of view of modeling, that is understandable. But for programmers, the "has–a" relationship makes a lot of sense. I like to use aggregation for another reason as well: The standard notation for associations is less clear. See Table 4.1.

The *inheritance*, or "is–a" relationship, expresses a relationship between a more special and a more general class. For example, a `RushOrder` class inherits from an `Order` class. The specialized `RushOrder` class has special methods for priority handling and a different method for computing shipping charges, but its other methods, such as adding items and billing, are inherited from the `Order` class. In general, if class `D` extends class `C`, class `D` inherits methods from class `C` but has more capabilities. (See the next chapter which discusses this important notion at some length.)

Many programmers use the UML (Unified Modeling Language) notation to draw *class diagrams* that describe the relationships between classes. You can see an example of such a diagram in Figure 4.2. You draw classes as rectangles, and relationships as arrows with various adornments. Table 4.1 shows the most common UML arrow styles.

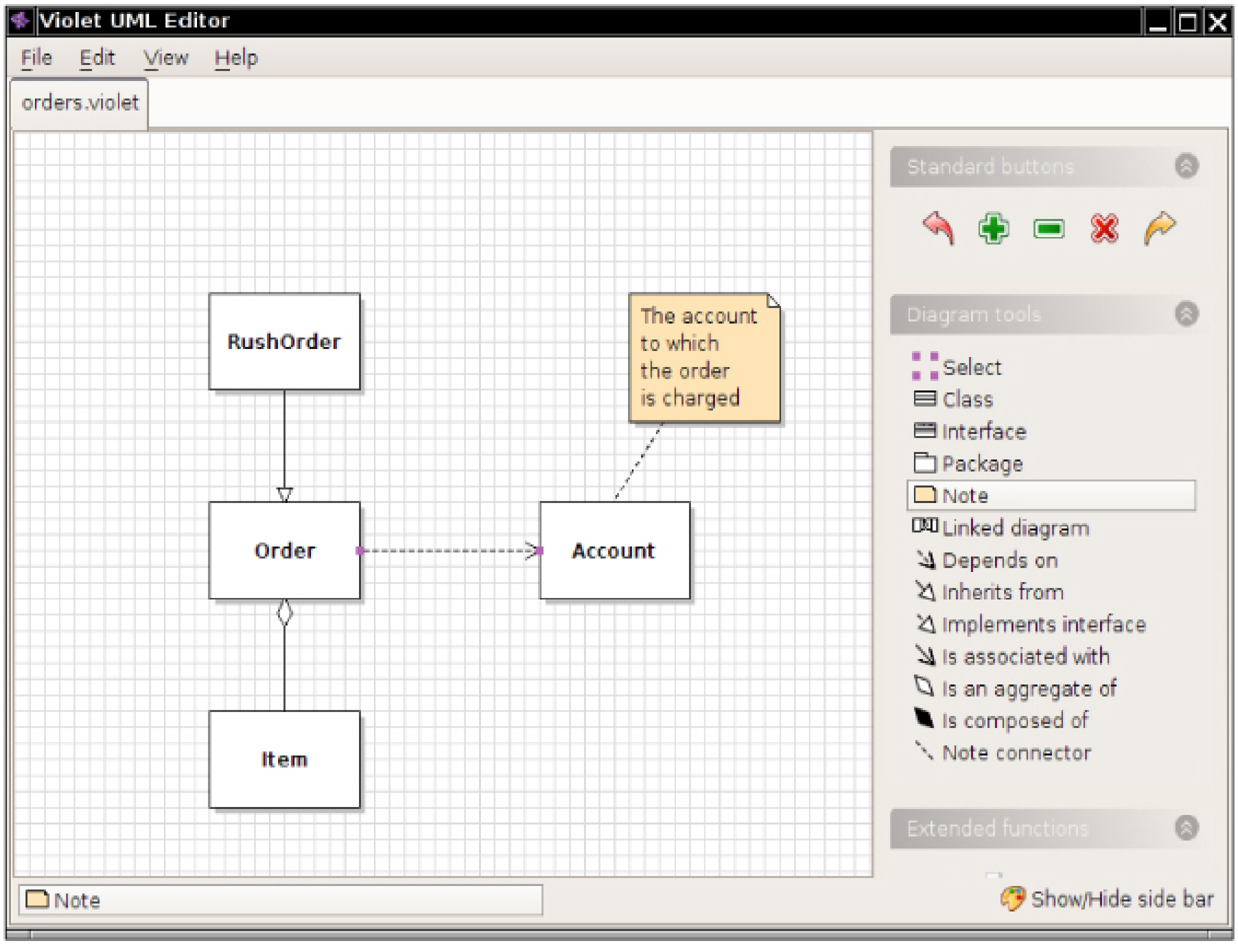


Figure 4.2 A class diagram

Table 4.1 UML Notation for Class Relationships

Relationship	UML Connector
Inheritance	
Interface implementation	
Dependency	
Aggregation	
Association	
Directed association	

4.2 Using Predefined Classes

You can't do anything in Java without classes, and you have already seen several classes at work. However, not all of these show off the typical features of object orientation. Take, for example, the `Math` class. You have seen that you can use methods of the `Math` class, such as `Math.random`, without needing to know how they are implemented—all you need to know is the name and parameters (if any). That's the point of encapsulation, and it will certainly be true of all classes. But the `Math` class *only* encapsulates functionality; it neither needs nor hides data. Since there is no data, you do not need to worry about making objects and initializing their instance fields—there aren't any!

In the next section, we will look at a more typical class, the `Date` class. You will see how to construct objects and call methods of this class.

4.2.1 Objects and Object Variables

To work with objects, you first construct them and specify their initial state. Then you apply methods to the objects.

In the Java programming language, you use *constructors* to construct new instances. A constructor is a special method whose purpose is to construct and initialize objects. Let us look at an example. The standard Java library contains a `Date` class. Its objects describe points in time, such as December 31, 1999, 23:59:59 GMT.

NOTE:

You may be wondering: Why use a class to represent dates rather than (as in some languages) a built-in type? For example, Visual Basic has a built-in date type, and programmers can specify dates in the format `#12/31/1999#`. On the surface, this sounds convenient—programmers can simply use the built-in date type without worrying about classes. But actually, how suitable is the Visual Basic design? In some locales, dates are specified as month/day/year, in others as day/month/year. Are the language designers really equipped to foresee these kinds of issues? If they do a poor job, the language becomes an unpleasant muddle, but unhappy programmers are powerless to do anything about it. With classes, the design task is offloaded to a library designer. If the class is not perfect, other programmers can easily write their own classes to enhance or replace the system classes. (To prove the point: The Java date library started out a bit muddled, and it has been redesigned twice.)

Constructors always have the same name as the class name. Thus, the constructor for the `Date` class is called `Date`. To construct a `Date` object, combine the constructor with the `new` operator, as follows:

```
new Date()
```

This expression constructs a new object. The object is initialized to the current date and time.

If you like, you can pass the object to a method:

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

Alternatively, you can apply a method to the object that you just constructed. One of the methods of the `Date` class is the `toString` method. That method yields a string representation of the date. Here is how you would apply the `toString`

method to a newly constructed `Date` object:

```
String s = new Date().toString();
```

In these two examples, the constructed object is used only once. Usually, you will want to hang on to the objects that you construct so that you can keep using them. Simply store the object in a variable:

```
Date rightNow = new Date();
```

Figure 4.3 shows the object variable `rightNow` that refers to the newly constructed object.

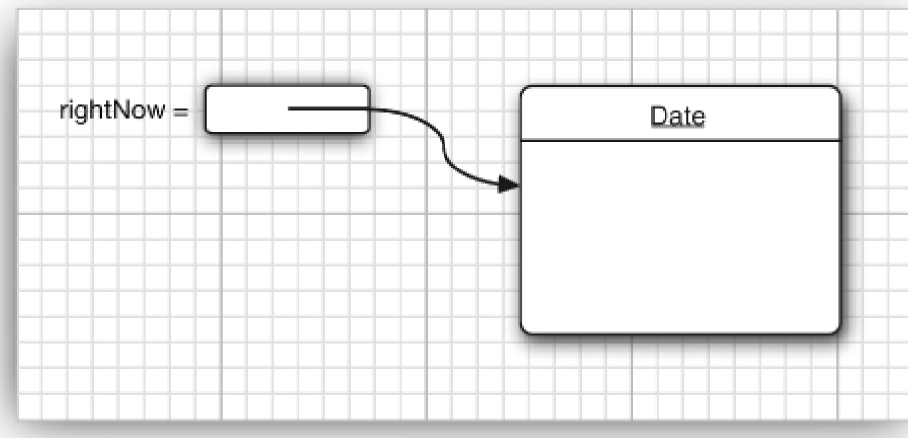


Figure 4.3 Creating a new object

There is an important difference between objects and object variables. For example, the statement

```
Date startTime; // startTime doesn't refer to any object
```

defines an object variable, `startTime`, that can refer to objects of type `Date`. It is important to realize that the variable `startTime` *is not an object* and, in fact, does not even refer to an object yet. You cannot use any `Date` methods on this variable at this time. The statement

```
s = startTime.toString(); // not yet
```

would cause a compile-time error.

You must first initialize the `startTime` variable. You have two choices. Of course, you can initialize the variable so that it refers to a newly constructed object:

```
startTime = new Date();
```

Or you can set the variable to refer to an existing object:

```
startTime = rightNow;
```

Now both variables refer to the *same* object (see Figure 4.4).

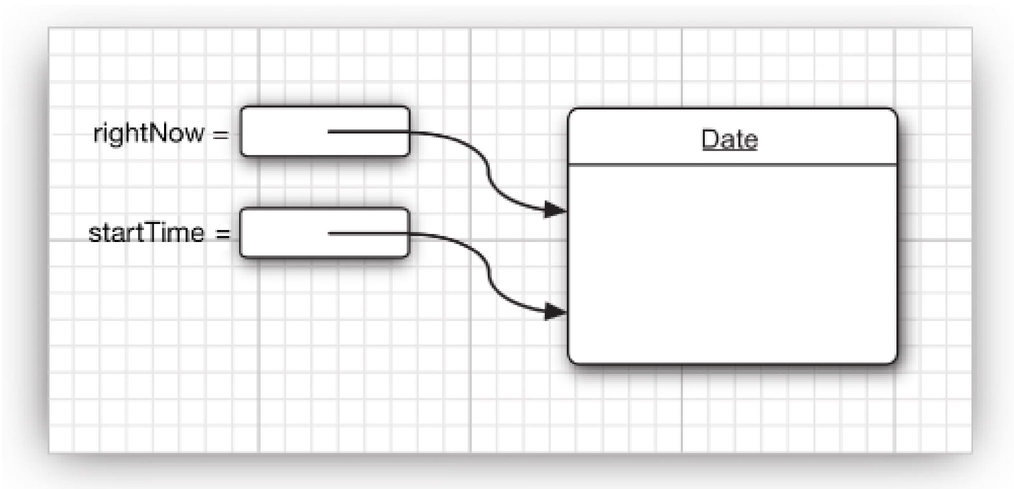


Figure 4.4 Object variables that refer to the same object

It is important to realize that an object variable doesn't actually contain an object. It only *refers* to an object.

In Java, the value of any object variable is a reference to an object that is stored elsewhere. The return value of the `new` operator is also a reference. A statement such as

```
Date startTime = new Date();
```

has two parts. The expression `new Date()` makes an object of type `Date`, and its value is a reference to that newly created object. That reference is then stored in the `startTime` variable.

You can explicitly set an object variable to `null` to indicate that it currently refers to no object.

```
startTime = null; . . .
if (startTime != null)
   System.out.println(startTime);
```

I discuss `null` in more detail in Section 4.3.6, "Working with `null` References," on p. 149.

C++ NOTE:

Some people mistakenly believe that Java object variables behave like C++ references. But in C++ there are no null references, and references cannot be assigned. You should think of Java object variables as analogous to *object pointers* in C++. For example,

```
Date rightNow; // Java
```

is really the same as

```
Date* rightNow; // C++
```

Once you make this association, everything falls into place. Of course, a `Date*` pointer isn't initialized until you initialize it with a call to `new`. The syntax is almost the same in C++ and Java.

```
Date* rightNow = new Date(); // C++
```

If you copy one variable to another, then both variables refer to the same date—they are pointers to the same object. The equivalent of the Java `null` reference is the C++ `NULL` pointer.

All Java objects live on the heap. When an object contains another object variable, it contains just a pointer to yet another heap object.

In C++, pointers make you nervous because they are so error-prone. It is easy to create bad pointers or to mess up memory management. In Java, these problems simply go away. If you use an uninitialized pointer, the runtime system will reliably generate a runtime error instead of producing random results. You don't have to worry about memory management, because the garbage collector takes care of it.

C++ makes quite an effort, with its support for copy constructors and assignment operators, to allow the implementation of objects that copy themselves automatically. For example, a copy of a linked list is a new linked list with the same contents but with an independent set of links. This makes it possible to design classes with the same copy behavior as the built-in types. In Java, you must use the `clone` method to get a complete copy of an object.

4.2.2 The `LocalDate` Class of the Java Library

In the preceding examples, we used the `Date` class that is a part of the standard Java library. An instance of the `Date` class has a state—namely, *a particular point in time*.

Although you don't need to know this when you use the `Date` class, the time is represented by the number of milliseconds (positive or negative) from a fixed point, the so-called *epoch*, which is 00:00:00 UTC, January 1, 1970. UTC is the Coordinated Universal Time, the scientific time standard which is, for practical purposes, the same as the more familiar GMT, or Greenwich Mean Time.

But as it turns out, the `Date` class is not very useful for manipulating the kind of calendar information that humans use for dates, such as "December 31, 1999". This particular description of a day follows the Gregorian calendar, which is the calendar used in most countries of the world. The same point in time would be described quite differently in the Chinese or Hebrew lunar calendars, not to mention the calendar used by your customers from Mars.

NOTE:

Throughout human history, civilizations grappled with the design of calendars to attach names to dates and bring order to the solar and lunar cycles. For a fascinating explanation of calendars around the world, from the French Revolutionary calendar to the Mayan long count, see *Calendrical Calculations* by Nachum Dershowitz and Edward M. Reingold (Cambridge University Press, 4th ed., 2018).

The library designers decided to separate the concerns of keeping time and attaching names to points in time. Therefore, the standard Java library contains two separate classes: the `Date` class, which represents a point in time, and the `LocalDate` class, which expresses days in the familiar calendar notation. Java 8 introduced quite a few other classes for manipulating various aspects of date and time—see Chapter 6 of Volume II.

Separating time measurement from calendars is good object-oriented design. In general, it is a good idea to use different classes to express different concepts.

You do not use a constructor to construct objects of the `LocalDate` class. Instead, use static *factory methods* that call constructors on your behalf. The expression

```
LocalDate.now()
```

constructs a new object that represents the date at which the object was constructed.

You can construct an object for a specific date by supplying year, month, and day:

```
LocalDate.of(1999, 12, 31)
```

Of course, you will usually want to store the constructed object in an object variable:

```
LocalDate newYearsEve = LocalDate.of(1999, 12, 31);
```

Once you have a `LocalDate` object, you can find out the year, month, and day with the methods `getYear`, `getMonthValue`, and `getDayOfMonth`:

```
int year = newYearsEve.getYear(); // 1999
int month = newYearsEve.getMonthValue(); // 12
int day = newYearsEve.getDayOfMonth(); // 31
```

This may seem pointless because they are the very same values that you just used to construct the object. But sometimes, you have a date that has been computed, and then you will want to invoke those methods to find out more about it. For example, the `plusDays` method yields a new `LocalDate` that is a given number of days away from the object to which you apply it:

```
LocalDate aThousandDaysLater = newYearsEve.plusDays(1000);
year = aThousandDaysLater.getYear(); // 2002
month = aThousandDaysLater.getMonthValue(); // 09
day = aThousandDaysLater.getDayOfMonth(); // 26
```

The `LocalDate` class has encapsulated instance fields to maintain the date to which it is set. Without looking at the source code, it is impossible to know the representation that the class uses internally. But, of course, the point of encapsulation is that this doesn't matter. What matters are the methods that a class exposes.

NOTE:

Actually, the `Date` class also has methods to get the day, month, and year, called `getDay`, `getMonth`, and `getYear`, but these methods are *deprecated*. A method is deprecated when a library designer realizes that the method should have never been introduced in the first place.

These methods were a part of the `Date` class before the library designers realized that it makes more sense to supply separate classes to deal with calendars. When an earlier set of calendar classes was introduced in Java

1.1, the `Date` methods were tagged as deprecated. You can still use them in your programs, but you will get unsightly compiler warnings if you do. It is a good idea to stay away from using deprecated methods because they may be removed in a future version of the library.

TIP:

The JDK provides the `jdeprscan` tool for checking whether your code uses deprecated features of the Java API. See `https://docs.oracle.com/en/java/javase/17/docs/specs/man/jdeprscan.html` for instructions.

4.2.3 Mutator and Accessor Methods

Have another look at the `plusDays` method call that you saw in the preceding section:

```
LocalDate aThousandDaysLater = newYearsEve.plusDays(1000);
```

What happens to `newYearsEve` after the call? Has it been changed to be a thousand days later? As it turns out, it has not. The `plusDays` method yields a new `LocalDate` object, which is then assigned to the `aThousandDaysLater` variable. The original object remains unchanged. We say that the `plusDays` method does not *mutate* the object on which it is invoked. (This is similar to the `toUpperCase` method of the `String` class that you saw in Chapter 3. When you call `toUpperCase` on a string, that string stays the same, and a new string with uppercase characters is returned.)

An earlier version of the Java library had a different class for dealing with calendars, called `GregorianCalendar`. Here is how you add a thousand days to a date represented by that class:

```
GregorianCalendar someDay = new GregorianCalendar(1999, 11,
31);
   // odd feature of that class: month numbers go from 0 to 11
someDay.add(Calendar.DAY_OF_MONTH, 1000);
```

Unlike the `LocalDate.plusDays` method, the `GregorianCalendar.add` method is a *mutator method*. After invoking it, the state of the `someDay` object has changed. Here is how you can find out the new state:

```
year = someDay.get(Calendar.YEAR); // 2002
month = someDay.get(Calendar.MONTH) + 1; // 09
day = someDay.get(Calendar.DAY_OF_MONTH); // 26
```

That's why the variable is called `someDay` and not `newYearsEve`—it no longer is new year's eve after calling the mutator method.

In contrast, methods that only access objects without modifying them are sometimes called *accessor methods*. For example, `LocalDate.getYear` and `GregorianCalendar.get` are accessor methods.

C++ NOTE:

In C++, the `const` suffix denotes accessor methods. A method that is not declared as `const` is assumed to be a mutator. However, in the Java programming language, no special syntax distinguishes accessors from mutators.

I finish this section with a program that puts the `LocalDate` class to work. The program displays a calendar for the current month, like this:

```
Mon Tue Wed Thu Fri Sat Sun
                          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
30
```

The current day is marked with an asterisk (*). As you can see, the program needs to know how to compute the length of a month and the weekday of a given day.

Let us go through the key steps of the program. First, we construct an object that is initialized with the current date.

```
LocalDate date = LocalDate.now();
```

We capture the current month and day.

```
int month = date.getMonthValue();
int today = date.getDayOfMonth();
```

Then we set `date` to the first of the month and get the weekday of that date.

```
date = date.minusDays(today - 1); // set to start of month
DayOfWeek weekday = date.getDayOfWeek();
int value = weekday.getValue(); // 1 = Monday, . . . , 7 =
Sunday
```

The variable `weekday` is set to an object of type `DayOfWeek`. We call the `getValue` method of that object to get a numerical value for the weekday. This yields an integer that follows the international convention where the weekend comes at the end of the week, returning `1` for Monday, `2` for Tuesday, and so on. Sunday has value `7`.

Note that the first line of the calendar is indented, so that the first day of the month falls on the appropriate weekday. Here is the code to print the header and the indentation for the first line:

```
System.out.println("Mon Tue Wed Thu Fri Sat Sun");
for (int i = 1; i < value; i++)
   System.out.print("    ");
```

Now, we are ready to print the body of the calendar. We enter a loop in which `date` traverses the days of the month.

In each iteration, we print the date value. If `date` is today, the date is marked with an `*`. Then, we advance `date` to the next day. When we reach the beginning of each new week, we print a new line:

```
while (date.getMonthValue() == month)
{
   System.out.printf("%3d", date.getDayOfMonth());
   if (date.getDayOfMonth() == today)
      System.out.print("*");
   else
      System.out.print(" ");
   date = date.plusDays(1);
   if (date.getDayOfWeek().getValue() == 1)
System.out.println();
}
```

When do we stop? We don't know whether the month has 31, 30, 29, or 28 days. Instead, we keep iterating while `date` is still in the current month.

Listing 4.1 shows the complete program.

As you can see, the `LocalDate` class makes it possible to write a calendar program that takes care of complexities such as weekdays and the varying month lengths. You don't need to know *how* the `LocalDate` class computes months and weekdays. You just use the *interface* of the class—the methods such as `plusDays` and `getDayOfWeek`.

The point of this example program is to show you how you can use the interface of a class to carry out fairly sophisticated tasks without having to know the implementation details.

Listing 4.1 `CalendarTest/CalendarTest.java`

```java
import java.time.*;

/**
 * @version 1.5 2015-05-08
 * @author Cay Horstmann
 */
public class CalendarTest
{
   public static void main(String[] args)
   {
      LocalDate date = LocalDate.now();
      int month = date.getMonthValue();
      int today = date.getDayOfMonth();

      date = date.minusDays(today - 1); // set to start of month
      DayOfWeek weekday = date.getDayOfWeek();
      int value = weekday.getValue(); // 1 = Monday, . . . , 7 = Sunday

      System.out.println("Mon Tue Wed Thu Fri Sat Sun");
      for (int i = 1; i < value; i++)
         System.out.print("    ");
      while (date.getMonthValue() == month)
      {
         System.out.printf("%3d", date.getDayOfMonth());
         if (date.getDayOfMonth() == today)
            System.out.print("*");
         else
            System.out.print(" ");
         date = date.plusDays(1);
         if (date.getDayOfWeek().getValue() == 1) System.out.println();
      }
      if (date.getDayOfWeek().getValue() != 1) System.out.println();
```

```
    }
}
```

java.time.LocalDate 8

- `static LocalDate now()`

  constructs an object that represents the current date.

- `static LocalDate of(int year, int month, int day)`

  constructs an object that represents the given date.

- `int getYear()`
- `int getMonthValue()`
- `int getDayOfMonth()`

  gets the year, month, and day of this date.

- `DayOfWeek getDayOfWeek()`

  gets the weekday of this date as an instance of the `DayOfWeek` class. Call `getValue` on the `DayOfWeek` instance to get a weekday between `1` (Monday) and `7` (Sunday).

- `LocalDate plusDays(int n)`
- `LocalDate minusDays(int n)`

  yields the date that is `n` days after or before this date.

4.3 Defining Your Own Classes

In Chapter 3, you started writing simple classes. However, all those classes had just a single `main` method. Now the time has come to show you how to write the kind of "workhorse classes" that are needed for more sophisticated applications. These classes typically do not have a `main` method. Instead, they have their own instance fields and methods. To build a complete program, you combine several classes, one of which has a `main` method.

4.3.1 An `Employee` Class

The simplest form for a class definition in Java is

```
class ClassName
{
   field1
   field2
   . . .
   constructor1
   constructor2
   . . .
   method1
   method2
   . . .
}
```

Consider the following, very simplified, version of an `Employee` class that might be used by a business in writing a payroll system:

```
class Employee
{
   // instance fields
   private String name;
   private double salary;
   private LocalDate hireDay;

   // constructor
   public Employee(String n, double s, int year, int month, int
day)
   {
      name = n;
      salary = s;
      hireDay = LocalDate.of(year, month, day);
   }

   // a method
```

```
   public String getName()
   {
      return name;
   }

   // more methods
   . . .
}
```

We break down the implementation of this class, in some detail, in the sections that follow. First, though, Listing 4.2 is a program that shows the `Employee` class in action.

In the program, we construct an `Employee` array and fill it with three `Employee` objects:

```
Employee[] staff = new Employee[3];

staff[0] = new Employee("Carl Cracker", . . .);
staff[1] = new Employee("Harry Hacker", . . .);
staff[2] = new Employee("Tony Tester", . . .);
```

Next, we use the `raiseSalary` method of the `Employee` class to raise each employee's salary by 5%:

```
for (Employee e : staff)
   e.raiseSalary(5);
```

Finally, we print out information about each employee, by calling the `getName`, `getSalary`, and `getHireDay` methods:

```
for (Employee e : staff)
   System.out.println("name=" + e.getName()
      + ",salary=" + e.getSalary()
      + ",hireDay=" + e.getHireDay());
```

Note that the example program consists of *two* classes: the `Employee` class and a class `EmployeeTest` with the `public` access specifier. The `main` method with the instructions that we just described is contained in the `EmployeeTest` class.

The name of the source file is `EmployeeTest.java` because the name of the file must match the name of the `public` class. You can only have one public class in a source file, but you can have any number of nonpublic classes.

Next, when you compile this source code, the compiler creates two class files in the directory: `EmployeeTest.class` and `Employee.class`.

You then start the program by giving the bytecode interpreter the name of the class that contains the `main` method of your program:

```
java EmployeeTest
```

The bytecode interpreter starts running the code in the `main` method in the `EmployeeTest` class. This code in turn constructs three new `Employee` objects and shows you their state.

Listing 4.2 `EmployeeTest/EmployeeTest.java`

```
import java.time.*;

/**
 * This program tests the Employee class.
 * @version 1.13 2018-04-10
 * @author Cay Horstmann
 */
public class EmployeeTest
{
   public static void main(String[] args)
   {
      // fill the staff array with three Employee objects
      Employee[] staff = new Employee[3];

      staff[0] = new Employee("Carl Cracker", 75000, 1987, 12,
```

```
15);
      staff[1] = new Employee("Harry Hacker", 50000, 1989, 10, 1);
      staff[2] = new Employee("Tony Tester", 40000, 1990, 3, 15);

      // raise everyone's salary by 5%
      for (Employee e : staff)
         e.raiseSalary(5);

      // print out information about all Employee objects
      for (Employee e : staff)
         System.out.println("name=" + e.getName() + ",salary=" + e.getSalary() + ",hireDay="
            + e.getHireDay());
   }
}

class Employee
{
   private String name;
   private double salary;
   private LocalDate hireDay;

   public Employee(String n, double s, int year, int month, int day)
   {
      name = n;
      salary = s;
      hireDay = LocalDate.of(year, month, day);
   }

   public String getName()
   {
      return name;
   }

   public double getSalary()
   {
```

```
         return salary;
      }

      public LocalDate getHireDay()
      {
         return hireDay;
      }

      public void raiseSalary(double byPercent)
      {
         double raise = salary * byPercent / 100;
         salary += raise;
      }
   }
```

4.3.2 Use of Multiple Source Files

The program in Listing 4.2 has two classes in a single source file. Many programmers prefer to put each class into its own source file. For example, you can place the `Employee` class into a file `Employee.java` and the `EmployeeTest` class into `EmployeeTest.java`.

If you like this arrangement, you have two choices for compiling the program. You can invoke the Java compiler with a wildcard:

```
javac Employee*.java
```

Then, all source files matching the wildcard will be compiled into class files. Or, you can simply type

```
javac EmployeeTest.java
```

You may find it surprising that the second choice works even though the `Employee.java` file is never explicitly compiled. However, when the Java compiler sees the `Employee` class being used inside `EmployeeTest.java`, it will look for a file named `Employee.class`. If it does not find that file, it automatically searches for `Employee.java` and compiles it. Moreover, if the timestamp of the version of `Employee.java` that it finds is newer than that of the existing `Employee.class` file, the Java compiler will *automatically* recompile the file.

NOTE:

If you are familiar with the `make` facility of UNIX (or one of its Windows cousins, such as `nmake`), you can think of the Java compiler as having the `make` functionality already built in.

4.3.3 Dissecting the `Employee` Class

In the sections that follow, we will dissect the `Employee` class. Let's start with the methods in this class. As you can see by examining the source code, this class has one constructor and four methods:

```
public Employee(String n, double s, int year, int month, int
day)
public String getName()
public double getSalary()
public LocalDate getHireDay()
public void raiseSalary(double byPercent)
```

All methods of this class are tagged as `public`. The keyword `public` means that any method in any class can call the method. (The four possible access levels are covered in this and the next chapter.)

Next, notice the three instance fields that will hold the data manipulated inside an instance of the `Employee` class.

```
private String name;
private double salary;
private LocalDate hireDay;
```

The `private` keyword makes sure that the *only* methods that can access these instance fields are the methods of the `Employee` class itself. No outside method can read or write to these fields.

NOTE:

You could use the `public` keyword with your instance fields, but it would be a very bad idea. Having `public` instance fields would allow any part of the program to read and modify the instance fields, completely ruining encapsulation. Any method of any class can modify public fields—and, in our experience, some code *will* take advantage of that access privilege when you least expect it. I strongly recommend to make all your instance fields `private`.

Finally, notice that two of the instance fields are themselves objects: The `name`

and `hireDay` fields are references to `String` and `LocalDate` objects. This is quite usual: Classes will often contain instance fields of class type.

4.3.4 First Steps with Constructors

Let's look at the constructor listed in our `Employee` class.

```
public Employee(String n, double s, int year, int month, int
day)
{
   name = n;
   salary = s;
   hireDay = LocalDate.of(year, month, day);
}
```

As you can see, the name of the constructor is the same as the name of the class. This constructor runs when you construct objects of the `Employee` class—giving the instance fields the initial state you want them to have.

For example, when you create an instance of the `Employee` class with code like this:

```
new Employee("James Bond", 100000, 1950, 1, 1)
```

you have set the instance fields as follows:

```
name = "James Bond";
salary = 100000;
hireDay = LocalDate.of(1950, 1, 1); // January 1, 1950
```

There is an important difference between constructors and other methods. A constructor can only be called in conjunction with the `new` operator. You can't apply a constructor to an existing object to reset the instance fields. For example,

```
james.Employee("James Bond", 250000, 1950, 1, 1) // ERROR
```

is a compile-time error.

We will have more to say about constructors later in this chapter. For now, keep the following in mind:

- A constructor has the same name as the class.
- A class can have more than one constructor.
- A constructor can take zero, one, or more parameters.
- A constructor has no return value.
- A constructor is always called with the `new` operator.

C++ NOTE:

Constructors work the same way in Java as they do in C++. Keep in mind, however, that all Java objects are constructed on the heap and that a constructor must be combined with `new`. It is a common error of C++ programmers to forget the `new` operator:

```
Employee number007("James Bond", 100000, 1950, 1, 1); // C++,
not Java
```

That works in C++ but not in Java.

CAUTION:

Be careful not to introduce local variables with the same names as the instance fields. For example, the following constructor will not set the `name` or `salary` instance fields:

```
public Employee(String n, double s, . . .)
{
String name = n; // ERROR
double salary = s; // ERROR
  . . .
}
```

The constructor declares *local* variables `name` and `salary`. These variables are only accessible inside the constructor. They *shadow* the instance fields with the same name. Some programmers accidentally write this kind of code when they type faster than they think, because their fingers are used to adding the data type. This is a nasty error that can be hard to track down. You just have to be careful in all of your methods to not use variable names that equal the names of instance fields.

4.3.5 Declaring Local Variables with `var`

As of Java 10, you can declare local variables with the `var` keyword instead of specifying their type, provided their type can be inferred from the initial value. For example, instead of declaring

```
Employee harry = new Employee("Harry Hacker", 50000, 1989, 10,
1);
```

you simply write

```
var harry = new Employee("Harry Hacker", 50000, 1989, 10, 1);
```

This is nice since it avoids the repetition of the type name `Employee`.

From now on, I will use the `var` notation in those cases where the type is obvious from the right-hand side without any knowledge of the Java API. But I won't use `var` with numeric types such as `int`, `long`, or `double` so that you don't have to look out for the difference between `0`, `0L`, and `0.0`. Once you are more experienced with the Java API, you may want to use the `var` keyword more frequently.

Note that the `var` keyword can only be used with *local* variables inside methods. You must always declare the types of parameters and fields.

4.3.6 Working with `null` References

In Section 4.2.1, "Objects and Object Variables," on p. 132, you saw that an object variable holds a reference to an object, or the special value `null` to indicate the absence of an object.

This sounds like a convenient mechanism for dealing with special situations, such as an unknown name or hire date. But you need to be very careful with `null` values.

If you apply a method to a `null` value, a `NullPointerException` occurs.

```
LocalDate rightNow = null;
String s = rightNow.toString(); // NullPointerException
```

This is a serious error, similar to an "index out of bounds" exception. If your program does not "catch" an exception, it is terminated. Normally, programs don't catch these kinds of exceptions but rely on programmers not to cause them in the first place.

TIP:

When your program is terminated with a `NullPointerException`, the stack trace shows you in which line of your code the problem occurred. Since Java 17, the error message includes the name of the variable or method with the `null` value. For example, in a call

```
String s = e.getHireDay().toString();
```

the error message tells you whether `e` was `null` or `getHireDay` returned `null`.

When you define a class, it is a good idea to be clear about which fields can be `null`. In our example, we don't want the `name` or `hireDay` field to be `null`. (We don't have to worry about the `salary` field. It has primitive type and can never be `null`.)

The `hireDay` field is guaranteed to be non-`null` because it is initialized with a new `LocalDate` object. But `name` will be `null` if the constructor is called with a `null` argument for `n`.

There are two solutions. The "permissive" approach is to turn a `null` argument into an appropriate non-`null` value:

```
if (n == null) name = "unknown"; else name = n;
```

The `Objects` class has a convenience method for this purpose:

```
public Employee(String n, double s, int year, int month, int
day)
```

```
{
   name = Objects.requireNonNullElse(n, "unknown");
   . . .
}
```

The “tough love” approach is to reject a `null` argument:

```
public Employee(String n, double s, int year, int month, int
day)
{
   name = Objects.requireNonNull(n, "The name cannot be null");
   . . .
}
```

If someone constructs an `Employee` object with a `null` name, then a `NullPointerException` occurs. At first glance, that may not seem a useful remedy. But there are two advantages:

1. The exception report has a description of the problem.
2. The exception report pinpoints the location of the problem. Otherwise, a `NullPointerException` would have occurred elsewhere, with no easy way of tracing it back to the faulty constructor argument.

NOTE:

Whenever you accept an object reference as a construction parameter, ask yourself whether you really intend to model values that can be present or absent. If not, the “tough love” approach is preferred.

4.3.7 Implicit and Explicit Parameters

Methods operate on objects and access their instance fields. For example, the method

```
public void raiseSalary(double byPercent)
{
   double raise = salary * byPercent / 100;
   salary += raise;
}
```

sets a new value for the `salary` instance field in the object on which this method is invoked. Consider the call

```
number007.raiseSalary(5);
```

The effect is to increase the value of the `number007.salary` field by 5%. More specifically, the call executes the following instructions:

```
double raise = number007.salary * 5 / 100;
number007.salary += raise;
```

The `raiseSalary` method has two parameters. The first parameter, called the *implicit* parameter, is the object of type `Employee` that appears before the method name. The second parameter, the number inside the parentheses after the method name, is an *explicit* parameter. (Some people call the implicit parameter the *target* or *receiver* of the method call.)

As you can see, the explicit parameters are explicitly listed in the method declaration—for example, `double byPercent`. The implicit parameter does not appear in the method declaration.

In every method, the keyword `this` refers to the implicit parameter. If you like, you can write the `raiseSalary` method as follows:

```
public void raiseSalary(double byPercent)
{
   double raise = this.salary * byPercent / 100;
   this.salary += raise;
}
```

Some programmers prefer that style because it clearly distinguishes between instance fields and local variables.

C++ NOTE:

In C++, you generally define methods outside the class:

```
void Employee::raiseSalary(double byPercent) // C++, not Java
{
   . . .
}
```

If you define a method inside a class, then it is, automatically, an inline method.

```
class Employee
{
   . . .
   int getName() { return name; } // inline in C++
}
```

In Java, all methods are defined inside the class itself. This does not make them inline. Finding opportunities for inline replacement is the job of the Java virtual machine. The just-in-time compiler watches for calls to methods that are short, commonly called, and not overridden, and optimizes them away.

4.3.8 Benefits of Encapsulation

Finally, let's look more closely at the rather simple `getName`, `getSalary`, and `getHireDay` methods.

```
public String getName()
{
```

```
      return name;
   }
   public double getSalary()
   {
      return salary;
   }
   public LocalDate getHireDay()
   {
      return hireDay;
   }
```

These are obvious examples of accessor methods. As they simply return the values of instance fields, they are sometimes called *field accessors*.

Wouldn't it be easier to make the `name`, `salary`, and `hireDay` fields public, instead of having separate accessor methods?

However, the `name` field is read-only. Once you set it in the constructor, there is no method to change it. Thus, we have a guarantee that the `name` field will never be corrupted.

The `salary` field is not read-only, but it can only be changed by the `raiseSalary` method. In particular, should the value ever turn out wrong, only that method needs to be debugged. Had the `salary` field been public, the culprit for messing up the value could have been anywhere.

Sometimes, it happens that you want to get and set the value of an instance field. Then you need to supply *three* items:

- A private instance field;
- A public field accessor method; and
- A public field mutator method.

This is a lot more tedious than supplying a single public instance field, but there are considerable benefits.

First, you can change the internal implementation without affecting any code other than the methods of the class. For example, if the storage of the name is changed to

```
String firstName;
String lastName;
```

then the `getName` method can be changed to return

```
firstName + " " + lastName
```

This change is completely invisible to the remainder of the program.

Of course, the accessor and mutator methods may need to do a lot of work to convert between the old and the new data representation. That leads us to our second benefit: Mutator methods can perform error checking, whereas code that simply assigns to a field may not go into the trouble. For example, a `setSalary` method might check that the salary is never less than 0.

CAUTION:

Be careful not to write accessor methods that return references to mutable objects. In a previous edition of this book, I violated that rule in the `Employee` class in which the `getHireDay` method returned an object of class `Date`:

```
class Employee
{
   private Date hireDay;
   . . .
   public Date getHireDay()
   {
      return hireDay; // BAD
   }
   . . .
}
```

Unlike the `LocalDate` class, which has no mutator methods, the `Date` class has a mutator method, `setTime`, where you can set the number of milliseconds.

The fact that `Date` objects are mutable breaks encapsulation! Consider the following rogue code:

```
Employee harry = . . .;
Date d = harry.getHireDay();
double tenYearsInMilliseconds = 10 * 365.25 * 24 * 60 * 60 *
1000;
d.setTime(d.getTime() - (long) tenYearsInMilliseconds);
// let's give Harry ten years of added seniority
```

The reason is subtle. Both `d` and `harry.hireDay` refer to the same object (see Figure 4.5). Applying mutator methods to `d` automatically changes the private state of the `Employee` object!

If you need to return a reference to a mutable object, you should *clone* it first. A clone is an exact copy of an object stored in a new location. Cloning is discussed in detail in Chapter 6. Here is the corrected code:

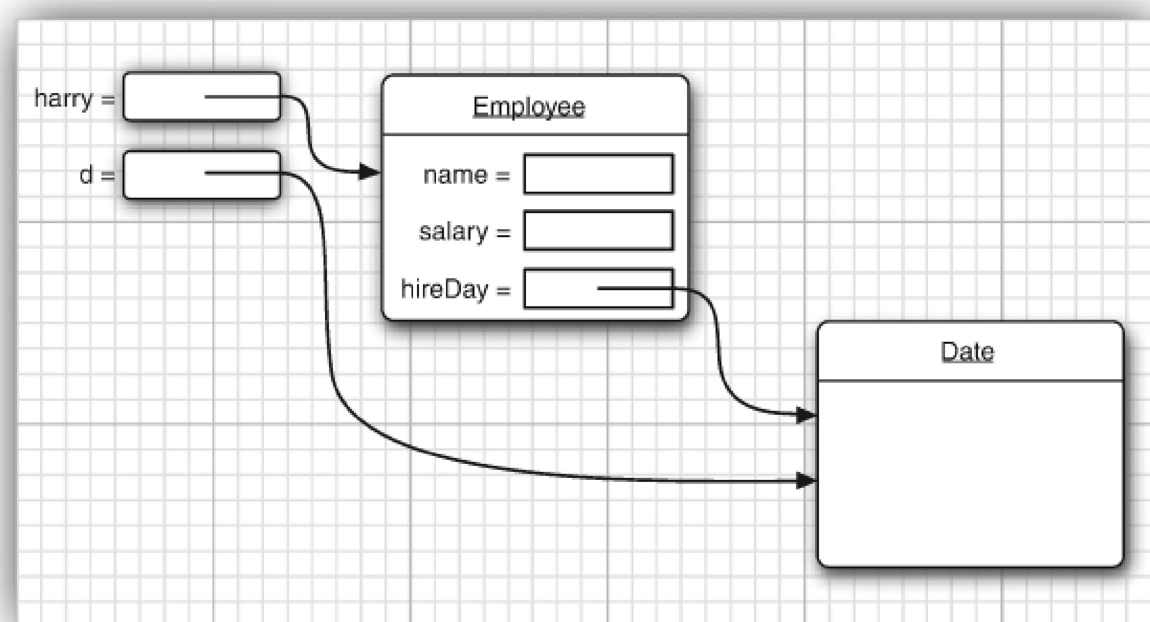


Figure 4.5 Returning a reference to a mutable instance field

```
class Employee
{
   . . .
   public Date getHireDay()
   {
      return (Date) hireDay.clone(); // OK
   }
   . . .
}
```

As a rule of thumb, always use `clone` whenever you need to return a copy of a mutable field.

4.3.9 Class-Based Access Privileges

You know that a method can access the private data of the object on which it is invoked. What people often find surprising is that a method can access the private data of *all objects of its class*. For example, consider a method `equals` that compares two employees.

```
class Employee
{
   . . .
   public boolean equals(Employee other)
   {
      return name.equals(other.name);
   }
}
```

A typical call is

```
if (harry.equals(boss)) . . .
```

This method accesses the private fields of `harry`, which is not surprising. It also accesses the private fields of `boss`. This is legal because `boss` is an object of type

`Employee`, and a method of the `Employee` class is permitted to access the private fields of *any* object of type `Employee`.

C++ NOTE:

C++ has the same rule. A method can access the private features of any object of its class, not just of the implicit parameter.

4.3.10 Private Methods

When implementing a class, we make all instance fields private because public data are dangerous. But what about the methods? While most methods are public, private methods are useful in certain circumstances. Sometimes, you may wish to break up the code for a computation into separate helper methods. Typically, these helper methods should not be part of the public interface—they may be too close to the current implementation or require a special protocol or calling order. Such methods are best implemented as private.

To implement a private method in Java, simply change the `public` keyword to `private`.

By making a method private, you are under no obligation to keep it available if you change your implementation. The method may well be *harder* to implement or *unnecessary* if the data representation changes; this is irrelevant. The point is that as long as the method is private, the designers of the class can be assured that it is never used elsewhere, so they can simply drop it. If a method is public, you cannot simply drop it because other code might rely on it.

4.3.11 Final Instance Fields

You can define an instance field as `final`. Such a field must be initialized when the object is constructed. That is, you must guarantee that the field value has been set after the end of every constructor. Afterwards, the field may not be modified again. For example, the `name` field of the `Employee` class may be declared as `final` because it never changes after the object is constructed—there is no `setName` method.

```
class Employee
{
   private final String name;
   . . .
}
```

The `final` modifier is particularly useful for fields whose type is primitive or an *immutable class*. (A class is immutable if none of its methods ever mutate its objects. For example, the `String` class is immutable.)

For mutable classes, the `final` modifier can be confusing. For example, consider a field

```
private final StringBuilder evaluations;
```

that is initialized in the `Employee` constructor as

```
evaluations = new StringBuilder();
```

The `final` keyword merely means that the object reference stored in the `evaluations` variable will never again refer to a different `StringBuilder` object. But the object can be mutated:

```
public void giveGoldStar()
{
   evaluations.append(LocalDate.now() + ": Gold star!\n");
}
```

4.4 Static Fields and Methods

In all sample programs that you have seen, the `main` method is tagged with the `static` modifier. We are now ready to discuss the meaning of this modifier.

4.4.1 Static Fields

If you define a field as `static`, then the field is not present in the objects of the class. There is only a single copy of each static field. You can think of static fields as belonging to the class, not to the individual objects. For example, let's suppose we want to assign a unique identification number to each employee. We add an instance field `id` and a static field `nextId` to the `Employee` class:

```
class Employee
{
   private static int nextId = 1;

   private int id;
   . . .
}
```

Every `Employee` object now has its own `id` field, but there is only one `nextId` field that is shared among all instances of the class. Let's put it another way. If there are 1,000 objects of the `Employee` class, then there are 1,000 instance fields `id`, one for each object. But there is a single static field `nextId`. Even if there are no `Employee` objects, the static field `nextId` is present. It belongs to the class, not to any individual object.

NOTE:

In some object-oriented programming languages, static fields are called *class fields*. The term "static" is a meaningless holdover from C++.

In the constructor, we assign the next available ID to the new `Employee` object and then increment it:

```
id = nextId;
nextId++;
```

Suppose we construct the object `harry`. Then the `id` field of `harry` is set to the current value of the static field `nextId`, and the value of the static field is incremented:

```
harry.id = Employee.nextId;
Employee.nextId++;
```

4.4.2 Static Constants

Static variables are quite rare. However, static constants are more common. For example, the `Math` class defines a static constant:

```
public class Math
{
   . . .
   public static final double PI = 3.14159265358979323846;
   . . .
}
```

You can access this constant in your programs as `Math.PI`.

If the keyword `static` had been omitted, then `PI` would have been an instance field of the `Math` class. That is, you would need an object of this class to access `PI`, and every `Math` object would have its own copy of `PI`.

Another static constant that you have used many times is `System.out`. It is declared in the `System` class as follows:

```
public class System
{
```

```
    . . .   public static final PrintStream out = . . .;
    . . .
}
```

As mentioned several times, it is never a good idea to have public fields, because everyone can modify them. However, public constants (that is, `final` fields) are fine. Since `out` has been declared as `final`, you cannot reassign another print stream to it:

```
System.out = new PrintStream(. . .); // ERROR--out is final
```

NOTE:

If you look at the `System` class, you will notice a method `setOut` that sets `System.out` to a different stream. You may wonder how that method can change the value of a `final` variable. However, the `setOut` method is a *native* method, not implemented in the Java programming language. Native methods can bypass the access control mechanisms of the Java language. This is a very unusual workaround that you should not emulate in your programs.

4.4.3 Static Methods

Static methods are methods that do not operate on objects. For example, the `pow` method of the `Math` class is a static method. The expression

```
Math.pow(x, a)
```

computes the power x^a. It does not use any `Math` object to carry out its task. In other words, it has no implicit parameter.

You can think of static methods as methods that don't have a `this` parameter. (In a nonstatic method, the `this` parameter refers to the implicit parameter of the method—see Section 4.3.7, “Implicit and Explicit Parameters,” on p. 150.)

A static method of the `Employee` class cannot access the `id` instance field because it does not operate on an object. However, a static method can access a static field. Here is an example of such a static method:

```
public static int advanceId()
{
   int r = nextId; // obtain next available id
   nextId++;
   return r;
}
```

To call this method, you supply the name of the class:

```
int n = Employee.advanceId();
```

Could you have omitted the keyword `static` for this method? Yes, but then you would need to have an object reference of type `Employee` to invoke the method.

NOTE:

It is legal to use an object to call a static method. For example, if `harry` is an `Employee` object, then you can call `harry.advanceId()` instead of `Employee.advanceId()`. However, I find that notation confusing. The `advanceId` method doesn’t look at `harry` at all to compute the result. I recommend that you use class names, not objects, to invoke static methods.

Use static methods in two situations:

- When a method doesn’t need to access the object state because all needed parameters are supplied as explicit parameters (example: `Math.pow`).

- When a method only needs to access static fields of the class (example: `Employee.advanceId`).

C++ NOTE:

Static fields and methods have the same functionality in Java and C++. However, the syntax is slightly different. In C++, you use the `::` operator to access a static field or method outside its scope, such as `Math::PI`.

The term "static" has a curious history. At first, the keyword `static` was introduced in C to denote local variables that don't go away when a block is exited. In that context, the term "static" makes sense: The variable stays around and is still there when the block is entered again. Then `static` got a second meaning in C, to denote global variables and functions that cannot be accessed from other files. The keyword `static` was simply reused to avoid introducing a new keyword. Finally, C++ reused the keyword for a third, unrelated, interpretation—to denote variables and functions that belong to a class but not to any particular object of the class. That is the same meaning the keyword has in Java.

4.4.4 Factory Methods

Here is another common use for static methods. Classes such as `LocalDate` and `NumberFormat` use static *factory methods* that construct objects. You have already seen the factory methods `LocalDate.now` and `LocalDate.of`. Here is how to obtain formatter objects for various styles:

```
NumberFormat currencyFormatter =
NumberFormat.getCurrencyInstance();
NumberFormat percentFormatter =
NumberFormat.getPercentInstance();
double x = 0.1;System.out.println(currencyFormatter.format(x));
// prints $0.10
System.out.println(percentFormatter.format(x)); // prints 10%
```

Why doesn't the `NumberFormat` class use a constructor instead? There are two reasons:

- You can't give names to constructors. The constructor name is always the same as the class name. But we want two different names to get the currency instance and the percent instance.
- When you use a constructor, you can't vary the type of the constructed object. But the factory methods actually return objects of the class `DecimalFormat`, a subclass that inherits from `NumberFormat`. (See Chapter 5 for more on inheritance.)

4.4.5 The `main` Method

Note that you can call static methods without having any objects. For example, you never construct any objects of the `Math` class to call `Math.pow`.

For the same reason, the `main` method is a static method.

```
public class Application
{
   public static void main(String[] args)
   {
      // construct objects here
      . . .
   }
}
```

The `main` method does not operate on any objects. In fact, when a program starts, there aren't any objects yet. The static `main` method executes, and constructs the objects that the program needs.

TIP:

Every class can have a `main` method. That is a handy trick for adding demonstration code to a class. For example, you can add a `main` method to the `Employee` class:

```
class Employee
{
   public Employee(String n, double s, int year, int month, int
day)
   {
      name = n;
      salary = s;
      hireDay = LocalDate.of(year, month, day);
   }
   . . .   public static void main(String[] args) // unit test
   {
      var e = new Employee("Romeo", 50000, 2003, 3, 31);
      e.raiseSalary(10);
      System.out.println(e.getName() + " " + e.getSalary());
   }
   . . .
}
```

To see a demo of the `Employee` class, simply execute

```
java Employee
```

If the `Employee` class is a part of a larger application, you start the application with

```
java Application
```

and the `main` method of the `Employee` class is never executed.

The program in Listing 4.3 contains a simple version of the `Employee` class with a static field `nextId` and a static method `advanceId`. We fill an array with three `Employee` objects and then print the employee information. Finally, we print the next available identification number, to demonstrate the static method.

Note that the `Employee` class also has a static `main` method for unit testing. Try running both

```
java Employee
```

and

```
java StaticTest
```

to execute both `main` methods.

Listing 4.3 `StaticTest/StaticTest.java`

```
/**
 * This program demonstrates static methods.
 * @version 1.02 2008-04-10
 * @author Cay Horstmann
 */
public class StaticTest
{
   public static void main(String[] args)
   {
      // fill the staff array with three Employee objects
      var staff = new Employee[3];

      staff[0] = new Employee("Tom", 40000);
      staff[1] = new Employee("Dick", 60000);
      staff[2] = new Employee("Harry", 65000);

      // print out information about all Employee objects
      for (Employee e : staff)
      {
         System.out.println("name=" + e.getName() + ",id=" + e.getId() + ",salary="
            + e.getSalary());
      }

```

```
       int n = Employee.getNextId(); // calls static method
       System.out.println("Next available id=" + n);
   }
}

class Employee
{
   private static int nextId = 1;

   private String name;
   private double salary;
   private int id;

   public Employee(String n, double s)
   {
      name = n;
      salary = s;
      id = advanceId();
   }

   public String getName()
   {
      return name;
   }

   public double getSalary()
   {
      return salary;
   }

   public int getId()
   {
      return id;
   }

   public static int advanceId()
   {
      int r = nextId; // obtain next available id
      nextId++;
```

```
      return r;
   }

   public static void main(String[] args) // unit test
   {
      var e = new Employee("Harry", 50000);
      System.out.println(e.getName() + " " + e.getSalary());
   }
}
```

`java.util.Objects` 7

- `static <T> void requireNonNull(T obj)`
- `static <T> void requireNonNull(T obj, String message)`
- `static <T> void requireNonNull(T obj, Supplier<String> messageSupplier)` 8

  If `obj` is `null`, these methods throw a `NullPointerException` with no message or the given message. (Chapter 6 explains how to obtain a value lazily with a supplier. Chapter 8 explains the `<T>` syntax.)

- `static <T> T requireNonNullElse(T obj, T defaultObj)` 9
- `static <T> T requireNonNullElseGet(T obj, Supplier<T> defaultSupplier)` 9

  returns `obj` if it is not `null`, or the default object if `obj` is `null`.

4.5 Method Parameters

Let us review the computer science terms that describe how parameters can be passed to a method (or a function) in a programming language. The term *call by value* means that the method gets just the value that the caller provides. In contrast, *call by reference* means that the method gets the *location* of the variable that the caller provides. Thus, a method can *modify* the value stored in a variable passed by reference but not in one passed by value. These "call by . . ." terms are standard computer science terminology describing the behavior of method parameters in various programming languages, not just Java. (There is also a *call by name* that is mainly of historical interest, being employed in the Algol programming language, one of the oldest high-level languages.)

The Java programming language *always* uses call by value. That means that the method gets a copy of all parameter values. In particular, the method cannot modify the contents of any parameter variables passed to it.

For example, consider the following call:

```
double percent = 10;
harry.raiseSalary(percent);
```

No matter how the method is implemented, we know that after the method call, the value of `percent` is still `10`.

Let us look a little more closely at this situation. Suppose a method tried to triple the value of a method parameter:

```
public static void tripleValue(double x) // doesn't work
{
   x = 3 * x;
}
```

Let's call this method:

```
double percent = 10;
tripleValue(percent);
```

However, this does not work. After the method call, the value of `percent` is still `10`. Here is what happens:

1. `x` is initialized with a copy of the value of `percent` (that is, `10`). 2. `x` is tripled—it is now `30`. But `percent` is still `10` (see Figure 4.6). 3. The method ends, and the parameter variable `x` is no longer in use.

There are, however, two kinds of method parameters:

- Primitive types (numbers, `boolean` values)
- Object references

You have seen that it is impossible for a method to change a primitive type parameter. The situation is different for object parameters. You can easily implement a method that triples the salary of an employee:

```
public static void tripleSalary(Employee x) // works
{
   x.raiseSalary(200);
}
```

When you call

```
harry = new Employee(. . .);
tripleSalary(harry);
```

then the following happens:

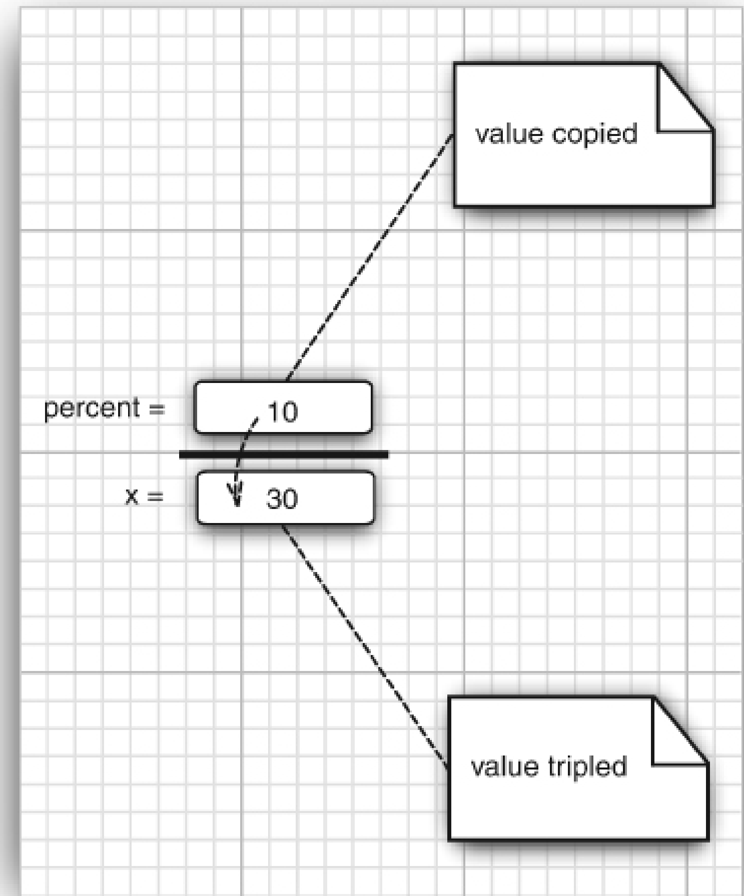


Figure 4.6 Modifying a parameter variable has no lasting effect.

1. `x` is initialized with a copy of the value of `harry`—that is, an object reference.
2. The `raiseSalary` method is applied to that object reference. The `Employee` object to which both `x` and `harry` refer gets its salary raised by 200 percent.
3. The method ends, and the parameter variable `x` is no longer in use. Of course, the object variable `harry` continues to refer to the object whose salary was tripled (see Figure 4.7).

As you have seen, it is easily possible—and in fact very common—to implement methods that change the state of an object parameter. The reason is simple. The method gets a copy of the object reference, and both the original and the copy refer to the same object.

Many programming languages (in particular, C++ and Pascal) have two mechanisms for parameter passing: call by value and call by reference. Some programmers (and unfortunately even some book authors) claim that Java uses call by reference for objects. That is false. As this is such a common misunderstanding, it is worth examining a counterexample in detail.

Let's try to write a method that swaps two `Employee` objects:

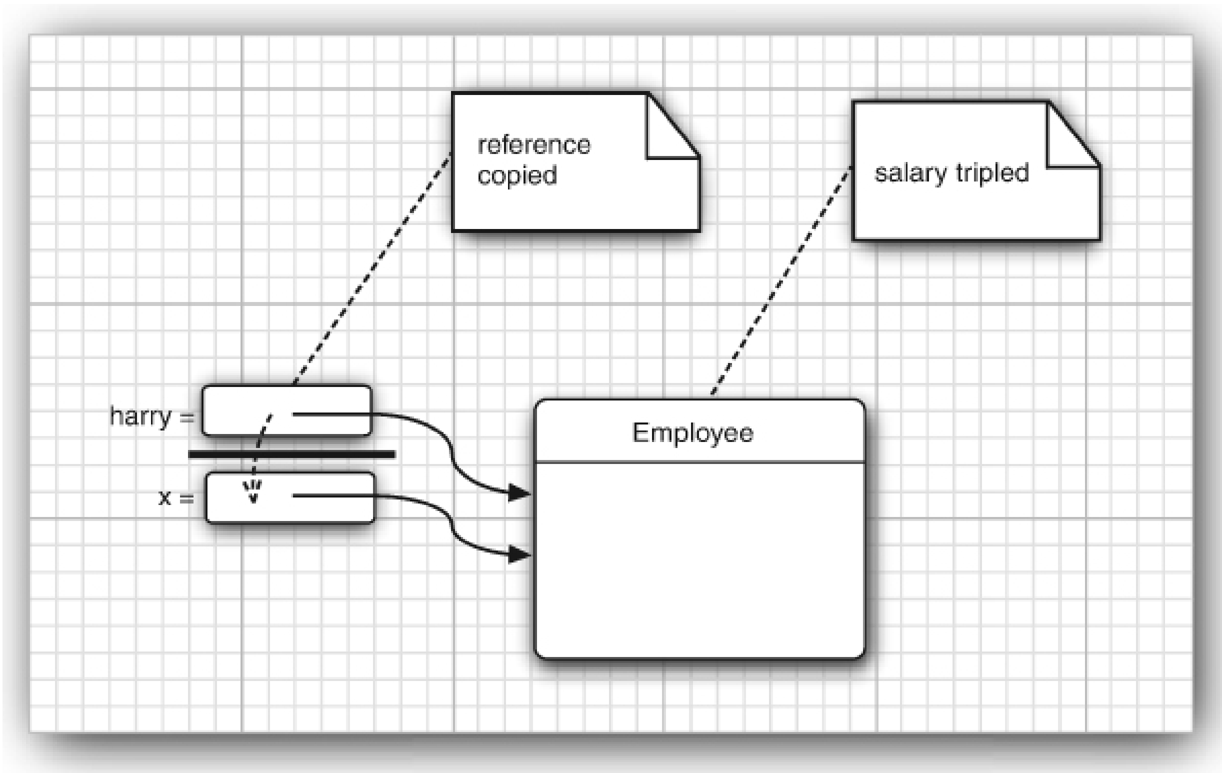


Figure 4.7 Modifying an object referenced by a parameter has a lasting effect.

```
public static void swap(Employee x, Employee y) // doesn't work
{
   Employee temp = x;
   x = y;
   y = temp;
}
```

If Java used call by reference for objects, this method would work:

```
var a = new Employee("Alice", . . .);
var b = new Employee("Bob", . . .);
swap(a, b);
// does a now refer to Bob, b to Alice?
```

However, the method does not actually change the object references that are stored in the variables `a` and `b`. The `x` and `y` parameters of the `swap` method are initialized with *copies* of these references. The method then proceeds to swap these copies.

```
// x refers to Alice, y to Bob
Employee temp = x;
x = y;
y = temp;
// now x refers to Bob, y to Alice
```

But ultimately, this is a wasted effort. When the method ends, the parameter variables `x` and `y` are abandoned. The original variables `a` and `b` still refer to the same objects as they did before the method call (see Figure 4.8).

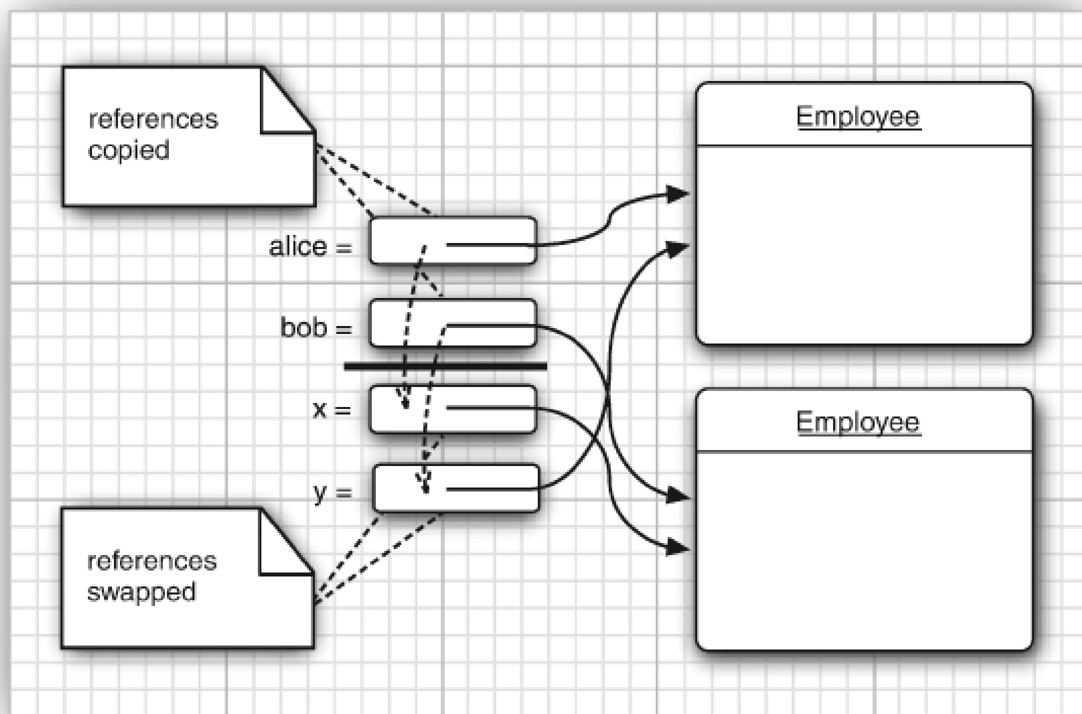


Figure 4.8 Swapping parameter variables has no lasting effect.

This demonstrates that the Java programming language does not use call by reference for objects. Instead, *object references are passed by value*.

Here is a summary of what you can and cannot do with method parameters in Java:

- A method cannot modify a parameter of a primitive type (that is, numbers or `boolean` values).
- A method can change the *state* of an object parameter.
- A method cannot make an object parameter refer to a new object.

The program in Listing 4.4 demonstrates these facts. The program first tries to triple the value of a number parameter and does not succeed:

```
Testing tripleValue:
Before: percent=10.0
```

```
End of method: x=30.0
After: percent=10.0
```

It then successfully triples the salary of an employee:

```
Testing tripleSalary:
Before: salary=50000.0
End of method: salary=150000.0
After: salary=150000.0
```

After the method, the state of the object to which `harry` refers has changed. This is possible because the method modified the state through a copy of the object reference.

Finally, the program demonstrates the failure of the `swap` method:

```
Testing swap:
Before: a=Alice
Before: b=Bob
End of method: x=Bob
End of method: y=Alice
After: a=Alice
After: b=Bob
```

As you can see, the parameter variables `x` and `y` are swapped, but the variables `a` and `b` are not affected.

C++ NOTE:

C++ has both call by value and call by reference. You tag reference parameters with `&`. For example, you can easily implement methods `void tripleValue(double& x)` or `void swap(Employee& x, Employee& y)` that modify their reference parameters.

Listing 4.4 `ParamTest/ParamTest.java`

```
/**
 * This program demonstrates parameter passing in Java.
 * @version 1.01 2018-04-10
 * @author Cay Horstmann
 */
public class ParamTest
{
   public static void main(String[] args)
   {
      /*
       * Test 1: Methods can't modify numeric parameters
       */
      System.out.println("Testing tripleValue:");
      double percent = 10;
      System.out.println("Before: percent=" + percent);
      tripleValue(percent);
      System.out.println("After: percent=" + percent);
      /*
       * Test 2: Methods can change the state of object parameters
       */
      System.out.println("\nTesting tripleSalary:");
      var harry = new Employee("Harry", 50000);
      System.out.println("Before: salary=" + harry.getSalary());
      tripleSalary(harry);
      System.out.println("After: salary=" + harry.getSalary());

      /*
       * Test 3: Methods can't attach new objects to object parameters
       */
      System.out.println("\nTesting swap:");
      var a = new Employee("Alice", 70000);
      var b = new Employee("Bob", 60000);
      System.out.println("Before: a=" + a.getName());
      System.out.println("Before: b=" + b.getName());
```

```
      swap(a, b);
      System.out.println("After: a=" + a.getName());
      System.out.println("After: b=" + b.getName());
   }

   public static void tripleValue(double x) // doesn't work
   {
      x = 3 * x;
      System.out.println("End of method: x=" + x);
   }

   public static void tripleSalary(Employee x) // works
   {
      x.raiseSalary(200);
      System.out.println("End of method: salary=" +
x.getSalary());
   }

   public static void swap(Employee x, Employee y)
   {
      Employee temp = x;
      x = y;
      y = temp;
      System.out.println("End of method: x=" + x.getName());
      System.out.println("End of method: y=" + y.getName());
   }
}

class Employee // simplified Employee class
{
    private String name;
    private double salary;

    public Employee(String n, double s)
    {
       name = n;
       salary = s;
    }

    public String getName()
```

```
    {
       return name;
    }

    public double getSalary()
    {
       return salary;
    }

    public void raiseSalary(double byPercent)
    {
       double raise = salary * byPercent / 100;
       salary += raise;
    }
 }
```

4.6 Object Construction

You have seen how to write simple constructors that define the initial state of your objects. However, since object construction is so important, Java offers quite a variety of mechanisms for writing constructors. We go over these mechanisms in the sections that follow.

4.6.1 Overloading

Some classes have more than one constructor. For example, you can construct an empty `StringBuilder` object as

```
var messages = new StringBuilder();
```

Alternatively, you can specify an initial string:

```
var todoList = new StringBuilder("To do:\n");
```

This capability is called *overloading*. Overloading occurs if several methods have the same name (in this case, the `StringBuilder` constructor method) but different parameters. The compiler must sort out which method to call. It picks the correct method by matching the parameter types in the headers of the various methods with the types of the values used in the specific method call. A compile-time error occurs if the compiler cannot match the parameters, either because there is no match at all or because there is not one that is better than all others. (The process of finding a match is called *overloading resolution*.)

NOTE:

Java allows you to overload any method—not just constructor methods. Thus, to completely describe a method, you need to specify its name together with its parameter types. This is called the *signature* of the method. For example, the `String` class has four public methods called `indexOf`. They have signatures

```
indexOf(int)
indexOf(int, int)
indexOf(String)
indexOf(String, int)
```

The return type is not part of the method signature. That is, you cannot have two methods with the same names and parameter types but different return types.

4.6.2 Default Field Initialization

If you don't set a field explicitly in a constructor, it is automatically set to a default value: numbers to `0`, `boolean` values to `false`, and object references to `null`. Some people consider it poor programming practice to rely on the defaults. Certainly, it makes it harder for someone to understand your code if fields are being initialized invisibly.

NOTE:

This is an important difference between fields and local variables. You must always explicitly initialize local variables in a method. But in a class, if you don't initialize a field, it is automatically initialized to a default (`0`, `false`, or `null`).

For example, consider the `Employee` class. Suppose you don't specify how to initialize some of the fields in a constructor. By default, the `salary` field would be initialized with `0` and the `name` and `hireDay` fields would be initialized with `null`.

However, that would not be a good idea. If anyone called the `getName` or `getHireDay` method, they would get a `null` reference that they probably don't expect:

```
LocalDate h = harry.getHireDay();
int year = h.getYear(); // throws exception if h is null
```

4.6.3 The Constructor with No Arguments

Many classes contain a constructor with no arguments that creates an object whose state is set to an appropriate default. For example, here is a no-argument constructor for the `Employee` class:

```
public Employee()
{
   name = "";
   salary = 0;
   hireDay = LocalDate.now();
}
```

If you write a class with no constructors whatsoever, then a no-argument constructor is provided for you. This constructor sets *all* the instance fields to their default values. So, all numeric data contained in the instance fields would be `0`, all `boolean` values would be `false`, and all object variables would be `null`.

If a class supplies at least one constructor but does not supply a no-argument constructor, it is illegal to construct objects without supplying arguments. For example, our original `Employee` class in Listing 4.2 provided a single constructor:

```
public Employee(String n, double s, int year, int month, int
day)
```

With that class, it was not legal to construct default employees. That is, the call

```
e = new Employee();
```

would have been an error.

CAUTION:

Please keep in mind that you get a free no-argument constructor *only* when your class has no other constructors. If you write your class with even a single constructor of your own and you want the users of your class to have the ability to create an instance by a call to

```
new ClassName()
```

then you must provide a no-argument constructor. Of course, if you are happy with the default values for all fields, you can simply supply

```
public ClassName()
{
}
```

C++ NOTE:

C++ has a special initializer list syntax for constructing fields, such as

```
Employee::Employee(String n, double s, int y, int m, int d) //
C++
:  name(n),
   salary(s),
   hireDay(y, m, d)
{
}
```

C++ uses this special syntax to avoid unnecessary invocations of no-argument constructors. In Java, there is no need for that because objects have no subobjects, only references to other objects.

4.6.4 Explicit Field Initialization

By overloading the constructor methods in a class, you can build many ways to set the initial state of the instance fields of your classes. It is always a good idea to make sure that, regardless of the constructor call, every instance field is set to something meaningful.

You can simply assign a value to any field in the class definition. For example:

```
class Employee
{
   private String name = "";
   . . .
}
```

This assignment is carried out before the constructor executes. This syntax is particularly useful if all constructors of a class need to set a particular instance field to the same value.

The initialization value doesn't have to be a constant value. Here is an example in which a field is initialized with a method call. Consider the `Employee` class where each employee has an `id` field. You can initialize it as follows:

```
class Employee
{
   private static int nextId;
   private int id = advanceId();
   . . .
   private static int advanceId()
   {
      int r = nextId;
      nextId++;
      return r;   }
   . . .
}
```

4.6.5 Parameter Names

When you write very trivial constructors (and you'll write a lot of them), it can be somewhat frustrating to come up with parameter names.

We have generally opted for single-letter parameter names:

```
public Employee(String n, double s)
{
   name = n;
   salary = s;
}
```

However, the drawback is that you need to read the code to tell what the `n` and `s` parameters mean.

Some programmers prefix each parameter with an "a":

```
public Employee(String aName, double aSalary)
{
   name = aName;
   salary = aSalary;
}
```

That is better. Any reader can immediately figure out the meaning of the parameters.

Another commonly used trick relies on the fact that parameter variables *shadow* instance fields with the same name. For example, if you call a parameter `salary`, then `salary` refers to the parameter, not the instance field. But you can still access the instance field as `this.salary`. Recall that `this` denotes the implicit parameter—that is, the object being constructed. Here is an example:

```
public Employee(String name, double salary)
{
   this.name = name;
   this.salary = salary;
}
```

C++ NOTE:

In C++, it is common to prefix instance fields with an underscore or a fixed letter. (The letters `m` and `x` are common choices.) For example, the salary field might be called `_salary`, `mSalary`, or `xSalary`. Java programmers don't usually do that.

4.6.6 Calling Another Constructor

The keyword `this` refers to the implicit parameter of a method. However, this keyword has a second meaning.

If *the first statement of a constructor* has the form `this(. . .)`, then the constructor calls another constructor of the same class. Here is a typical example:

```
public Employee(double s)
{
   // calls Employee(String, double)
   this("Employee #" + nextId, s);
  nextId++;
}
```

When you call `new Employee(60000)`, the `Employee(double)` constructor calls the `Employee(String, double)` constructor.

Using the `this` keyword in this manner is useful—you only need to write common construction code once.

C++ NOTE:

The `this` reference in Java is identical to the `this` pointer in C++. However, in C++ it is not possible for one constructor to call another. If you want to factor out common initialization code in C++, you must write a separate method.

4.6.7 Initialization Blocks

You have already seen two ways to initialize a instance field:

- By setting a value in a constructor
- By assigning a value in the declaration

There is a third mechanism in Java, called an *initialization block*. Class declarations can contain arbitrary blocks of code. These blocks are executed whenever an object of that class is constructed. For example:

```
class Employee
{
   private static int nextId;
   private int id;
   private String name;
   private double salary;

   // object initialization block   {
      id = nextId;
      nextId++;
   }

   public Employee(String n, double s)
   {
      name = n;
      salary = s;
   }

   public Employee()
   {
      name = "";
      salary = 0;
   }
   . . .
}
```

In this example, the `id` field is initialized in the object initialization block, no matter which constructor is used to construct an object. The initialization block runs first, and then the body of the constructor is executed.

This mechanism is never necessary and is not common. It is usually more straightforward to place the initialization code inside a constructor.

NOTE:

It is legal to set fields in initialization blocks even if they are only defined later in the class. However, to avoid circular definitions, it is not legal to read from fields that are only initialized later. The exact rules are spelled out in Section 8.3.3 of the Java Language Specification (`http://docs.oracle.com/javase/specs`). The rules are complex enough to baffle the compiler implementors—early versions of Java implemented them with subtle errors. Therefore, you should always place initialization blocks after the field definitions.

With so many ways of initializing instance fields, it can be quite confusing to give all possible pathways for the construction process. Here is what happens in detail when a constructor is called:

1. If the first line of the constructor calls a second constructor, then the second constructor executes with the provided arguments. 2. Otherwise,

- All instance fields are initialized to their default values (`0`, `false`, or `null`).
- All field initializers and initialization blocks are executed, in the order in which they occur in the class declaration.

3. The body of the constructor is executed.

Naturally, it is always a good idea to organize your initialization code so that another programmer could easily understand it without having to be a language lawyer. For example, it would be quite strange and somewhat error-prone to have a class whose constructors depend on the order in which the instance fields are declared.

To initialize a static field, either supply an initial value or use a static initialization block. You have already seen the first mechanism:

```
private static int nextId = 1;
```

If the static fields of your class require complex initialization code, use a static initialization block.

Place the code inside a block and tag it with the keyword `static`. Here is an example. We want the employee ID numbers to start at a random integer less than 10,000.

```
private static Random generator = new Random();
// static initialization block
static
{
   nextId = generator.nextInt(10000);
}
```

Static initialization occurs when the class is first loaded. Like instance fields, static fields are `0`, `false`, or `null` unless you explicitly set them to another value. All static field initializers and static initialization blocks are executed in the order in which they occur in the class declaration.

NOTE:

Amazingly enough, up to JDK 6, it was possible to write a “Hello, World” program in Java without ever writing a `main` method.

```
public class Hello
{
   static
   {
      System.out.println("Hello, World");
   }
}
```

When you invoked the class with `java Hello`, the class was loaded, the static initialization block printed “Hello, World”, and only then was a message displayed that `main` is not defined. Since Java 7, the `java` program first checks that there is a `main` method.

This example uses the `Random` class for generating random numbers. Since JDK 17, the `java.util.random` package provides implementations of strong algorithms with various tradeoffs. Read through the API documentation of the `java.util.random` package for advice which algorithm to choose. Then obtain an instance by providing the algorithm name like this:

```
RandomGenerator generator =
RandomGenerator.of("L64X128MixRandom");
```

Generate random numbers by calling `generator.nextInt(n)` or other `RandomGenerator` methods. (`RandomGenerator` is an *interface*, a concept introduced in Chapter 6. You can use all `RandomGenerator` methods with objects of the `Random` class.)

The program in Listing 4.5 shows many of the features discussed in this section:

- Overloaded constructors
- A call to another constructor with `this(. . .)`
- A no-argument constructor
- An object initialization block
- A static initialization block
- An instance field initialization

Listing 4.5 `ConstructorTest/ConstructorTest.java`

```
import java.util.*;

/**
 * This program demonstrates object construction.
 * @version 1.02 2018-04-10
 * @author Cay Horstmann
 */
public class ConstructorTest
{
```

```
   public static void main(String[] args)
   {
      // fill the staff array with three Employee objects
      var staff = new Employee[3];

      staff[0] = new Employee("Harry", 40000);
      staff[1] = new Employee(60000);
      staff[2] = new Employee();

      // print out information about all Employee objects
      for (Employee e : staff)
         System.out.println("name=" + e.getName() + ",id=" +
e.getId() + ",salary="
            + e.getSalary());
   }
}

class Employee
{
 private static int nextId;

 private int id;
 private String name = ""; // instance field initialization
 private double salary;

 private static Random generator = new Random();

 // static initialization block
 static
 {
    // set nextId to a random number between 0 and 9999
    nextId = generator.nextInt(10000);
 }

 // object initialization block
 {
    id = nextId;
    nextId++;
 }
```

```java

   // three overloaded constructors
   public Employee(String n, double s)
   {
      name = n;
      salary = s;
   }

   public Employee(double s)
   {
      // calls the Employee(String, double) constructor
      this("Employee #" + nextId, s);
   }

   // the default constructor
   public Employee()
   {
      // name initialized to ""--see above
      // salary not explicitly set--initialized to 0
      // id initialized in initialization block
   }

   public String getName()
   {
      return name;
   }

   public double getSalary()
   {
      return salary;
   }

   public int getId()
   {
      return id;
   }
}
```

java.util.Random 1.0

- `Random()`

  constructs a new random number generator.

`java.util.random.RandomGenerator` 17

- `int nextInt(int n)`

  returns a random integer between 0 and `n` – 1.

- `static RandomGenerator of(String name)`

  yields a random generator for the given algorithm name. The algorithm with name `"L64X128MixRandom"` is suitable for most applications.

4.6.8 Object Destruction and the `finalize` Method

Some object-oriented programming languages, notably C++, have explicit destructor methods for any cleanup code that may be needed when an object is no longer used. The most common activity in a destructor is reclaiming the memory set aside for objects. Since Java does automatic garbage collection, manual memory reclamation is not needed, so Java does not support destructors.

Of course, some objects utilize a resource other than memory, such as a file or a handle to another object that uses system resources. In this case, it is important that the resource be reclaimed and recycled when it is no longer needed.

If a resource needs to be closed as soon as you have finished using it, supply a `close` method that does the necessary cleanup. You can call the `close` method when you are done with the object. In Chapter 7, you will see how you can ensure that this method is called automatically.

If you can wait until the virtual machine exits, add a "shutdown hook" with the method `Runtime.addShutdownHook`. As of Java 9, you can use the `Cleaner` class to register an action that is carried out when an object is no longer reachable (other than by the cleaner). These are uncommon situations in practice. See the API documentation for details on these two approaches.

CAUTION:

Do not use the `finalize` method for cleanup. That method was intended to be called before the garbage collector sweeps away an object. However, you simply cannot know when this method will be called, and it is now deprecated.

4.7 Records

Sometimes, data is just data, and the data hiding that object-oriented programming provides gets in the way. Consider a class `Point` that describes a point in the plane, with *x*- and *y*-coordinates.

Sure, you can create a class:

```
class Point
{
   private final double x;
   private final double y;
   public Point(double x, double y) { this.x = x; this.y = y; }
   public getX() { return x; }
   public getY() { return y; }
   public String toString() { return "Point[x=%d,
y=%d]".formatted(x, y); }
   // More methods ...
}
```

But does it really buy us anything to hide `x` and `y`, and then make the values available through the getter methods?

Would we ever want to change the implementation of a `Point`? Sure, there are polar coordinates, but you would not use them with a graphics API. In practice, a point in the plane is completely described by its *x*- and *y*-coordinates.

To define such classes more concisely, JDK 14 introduced "records" as a preview feature. The final version was delivered in JDK 16.

4.7.1 The Record Concept

A record is a special form of a class whose state is immutable and readable by the public. Here is how you define `Point` as a record:

```
record Point(double x, double y) { }
```

The result is a class with instance fields:

```
private final double x;
private final double y;
```

In the Java language specification, the instance fields of a record are called its *components*.

The class has a constructor

```
Point(double x, double y)
```

and accessor methods

```
public double x()
public double y()
```

Note that the accessors are called `x` and `y`, not `getX` and `getY`. (It is legal in Java to have an instance field and a method with the same name.)

```
var p = new Point(3, 4);
System.out.println(p.x() + " " + p.y());
```

NOTE:

Java doesn't follow the `get` convention because it is a bit messy. For Boolean fields, it is common to use `is` instead of `get`. And the capitalization of the first letter can be problematic. What should happen if a class has fields `x` and `X`? Some programmers are unhappy because their legacy classes cannot trivially become records. But in practice, many of those legacy classes are mutable and therefore not candidates for conversion to records.

In addition to the field accessor methods, every record has three methods defined automatically: `toString`, `equals`, and `hashCode`. You will learn more about these methods in the next chapter.

CAUTION:

You can define your own versions of the automatically provided methods, as long as they have the same parameter and return types. For example, this definition is legal:

```
record Point(double x, double y)
{
   public double x() { return y; } // BAD
}
```

But it is surely not a good idea.

You can add your own methods to a record:

```
record Point(double x, double y)
{
   public double distanceFromOrigin() { return Math.hypot(x,
y); }
}
```

A record, like any class, can have static fields and methods:

```
record Point(double x, double y)
{
   public static Point ORIGIN = new Point(0, 0);
   public static double distance(Point p, Point q)
   {
      return Math.hypot(p.x - q.x, p.y - q.y);
   }
   ...
}
```

However, you cannot add *instance* fields to a record.

```
record Point(double x, double y)
{
   private double r; // ERROR
   ...
}
```

CAUTION:

Instance fields of a record are automatically `final`. However, they may be references to mutable objects:

```
record PointInTime(double x, double y, Date when) { }
```

Then record instances are mutable:

```
var pt = new PointInTime(0, 0, new Date());
pt.when().setTime(0);
```

If you intend record instances to be immutable, don't use mutable types for fields.

TIP:

Use a record instead of a class for immutable data that is completely represented by a set of variables. Use a class if the data is mutable, or if the representation may evolve over time. Records are easier to read, more efficient, and safer in concurrent programs.

4.7.2 Constructors: Canonical, Custom, and Compact

The automatically defined constructor that sets all instance fields is called the *canonical constructor*.

You can define additional *custom constructors*. The first statement of such a constructor must call another constructor, so that ultimately the canonical constructor is invoked. Here is an example:

```
record Point(double x, double y)
{
   public Point() { this(0, 0); }
}
```

This record has two constructors: the canonical constructor and a no-argument constructor yielding the origin.

If the canonical constructor needs to do additional work, you can provide your own implementation:

```
record Range(int from, int to)
{
   public Range(int from, int to)
   {
      if (from <= to)
      {
         this.from = from;
         this.to = to;
      }
      else
      {
         this.from = to;
         this.to = from;
      }
   }
}
```

However, you are encouraged to use a *compact* form when implementing the canonical constructor. You don't specify the parameter list:

```
record Range(int from, int to)
{
   public Range // Compact form
   {      if (from > to) // Swap the bounds
      {
         int temp = from;
         from = to;
         to = temp;
      }
   }
}
```

The body of the compact form is the "prelude" to the canonical constructor. It merely modifies the parameter variables `from` and `to` before they are assigned to the instance fields `this.from` and `this.to`. You cannot read or modify the instance fields in the body of the compact constructor.

Listing 4.6 `RecordTest/RecordTest.java`

```java
import java.util.*;

/**
 * This program demonstrates records.
 * @version 1.0 2021-05-13
 * @author Cay Horstmann
 */
public class RecordTest
{
   public static void main(String[] args)
   {
      var p = new Point(3, 4);
      System.out.println("Coordinates of p: " + p.x() + " " + p.y());
      System.out.println("Distance from origin: " + p.distanceFromOrigin());
      // Same computation with static field and method
      System.out.println("Distance from origin: " + Point.distance(Point.ORIGIN, p));

      // A mutable record
      var pt = new PointInTime(3, 4, new Date());
      System.out.println("Before: " + pt);
      pt.when().setTime(0);
      System.out.println("After: " + pt);

      // Invoking a compact constructor

      var r = new Range(4, 3);
      System.out.println("r: " + r);
   }
}

record Point(double x, double y)
{
  // A custom constructor
  public Point() { this(0, 0); }
```

```
   // A method
   public double distanceFromOrigin()
   {
      return Math.hypot(x, y);
   }
   // A static field and method
   public static Point ORIGIN = new Point();
   public static double distance(Point p, Point q)
   {
      return Math.hypot(p.x - q.x, p.y - q.y);
   }
}

record PointInTime(double x, double y, Date when) { }

record Range(int from, int to)
{
   // A compact constructor
   public Range
   {
      if (from > to) // Swap the bounds
      {
         int temp = from;
         from = to;
         to = temp;
      }
   }
}
```

4.8 Packages

Java allows you to group classes in a collection called a *package*. Packages are convenient for organizing your work and for separating your work from code libraries provided by others. In the following sections, you will learn how to use and create packages.

4.8.1 Package Names

The main reason for using packages is to guarantee the uniqueness of class names. Suppose two programmers come up with the bright idea of supplying an `Employee` class. As long as both of them place their class into different packages, there is no conflict. In fact, to absolutely guarantee a unique package name, use an Internet domain name (which is known to be unique) written in reverse. You then use subpackages for different projects. For example, consider the domain `horstmann.com`. When written in reverse order, it turns into the package name `com.horstmann`. You can then append a project name, such as `com.horstmann.corejava`. If you then place the `Employee` class into that package, the "fully qualified" name becomes `com.horstmann.corejava.Employee`.

NOTE:

From the point of view of the compiler, there is absolutely no relationship between nested packages. For example, the packages `java.util` and `java.util.jar` have nothing to do with each other. Each is its own independent collection of classes.

4.8.2 Class Importation

A class can use all classes from its own package and all *public* classes from other packages.

You can access the public classes in another package in two ways. The first is simply to use the *fully qualified name*; that is, the package name followed by the class name. For example:

```
java.time.LocalDate today = java.time.LocalDate.now();
```

That is obviously tedious. A simpler, and more common, approach is to use the `import` statement. The point of the `import` statement is to give you a shorthand to refer to the classes in the package. Once you add an `import`, you no longer have to give the classes their full names.

You can import a specific class or the whole package. You place `import` statements at the top of your source files (but below any `package` statements). For example, you can import all classes in the `java.time` package with the statement

```
import java.time.*;
```

Then you can use

```
LocalDate today = LocalDate.now();
```

without a package prefix. You can also import a specific class inside a package:

```
import java.time.LocalDate;
```

The `java.time.*` syntax is less tedious. It has no negative effect on code size. However, if you import classes explicitly, the reader of your code knows exactly which classes you use.

TIP:

In Eclipse, you can select the menu option Source → Organize Imports. Package statements such as import `java.util.*;` are automatically expanded into a list of specific imports such as

```
import java.util.ArrayList;
import java.util.Date;
```

This is an extremely convenient feature.

However, note that you can only use the `*` notation to import a single package. You cannot use `import java.*` or `import java.*.*` to import all packages with the `java` prefix.

Most of the time, you just import the packages that you need, without worrying too much about them. The only time that you need to pay attention to packages is when you have a name conflict. For example, both the `java.util` and `java.sql` packages have a Date class. Suppose you write a program that imports both packages.

```
import java.util.*;
import java.sql.*;
```

If you now use the `Date` class, you get a compile-time error:

```
Date today; // ERROR--java.util.Date or java.sql.Date?
```

The compiler cannot figure out which Date class you want. You can solve this problem by adding a specific `import` statement:

```
import java.util.*;
import java.sql.*;
import java.util.Date;
```

What if you really need both Date classes? Then use the full package name with every class name:

```
var startTime = new java.util.Date();
var today = new java.sql.Date(. . .);
```

Locating classes in packages is an activity of the *compiler*. The bytecodes in class files always use full package names to refer to other classes.

C++ NOTE:

C++ programmers sometimes confuse `import` with `#include`. The two have nothing in common. In C++, you must use `#include` to include the declarations of external features because the C++ compiler does not look inside any files except the one that it is compiling and its explicitly included header files. The Java compiler will happily look inside other files provided you tell it where to look.

In Java, you can entirely avoid the `import` mechanism by explicitly naming all classes, such as `java.util.Date`. In C++, you cannot avoid the `#include` directives.

The only benefit of the `import` statement is convenience. You can refer to a class by a name shorter than the full package name. For example, after an `import java.util.*` (or `import java.util.Date`) statement, you can refer to the `java.util.Date` class simply as `Date`.

In C++, the construction analogous to the package mechanism is the namespace feature. Think of the `package` and `import` statements in Java as the analogs of the `namespace` and `using` directives in C++.

4.8.3 Static Imports

A form of the `import` statement permits the importing of static methods and fields, not just classes.

For example, if you add the directive

```
import static java.lang.System.*;
```

to the top of your source file, then you can use the static methods and fields of the `System` class without the class name prefix:

```
out.println("Goodbye, World!"); // i.e., System.out
exit(0); // i.e., System.exit
```

You can also import a specific method or field:

```
import static java.lang.System.out;
```

In practice, it seems doubtful that many programmers will want to abbreviate `System.out` or `System.exit`. The resulting code seems less clear. On the other hand,

```
sqrt(pow(x, 2) + pow(y, 2))
```

seems much clearer than

```
Math.sqrt(Math.pow(x, 2) + Math.pow(y, 2))
```

4.8.4 Addition of a Class into a Package

To place classes inside a package, put the name of the package at the top of your source file, *before* the code that defines the classes in the package. For example, the file `Employee.java` in Listing 4.8 starts out like this:

```
package com.horstmann.corejava;
public class Employee
{
   . . .
}
```

If you don't put a `package` statement in the source file, then the classes in that source file belong to the *unnamed package*. The unnamed package has no package name. Up to now, all our example classes were located in the unnamed package.

Place source files into a subdirectory that matches the full package name. For example, all source files in the `com.horstmann.corejava` package should be in a subdirectory `com/horstmann/corejava` (`com\horstmann\corejava` on Windows). The compiler places the class files into the same directory structure.

The program in Listings 4.7 and 4.8 is distributed over two packages: The `PackageTest` class belongs to the unnamed package, and the `Employee` class belongs to the `com.horstmann.corejava` package. Therefore, the `Employee.java` file must be in a subdirectory `com/horstmann/corejava`. In other words, the directory structure is as follows:

```
. (base directory)
├─ PackageTest.java
├─ PackageTest.class
└─ com/
   └─ horstmann/
      └─ corejava/
         ├─ Employee.java
         └─ Employee.class
```

To compile this program, simply change to the base directory and run the command

```
javac PackageTest.java
```

The compiler automatically finds the file `com/horstmann/corejava/Employee.java` and compiles it.

Let’s look at a more realistic example, in which we don’t use the unnamed package but have classes distributed over several packages (`com.horstmann.corejava` and `com.mycompany`).

```
. (base directory)
└─ com/
   ├─ horstmann/
   │  └─ corejava/
   │     ├─ Employee.java
   │     └─ Employee.class
   └─ mycompany/
      ├─ PayrollApp.java
      └─ PayrollApp.class
```

In this situation, you still must compile and run classes from the *base* directory—that is, the directory containing the `com` directory:

```
javac com/mycompany/PayrollApp.java
java com.mycompany.PayrollApp
```

Note again that the compiler operates on *files* (with file separators and an extension `.java`), whereas the Java interpreter loads a *class* (with dot separators).

TIP:

Starting with the next chapter, we will use packages for the source code. That way, you can make an IDE project for each chapter instead of each section.

CAUTION:

The compiler does *not* check the directory structure when it compiles source files. For example, suppose you have a source file that starts with the directive

```
package com.mycompany;
```

You can compile the file even if it is not contained in a subdirectory `com/mycompany`. The source file will compile without errors *if it doesn't depend on other packages*. However, the resulting program will not run unless you first move all class files to the right place. The *virtual machine* won't find the classes if the packages don't match the directories.

Listing 4.7 `PackageTest/PackageTest.java`

```
import com.horstmann.corejava.*;
// the Employee class is defined in that package
```

```

import static java.lang.System.*;

/**
 * This program demonstrates the use of packages.
 * @version 1.11 2004-02-19 9   * @author Cay Horstmann
 */
public class PackageTest
{
   public static void main(String[] args)
   {
      // because of the import statement, we don't have to use
      // com.horstmann.corejava.Employee here
      var harry = new Employee("Harry Hacker", 50000, 1989, 10, 1);

      harry.raiseSalary(5);

      // because of the static import statement, we don't have to use System.out here
      out.println("name=" + harry.getName() + ",salary=" + harry.getSalary());
   }
}
```

Listing 4.8 `PackageTest/com/horstmann/corejava/Employee.java`

```
package com.horstmann.corejava;

// the classes in this file are part of this package

import java.time.*;

// import statements come after the package statement

/**
 * @version 1.11 2015-05-08
 * @author Cay Horstmann
```

```
 */
public class Employee
{
   private String name;
   private double salary;
   private LocalDate hireDay;

   public Employee(String name, double salary, int year, int month, int day)
   {
      this.name = name;
      this.salary = salary;
      hireDay = LocalDate.of(year, month, day);
   }

   public String getName()
   {
      return name;
   }

   public double getSalary()
   {
      return salary;
   }

   public LocalDate getHireDay()
   {
      return hireDay;
   }

   public void raiseSalary(double byPercent)
   {
      double raise = salary * byPercent / 100;
      salary += raise;
   }
}
```

4.8.5 Package Access

You have already encountered the access modifiers `public` and `private`. Features tagged as `public` can be used by any class. Private features can be used only by the class that defines them. If you don't specify either `public` or `private`, the feature (that is, the class, method, or variable) can be accessed by all methods in the same *package*.

Consider the program in Listing 4.2. The `Employee` class was not defined as a public class. Therefore, only the other classes (such as `EmployeeTest`) in the same package—the unnamed package in this case—can access it. For classes, this is a reasonable default. However, for variables, this was an unfortunate choice. Variables must explicitly be marked `private`, or they will default to having package access. This, of course, breaks encapsulation. The problem is that it is awfully easy to forget to type the `private` keyword. Here is an example from the `Window` class in the `java.awt` package, which is part of the source code supplied with the JDK:

```
public class Window extends Container
{
   String warningString;
   . . .
}
```

Note that the `warningString` variable is not `private`! That means the methods of all classes in the `java.awt` package can access this variable and set it to whatever they like (such as `"Trust me!"`). Actually, the only methods that access this variable are in the `Window` class, so it would have been entirely appropriate to make the variable private. Perhaps the programmer typed the code in a hurry and simply forgot the `private` modifier? Perhaps nobody cared? After more than twenty years, that variable is still not private. Not only that—new fields have been added to the class over time, and about half of them aren't private either.

This can be a problem. By default, packages are not closed entities. That is, anyone can add more classes to a package. Of course, hostile or clueless programmers can then add code that modifies variables with package access. For example, in early versions of Java, it was an easy matter to smuggle another class into the `java.awt` package. Simply start out the class with

```
package java.awt;
```

Then, place the resulting class file inside a subdirectory `java/awt` somewhere on the class path, and you have gained access to the internals of the `java.awt` package. Through this subterfuge, it was possible to modify warning strings (see Figure 4.9).

Figure 4.9 Changing the warning string in an applet window

Starting with version 1.2, the JDK implementors rigged the class loader to explicitly disallow loading of user-defined classes whose package name starts with `"java."`. Of course, your own classes don't benefit from that protection. Another mechanism, now obsolete, lets a JAR file declare packages as *sealed*, preventing third parties from augmenting them. Nowadays, you should use modules to encapsulate packages. Modules are discussed in detail in Chapter 9 of Volume II.

4.8.6 The Class Path

As you have seen, classes are stored in subdirectories of the file system. The path to the class must match the package name.

Class files can also be stored in a JAR (Java archive) file. A JAR file contains multiple class files and subdirectories in a compressed format, saving space and improving performance. When you use a third-party library in your programs, you will usually be given one or more JAR files to include. You will see in Chapter 11 how to create your own JAR files.

TIP:

JAR files use the ZIP format to organize files and subdirectories. You can use any ZIP utility to peek inside JAR files.

To share classes among programs, you need to do the following:

1. Place your class files inside a directory—for example, `/home/user/classdir`. Note that this directory is the *base* directory for the package tree. If you add the class `com.horstmann.corejava.Employee`, then the `Employee.class` file must be located in the subdirectory `/home/user/classdir/com/horstmann/corejava`.
2. Place any JAR files inside a directory—for example, `/home/user/archives`.
3. Set the *class path*. The class path is the collection of all locations that can contain class files.

In UNIX, the elements on the class path are separated by colons:

```
/home/user/classdir:.:/home/user/archives/archive.jar
```

In Windows, they are separated by semicolons:

```
c:\classdir;.;c:\archives\archive.jar
```

In both cases, the period denotes the current directory.

This class path contains

- The base directory `/home/user/classdir` or `c:\classdir`;
- The current directory (`.`); and
- The JAR file `/home/user/archives/archive.jar` or `c:\archives\archive.jar`.

Starting with Java 6, you can specify a wildcard for a JAR file directory, like this:

```
/home/user/classdir:.:/home/user/archives/'*'
```

or

```
c:\classdir;.;c:\archives\*
```

In UNIX, the `*` must be escaped to prevent shell expansion.

All JAR files (but not `.class` files) in the `archives` directory are included in this class path.

The Java API is always searched for classes; don't include it explicitly in the class path.

CAUTION:

The `javac` compiler always looks for files in the current directory, but the `java` virtual machine launcher only looks into the current directory if the "`.`" directory is on the class path. If you have no class path set, it's not a problem — the default class path consists of the "`.`" directory. But if you have set the class path and forgot to include the "`.`" directory, your programs will compile without error, but they won't run.

The class path lists all directories and archive files that are *starting points* for locating classes. Let's consider our sample class path:

```
/home/user/classdir:.:/home/user/archives/archive.jar
```

Suppose the virtual machine searches for the class file of the `com.horstmann.corejava.Employee` class. It first looks in the Java API classes. It won't find the class file there, so it turns to the class path. It then looks for the following files:

- `/home/user/classdir/com/horstmann/corejava/Employee.class`
- `com/horstmann/corejava/Employee.class` starting from the current directory
- `com/horstmann/corejava/Employee.class` inside `/home/user/archives/archive.jar`

The compiler has a harder time locating files than does the virtual machine. If you refer to a class without specifying its package, the compiler first needs to find out the package that contains the class. It consults all `import` directives as possible sources for the class. For example, suppose the source file contains directives

```
import java.util.*;
import com.horstmann.corejava.*;
```

and the source code refers to a class `Employee`. The compiler then tries to find `java.lang.Employee` (because the `java.lang` package is always imported by default), `java.util.Employee`, `com.horstmann.corejava.Employee`, and `Employee` in the current package. It searches for *each* of these classes in all of the locations of the class path. It is a compile-time error if more than one class is found. (Fully qualified class names must be unique, so the order of the `import` statements doesn't matter.)

The compiler goes one step further. It looks at the *source files* to see if the source is newer than the class file. If so, the source file is recompiled automatically. Recall that you can import only public classes from other packages. A source file can only contain one public class, and the names of the file and the public class must match. Therefore, the compiler can easily locate source files for public classes. However, you can import nonpublic classes from the current package. These classes may be defined in source files with different names. If you import a class from the current package, the compiler searches *all* source files of the current package to see which one defines the class.

4.8.7 Setting the Class Path

It is best to specify the class path with the option `-classpath` (or `-cp` or, as of Java 9, `--class-path`):

```
java -classpath
/home/user/classdir:.:/home/user/archives/archive.jar MyProg
```

or

```
java -classpath c:\classdir;.;c:\archives\archive.jar MyProg
```

The entire command must be typed onto a single line. It is a good idea to place such a long command line into a shell script or a batch file.

Using the `-classpath` option is the preferred approach for setting the class path. An alternate approach is the `CLASSPATH` environment variable. The details depend on your shell. With the Bourne Again shell (bash), use the command

```
export
CLASSPATH=/home/user/classdir:.:/home/user/archives/archive.jar
```

With the Windows shell, use

```
set CLASSPATH=c:\classdir;.;c:\archives\archive.jar
```

The class path is set until the shell exits.

CAUTION:

Some people recommend to set the `CLASSPATH` environment variable permanently. This is generally a bad idea. People forget the global setting, and are surprised when their classes are not loaded properly. A particularly reprehensible example is Apple's QuickTime installer in Windows. For several years, it globally set `CLASSPATH` to point to a JAR file it needed, but did not include the current directory in the classpath. As a result, countless Java programmers were driven to distraction when their programs compiled but failed to run.

CAUTION:

In the past, some people recommended to bypass the class path altogether, by dropping all JAR files into the `jre/lib/ext` directory. That mechanism is obsolete with Java 9, but it was always bad advice. It was easy to get confused when long-forgotten classes were loaded from the extension directory.

NOTE:

As of Java 9, classes can also be loaded from the *module path*. Modules and the module path are discussed in Chapter 9 of Volume II.

4.9 JAR Files

When you package your application, you want to give your users a single file, not a directory structure filled with class files. Java Archive (JAR) files were designed for this purpose. A JAR file can contain both class files and other file types such as image and sound files. Moreover, JAR files are compressed, using the familiar ZIP compression format.

4.9.1 Creating JAR files

Use the `jar` tool to make JAR files. (In the default JDK installation, it's in the *jdk*`/bin` directory.) The most common command to make a new JAR file uses the following syntax:

```
jar cvf jarFileName file1 file2 . . .
```

For example:

```
jar cvf CalculatorClasses.jar *.class icon.gif
```

In general, the `jar` command has the following format:

```
jar options file1 file2 . . .
```

Table 4.2 lists all the options for the `jar` program. They are similar to the options of the UNIX `tar` command.

You can package application programs and code libraries into JAR files. For example, if you want to send mail in a Java program, you use a library that is packaged in a file `javax.mail.jar`.

Table 4.2 `jar` Program Options

Option	Description
c	Creates a new or empty archive and adds files to it. If any of the specified file names are directories, the jar program processes them recursively.
C	Temporarily changes the directory. For example, `jar cvf jarFileName.jar -C classes *.class` changes to the classes subdirectory to add class files.
e	Creates an entry point in the manifest (see Section 4.9.3).
f	Specifies the JAR file name as the second command-line argument. If this parameter is missing, jar will write the result to standard output (when creating a JAR file) or read it from standard input (when extracting or tabulating a JAR file).
i	Creates an index file (for speeding up lookups in a large archive).
m	Adds a *manifest* to the JAR file. A manifest is a description of the archive contents and origin. Every archive has a default manifest, but you can supply your own if you want to authenticate the contents of the archive.
M	Does not create a manifest file for the entries.
t	Displays the table of contents.
u	Updates an existing JAR file.
v	Generates verbose output.
x	Extracts files. If you supply one or more file names, only those files are extracted. Otherwise, all files are extracted.
0	Stores without ZIP compression.

4.9.2 The Manifest

In addition to class files, images, and other resources, each JAR file contains a *manifest* file that describes special features of the archive.

The manifest file is called `MANIFEST.MF` and is located in a special `META-INF` subdirectory of the JAR file. The minimum legal manifest is quite boring—just

```
Manifest-Version: 1.0
```

Complex manifests can have many more entries. The manifest entries are grouped into sections. The first section in the manifest is called the *main section*. It applies to the whole JAR file. Subsequent entries can specify properties of named entities such as individual files, packages, or URLs. Those entries must begin with a `Name` entry. Sections are separated by blank lines. For example:

```
Manifest-Version: 1.0
lines describing this archive

Name: Woozle.class
lines describing this file
Name: com/mycompany/mypkg/
lines describing this package
```

To edit the manifest, place the lines that you want to add to the manifest into a text file. Then run

```
jar cfm jarFileName manifestFileName . . .
```

For example, to make a new JAR file with a manifest, run

```
jar cfm MyArchive.jar manifest.mf com/mycompany/mypkg/*.class
```

To update the manifest of an existing JAR file, place the additions into a text file and use a command such as

```
jar ufm MyArchive.jar manifest-additions.mf
```

NOTE:

See https://docs.oracle.com/javase/10/docs/specs/jar/jar.html for more information on the JAR and manifest file formats.

4.9.3 Executable JAR Files

You can use the `e` option of the `jar` command to specify the *entry point* of your program—the class that you would normally specify when invoking the `java` program launcher:

```
jar cvfe MyProgram.jar com.mycompany.mypkg.MainAppClass files
to add
```

Alternatively, you can specify the *main class* of your program in the manifest, including a statement of the form

```
Main-Class: com.mycompany.mypkg.MainAppClass
```

Do not add a `.class` extension to the main class name.

CAUTION:

The last line in the manifest must end with a newline character. Otherwise, the manifest will not be read correctly. It is a common error to produce a text file containing just the `Main-Class` line without a line terminator.

With either method, users can simply start the program as

```
java -jar MyProgram.jar
```

Depending on the operating system configuration, users may even be able to launch the application by double-clicking the JAR file icon. Here are behaviors for various operating systems:

- On Windows, the Java runtime installer creates a file association for the "`.jar`" extension that launches the file with the `javaw -jar` command. (Unlike the `java` command, the `javaw` command doesn't open a shell window.)
- On Mac OS X, the operating system recognizes the "`.jar`" file extension and executes the Java program when you double-click a JAR file.

However, a Java program in a JAR file does not have the same feel as a native application. On Windows, you can use third-party wrapper utilities that turn JAR files into Windows executables. A wrapper is a Windows program with the familiar `.exe` extension that locates and launches the Java virtual machine (JVM) or tells the user what to do when no JVM is found. There are a number of commercial and open source products, such as Launch4J (`http://launch4j.sourceforge.net`) and IzPack (`http://izpack.org`).

4.9.4 Multi-Release JAR Files

With the introduction of modules and strong encapsulation of packages, some previously accessible internal APIs are no longer available. This may require library providers to distribute different code for different Java versions. Java 9 introduces *multi-release JARs* for this purpose.

For backwards compatibility, version-specific class files are placed in the

```
Application.class
BuildingBlocks.class
Util.class
META-INF
  ├─ MANIFEST.MF (with line Multi-Release: true)
  └─ versions
       ├─ 9
       │   ├─ Application.class
       │   └─ BuildingBlocks.class
       └─ 10
           └─ BuildingBlocks.class
```

Suppose the `Application` class makes use of the `CssParser` class. Then the legacy

`Application.class` file can be compiled to use `com.sun.javafx.css.CssParser`, while the Java 9 version uses `javafx.css.CssParser`.

Java 8 knows nothing about the `META-INF/versions` directory and will simply load the legacy classes. When the JAR file is read by Java 9, the new version is used instead.

To add versioned class files, use the `--release` flag:

```
jar uf MyProgram.jar --release 9 Application.class
```

To build a multi-release JAR file from scratch, use the `-C` option and switch to a different class file directory for each version:

```
jar cf MyProgram.jar -C bin/8 . --release 9 -C bin/9
Application.class
```

When compiling for different releases, use the `--release` flag and the `-d` flag to specify the output directory:

```
javac -d bin/8 --release 8 . . .
```

As of Java 9, the `-d` option creates the directory if it doesn't exist.

The `--release` flag is also new with Java 9. In older versions, you needed to use the `-source`, `-target`, and `-bootclasspath` flags. The JDK now ships with symbol files for two prior versions of the API. In Java 9, you can compile with `--release` set to `9`, `8`, or `7`.

Multi-release JARs are not intended for different versions of a program or library. The public API of all classes should be the same for both releases. The sole purpose of multi-release JARs is to enable a particular version of your program or library to work with multiple JDK releases. If you add functionality or change an API, you should provide a new version of the JAR instead.

NOTE:

Tools such as `javap` are not retrofitted to handle multi-release JAR files. If you call

```
javap -classpath MyProgram.jar Application.class
```

you get the base version of the class (which, after all, is supposed to have the same public API as the newer version). If you must look at the newer version, call

```
javap -classpath MyProgram.jar\!/META-INF/versions/9/Application.class
```

4.9.5 A Note about Command-Line Options

The options of commands in the Java Development Kit have traditionally used single dashes followed by multiletter option names, such as

```
java -jar . . .
javac -Xlint:unchecked -classpath . . .
```

The exception was the `jar` command, which followed the classic option format of the `tar` command without dashes:

```
jar cvf . . .
```

Starting with Java 9, the Java tools are moving towards a more common option format where multiletter option names are preceded by double dashes, with single-letter shortcuts for common options. For example, the Linux `ls` command can be called with a “human-readable” option as

```
ls --human-readable
```

or

```
ls -h
```

As of Java 9, you can use `--version` instead of `-version` and `--class-path` instead of `-classpath`. As you will see in Chapter 9 of Volume II, the `--module-path` option has a shortcut `-p`.

You can find the details in the JEP 293 enhancement request at http://openjdk.java.net/jeps/293. As part of this cleanup, the authors also propose to standardize option arguments. Arguments of options with `--` and multiple letters are separated by whitespace or an `=` sign:

```
javac --class-path /home/user/classdir . . .
```

or

```
javac --class-path=/home/user/classdir . . .
```

Arguments of single-letter options can be separated by whitespace or directly follow the option:

```
javac -p moduledir . . .
```

or

```
javac -pmoduledir . . .
```

CAUTION:

The latter doesn't currently work, and it also seems like a bad idea in general. Why invite conflicts with legacy options if the module directory happens to be `arameters` or `rocessor`?

Single-letter options without arguments can be grouped together:

```
jar -cvf MyProgram.jar -e mypackage.MyProgram */*.class
```

CAUTION:

That doesn't currently work, and it is bound to lead to confusion. Suppose `javac` gains a `-c` option. Does `javac -cp` mean `javac -c -p`, or does the legacy `-cp` take precedence?

This has created a muddle that will hopefully get cleaned up over time. As much as I'd like to move away from the archaic `jar` options, it seems best to wait until the dust has settled. But if you want to be thoroughly modern, you can safely use the long options of the `jar` command:

```
jar --create --verbose --file jarFileName file1 file2 . . .
```

Single-letter options also work if you don't group them:

```
jar -c -v -f jarFileName file1 file2 . . .
```

4.10 Documentation Comments

The JDK contains a very useful tool, called `javadoc`, that generates HTML documentation from your source files. In fact, the online API documentation described in Chapter 3 is simply the result of running `javadoc` on the source code of the standard Java library.

If you add comments that start with the special delimiter `/**` to your source code, you too can easily produce professional-looking documentation. This is a very nice approach because it lets you keep your code and documentation in one place. If you put your documentation into a separate file, then, as you probably know, the code and comments tend to diverge over time. When documentation comments are in the same file as the source code, it is an easy matter to update both and run `javadoc` again.

4.10.1 Comment Insertion

The `javadoc` utility extracts information for the following items:

- Modules
- Packages
- Public classes and interfaces
- Public and protected fields
- Public and protected constructors and methods

Protected features are introduced in Chapter 5, interfaces in Chapter 6, and modules in Chapter 9 of Volume II.

You can (and should) supply a comment for each of these features. Each comment is placed immediately *above* the feature it describes. A comment starts with a /** and ends with a */.

Each /** . . . */ documentation comment contains *free-form text* followed by *tags*. A tag starts with an @, such as @since or @param.

The *first sentence* of the free-form text should be a *summary statement*. The

javadoc utility automatically generates summary pages that extract these sentences.

In the free-form text, you can use HTML modifiers such as . . . for emphasis, . . . for strong emphasis, / for bulleted lists, and to include an image. To type monospaced code, use {@code . . . } instead of <code>. . .</code>—then you don't have to worry about escaping < characters inside the code.

NOTE:

If your comments contain links to other files such as images (for example, diagrams or images of user interface components), place those files into a subdirectory, named doc-files, of the directory containing the source file. The javadoc utility will copy the doc-files directories and their contents from the source directory to the documentation directory. You need to use the doc-files directory in your link, for example .

4.10.2 Class Comments

The class comment must be placed *after* any import statements, directly before the class definition.

Here is an example of a class comment:

```
/**
 * A {@code Card} object represents a playing card, such
 * as "Queen of Hearts". A card has a suit (Diamond, Heart,
 * Spade or Club) and a value (1 = Ace, 2 . . . 10, 11 = Jack,
 * 12 = Queen, 13 = King)
 */
public class Card
{
   . . .
}
```

NOTE:

There is no need to add an `*` in front of every line. For example, the following comment is equally valid:

```
/**
   A <code>Card</code> object represents a playing card, such
   as "Queen of Hearts". A card has a suit (Diamond, Heart,
   Spade or Club) and a value (1 = Ace, 2 . . . 10, 11 = Jack,
   12 = Queen, 13 = King).
*/
```

However, most IDEs supply the asterisks automatically and rearrange them when the line breaks change.

4.10.3 Method Comments

Each method comment must immediately precede the method that it describes. In addition to the general-purpose tags, you can use the following tags:

- `@param` *variable description*

This tag adds an entry to the "parameters" section of the current method. The description can span multiple lines and can use HTML tags. All `@param` tags for one method must be kept together.

- `@return` *description*

  This tag adds a "returns" section to the current method. The description can span multiple lines and can use HTML tags.

- `@throws` *class description*

  This tag adds a note that this method may throw an exception. Exceptions are the topic of Chapter 7.

Here is an example of a method comment:

```
/**
 * Raises the salary of an employee.
 * @param  byPercent the percentage by which to raise the
salary (e.g., 10 means 10%)
 * @return  the amount of the raise
 */
public double raiseSalary(double byPercent)
{
   double raise = salary * byPercent / 100;
   salary += raise;
   return raise;
}
```

4.10.4 Field Comments

You only need to document public fields—generally that means static constants. For example:

```
/**
 * The "Hearts" card suit
 */
public static final int HEARTS = 1;
```

4.10.5 General Comments

The tag `@since` *text* makes a "since" entry. The *text* can be any description of the version that introduced this feature. For example, `@since 1.7.1`.

The following tags can be used in class documentation comments:

- `@author` *name*

  This tag makes an "author" entry. You can have multiple `@author` tags, one for each author. Don't feel compelled to use this tag—your version control system does a more thorough job tracking authorship.

- `@version` *text*

  This tag makes a "version" entry. The `text` can be any description of the current version.

You can use hyperlinks to other relevant parts of the `javadoc` documentation, or to external documents, with the `@see` and `@link` tags.

The tag `@see` *reference* adds a hyperlink in the "see also" section. It can be used with both classes and methods. Here, *reference* can be one of the following:

package`.`*class*`#`*feature label*
`<a href=". . .">`*label*`</a>`
`"`*text*`"`

The first case is the most useful. You supply the name of a class, method, or variable, and `javadoc` inserts a hyperlink to the documentation. For example,

```
@see com.horstmann.corejava.Employee#raiseSalary(double)
```

makes a link to the `raiseSalary(double)` method in the `com.horstmann.corejava.Employee` class. You can omit the name of the package, or both the package and class names. Then, the feature will be located in the current package or class. Note that you must use a `#`, not a period, to separate the class from the method or variable name. The Java compiler itself is highly skilled in determining the various meanings of the period character as separator between packages, subpackages, classes, inner classes, and methods and variables. But the `javadoc` utility isn't quite as clever, so you have to help it along.

If the `@see` tag is followed by a `<` character, then you need to specify a hyperlink. You can link to any URL you like. For example:

```
@see <a href="www.horstmann.com/corejava.html">The Core Java
home page</a>
```

In each of these cases, you can specify an optional *label* that will appear as the link anchor. If you omit the label, the user will see the target code name or URL as the anchor.

If the `@see` tag is followed by a `"` character, then the text is displayed in the "see also" section. For example:

```
@see "Core Java 2 volume 2"
```

You can add multiple `@see` tags for one feature, but you must keep them all together.

If you like, you can place hyperlinks to other classes or methods anywhere in any of your documentation comments. Insert a special tag of the form

`{@link` *package*`.`*class#feature label*`}`

anywhere in a comment. The feature description follows the same rules as for the `@see` tag.

Finally, as of Java 9, you can use the `{@index` *entry*`}` tag to add an entry to the search box.

4.10.6 Package Comments

Place the class, method, and variable comments directly into the Java source files, delimited by `/** . . . */` documentation comments. However, to generate *package* comments, you need to add a separate file in each package directory. You have two choices:

1. Supply a Java file named `package-info.java`. The file must contain an initial Javadoc comment, delimited with `/**` and `*/`, followed by a `package` statement. It should contain no further code or comments.
2. Supply an HTML file named `package.html`. All text between the tags `<body> . . .</body>` is extracted.

4.10.7 Comment Extraction

Here, *docDirectory* is the name of the directory where you want the HTML files to go. Follow these steps:

1. Change to the directory that contains the source files you want to document. If you have nested packages to document, such as `com.horstmann.corejava`, you must be working in the directory that contains the subdirectory `com`. (This is the directory that contains the `overview.html` file, if you supplied one.)
2. Run the command

```
javadoc -d docDirectory nameOfPackage
```

for a single package. Or, run

```
javadoc -d docDirectory nameOfPackage1 nameOfPackage2. . .
```

to document multiple packages. If your files are in the unnamed package, run instead

```
javadoc -d docDirectory *.java
```

If you omit the `-d` *docDirectory* option, the HTML files are extracted to the current directory. That can get messy, and I don't recommend it.

The `javadoc` program can be fine-tuned by numerous command-line options. For example, you can use the `-author` and `-version` options to include the `@author` and `@version` tags in the documentation. (By default, they are omitted.) Another useful option is `-link`, to include hyperlinks to standard classes. For example, if you use the command

```
javadoc -link http://docs.oracle.com/javase/9/docs/api *.java
```

all standard library classes are automatically linked to the documentation on the Oracle web site.

If you use the `-linksource` option, each source file is converted to HTML (without color coding, but with line numbers), and each class and method name turns into a hyperlink to the source.

You can also supply an overview comment for all source files. Place it in a file such as `overview.html` and run the `javadoc` tool with the command line option `-overview` *filename*. All text between the tags `<body>. . .</body>` is extracted. The content is displayed when the user selects "Overview" from the navigation bar.

For additional options, refer to the online documentation of the `javadoc` utility at `https://docs.oracle.com/javase/9/javadoc/javadoc.htm`.

4.11 Class Design Hints

Without trying to be comprehensive or tedious, I want to end this chapter with some hints that will make your classes more acceptable in well-mannered OOP circles.

1. *Always keep data private.*

   This is first and foremost; doing anything else violates encapsulation. You may need to write an accessor or mutator method occasionally, but you are still better off keeping the instance fields private. Bitter experience shows that the data representation may change, but how this data are used will change much less frequently. When data are kept private, changes in their representation will not affect the users of the class, and bugs are easier to detect.

2. *Always initialize data.*

   Java won't initialize local variables for you, but it will initialize instance fields of objects. Don't rely on the defaults, but initialize all variables explicitly, either by supplying a default or by setting defaults in all constructors.

3. *Don't use too many basic types in a class.*

   The idea is to replace multiple *related* uses of basic types with other classes. This keeps your classes easier to understand and to change. For example, replace the following instance fields in a `Customer` class:

```
private String street;
private String city;
private String state;
private int zip;
```

with a new class called `Address`. This way, you can easily cope with changes to addresses, such as the need to deal with international addresses.

4. *Not all fields need individual field accessors and mutators.*

   You may need to get and set an employee's salary. You certainly won't need to change the hiring date once the object is constructed. And, quite often, objects have instance fields that you don't want others to get or set, such as an array of state abbreviations in an `Address` class.

5. *Break up classes that have too many responsibilities.*

   This hint is, of course, vague: "too many" is obviously in the eye of the beholder. However, if there is an obvious way to break one complicated class into two classes that are conceptually simpler, seize the opportunity. (On the other hand, don't go overboard; ten classes, each with only one method, are usually an overkill.)

   Here is an example of a bad design:

```
public class CardDeck // bad design
{
   private int[] value;
```

```
   private int[] suit;
   public CardDeck() { . . . }
   public void shuffle() { . . . }
   public int getTopValue() { . . . }
   public int getTopSuit() { . . . }
   public void draw() { . . . }
}
```

This class really implements two separate concepts: a *deck of cards*, with its `shuffle` and `draw` methods, and a *card*, with the methods to inspect its value and suit. It makes sense to introduce a `Card` class that represents an individual card. Now you have two classes, each with its own responsibilities:

```
public class CardDeck
{
   private Card[] cards;
   public CardDeck() { . . . }
   public void shuffle() { . . . }
   public Card getTop() { . . . }
   public void draw() { . . . }
}
public class Card
{
   private int value;
   private int suit;
   public Card(int aValue, int aSuit) { . . . }
   public int getValue() { . . . }
   public int getSuit() { . . . }
}
```

6. *Make the names of your classes and methods reflect their responsibilities*.

Just as variables should have meaningful names that reflect what they represent, so should classes. (The standard library certainly contains some dubious examples, such as the `Date` class that describes time.)

A good convention is that a class name should be a noun (`Order`), or a noun preceded by an adjective (`RushOrder`) or a gerund (an "-ing" word, as in `BillingAddress`). As for methods, follow the standard convention that accessor methods begin with a lowercase `get` (`getSalary`) and mutator methods use a lowercase `set` (`setSalary`).

7. *Prefer immutable classes*.

   The `LocalDate` class, and other classes from the `java.time` package, are immutable—no method can modify the state of an object. Instead of mutating objects, methods such as `plusDays` return new objects with the modified state.

   The problem with mutation is that it can happen concurrently when multiple threads try to update an object at the same time. The results are unpredictable. When classes are immutable, it is safe to share their objects among multiple threads.

   Therefore, it is a good idea to make classes immutable when you can. This is particularly easy with classes that represent values, such as a string or a point in time. Computations can simply yield new values instead of updating existing ones.

   Of course, not all classes should be immutable. It would be strange to have the `raiseSalary` method return a new `Employee` object when an employee gets a raise.

In this chapter, we covered the fundamentals of objects and classes that make Java an "object-based" language. In order to be truly object-oriented, a programming language must also support inheritance and polymorphism. The Java support for these features is the topic of the next chapter.

Chapter 5. Inheritance

In this chapter

Chapter 4 introduced you to classes and objects. In this chapter, you will learn about *inheritance,* another fundamental concept of object-oriented programming. The idea behind inheritance is that you can create new classes that are built on existing classes. When you inherit from an existing class, you reuse (or inherit) its methods, and you can add new methods and fields to adapt your new class to new situations. This technique is essential in Java programming.

This chapter also covers *reflection,* the ability to find out more about classes and their properties in a running program. Reflection is a powerful feature, but it is undeniably complex. Since reflection is of greater interest to tool builders than to application programmers, you can probably glance over that part of the chapter upon first reading and come back to it later.

5.1 Classes, Superclasses, and Subclasses

Let's return to the `Employee` class discussed in the previous chapter. Suppose (alas) you work for a company where managers are treated differently from other employees. Managers are, of course, just like employees in many respects. Both employees and managers are paid a salary. However, while employees are expected to complete their assigned tasks in return for receiving their salary, managers get *bonuses* if they actually achieve what they are supposed to do. This is the kind of situation that cries out for inheritance. Why? Well, you need to define a new class, `Manager`, and add functionality. But you can retain some of what you have already programmed in the `Employee` class, and *all* the fields of the original class can be preserved. More abstractly, there is an obvious "is–a" relationship between `Manager` and `Employee`. Every manager *is an* employee: This "is–a" relationship is the hallmark of inheritance.

NOTE:

In this chapter, I use the classic example of employees and managers, but I must ask you to take this example with a grain of salt. In the real world, an employee can become a manager, so you would want to model being a manager as a role of an employee, not a subclass. In my example, however, I assume the corporate world is populated by two kinds of people: those who are forever employees, and those who have always been managers.

5.1.1 Defining Subclasses

Here is how you define a `Manager` class that inherits from the `Employee` class. Use the Java keyword `extends` to denote inheritance.

```
public class Manager extends Employee
{
   added methods and fields
}
```

C++ NOTE:

Inheritance is similar in Java and C++. Java uses the `extends` keyword instead of the `:` token. All inheritance in Java is public inheritance; there is no analog to the C++ features of private and protected inheritance.

The keyword `extends` indicates that you are making a new class that derives from an existing class. The existing class is called the *superclass*, *base class*, or *parent class*. The new class is called the *subclass*, *derived class*, or *child class*. The terms superclass and subclass are those most commonly used by Java programmers, although some programmers prefer the parent/child analogy, which also ties in nicely with the "inheritance" theme.

The `Employee` class is a superclass, but not because it is superior to its subclass or contains more functionality. *In fact, the opposite is true:* Subclasses have *more* functionality than their superclasses. For example, as you will see when we go over the rest of the `Manager` class code, the `Manager` class encapsulates more data and has more functionality than its superclass `Employee`.

NOTE:

The prefixes *super* and *sub* come from the language of sets used in theoretical computer science and mathematics. The set of all employees contains the set of all managers, and thus is said to be a *superset* of the set of managers. Or, to put it another way, the set of all managers is a *subset* of the set of all employees.

Our `Manager` class has a new field to store the bonus, and a new method to set it:

```
public class Manager extends Employee
{
   private double bonus;
   . . .
   public void setBonus(double bonus)
   {
      this.bonus = bonus;
   }
}
```

There is nothing special about these methods and fields. If you have a `Manager` object, you can simply apply the `setBonus` method.

```
Manager boss = . . .;
boss.setBonus(5000);
```

Of course, if you have an `Employee` object, you cannot apply the `setBonus` method—it is not among the methods defined in the `Employee` class.

However, you *can* use methods such as `getName` and `getHireDay` with `Manager` objects. Even though these methods are not explicitly defined in the `Manager` class, they are automatically inherited from the `Employee` superclass.

Every `Manager` object has four fields: `name`, `salary`, `hireDay`, and `bonus`. The fields `name`, `salary`, and `hireDay` are taken from the superclass.

NOTE:

The Java language specification states: “Members of a class that are declared private are not inherited by subclasses of that class.” This has confused my readers over the years. The specification uses the word “inherits” narrowly. It considers the private fields non-inherited because the `Manager` class cannot access them directly. Thus, every `Manager` object has three fields from the superclass, but the `Manager` class does not “inherit” them.

When defining a subclass by extending its superclass, you only need to indicate the *differences* between the subclass and the superclass. When designing classes, you place the most general methods in the superclass and more specialized methods in its subclasses. Factoring out common functionality by moving it to a superclass is routine in object-oriented programming.

NOTE:

In chapter 4, you learned about *records*: classes whose state is entirely defined by the constructor parameters. You cannot extend a record, and a record cannot extend another class.

5.1.2 Overriding Methods

Some of the superclass methods are not appropriate for the `Manager` subclass. In particular, the `getSalary` method should return the sum of the base salary and the bonus. You need to supply a new method to *override* the superclass method:

```
public class Manager extends Employee
{
   . . .
   public double getSalary()
   {
      . . .
   }
   . . .
}
```

How can you implement this method? At first glance, it appears to be simple — just return the sum of the `salary` and `bonus` fields:

```
public double getSalary()
{
   return salary + bonus; // won't work
}
```

However, that won't work. Recall that only the `Employee` methods have direct access to the private fields of the `Employee` class. This means that the `getSalary` method of the `Manager` class cannot directly access the `salary` field. If the `Manager` methods want to access those private fields, they have to do what every other method does—use the public interface, in this case the public `getSalary` method of the `Employee` class.

So, let's try again. You need to call `getSalary` instead of simply accessing the `salary` field:

```
public double getSalary()
{
   double baseSalary = getSalary(); // still won't work
   return baseSalary + bonus;
}
```

Now, the problem is that the call to `getSalary` simply calls *itself,* because the `Manager` class has a `getSalary` method (namely, the method we are trying to implement). The consequence is an infinite chain of calls to the same method, leading to a program crash.

We need to indicate that we want to call the `getSalary` method of the `Employee` superclass, not the current class. Use the special keyword `super` for this purpose. The call

```
super.getSalary()
```

calls the `getSalary` method of the `Employee` class. Here is the correct version of the `getSalary` method for the `Manager` class:

```
public double getSalary()
{
   double baseSalary = super.getSalary();
   return baseSalary + bonus;
}
```

NOTE:

Some people think of `super` as being analogous to the `this` reference. However, that analogy is not quite accurate: `super` is not a reference to an object. For example, you cannot assign the value `super` to another object variable. Instead, `super` is a special keyword that directs the compiler to invoke the superclass method.

As you saw, a subclass can *add* fields, and it can *add* methods or *override* the methods of the superclass. However, inheritance can never take away any fields or methods.

C++ NOTE:

Java uses the keyword `super` to call a superclass method. In C++, you would use the name of the superclass with the `::` operator instead. For example, the `getSalary` method of the `Manager` class would call `Employee::getSalary` instead of `super.getSalary`.

5.1.3 Subclass Constructors

To complete our example, let us supply a constructor.

```
public Manager(String name, double salary, int year, int month,
int day)
```

```
{
   super(name, salary, year, month, day);
   bonus = 0;
}
```

Here, the keyword `super` has a different meaning. The instruction

```
super(name, salary, year, month, day);
```

is shorthand for "call the constructor of the `Employee` superclass with `n`, `s`, `year`, `month`, and `day` as parameters."

Since the `Manager` constructor cannot access the private fields of the `Employee` class, it must initialize them through a constructor. The constructor is invoked with the special `super` syntax. The call using `super` must be the first statement in the constructor for the subclass.

When a subclass object is constructed without explicit invocation of a superclass constructor, the superclass must have a no-argument constructor. That constructor is invoked prior to the subclass construction.

NOTE:

Recall that the `this` keyword has two meanings: to denote a reference to the implicit parameter and to call another constructor of the same class. Likewise, the `super` keyword has two meanings: to invoke a superclass method and to invoke a superclass constructor. When used to invoke constructors, the `this` and `super` keywords are closely related. The constructor calls can only occur as the first statement in another constructor. The constructor parameters are either passed to another constructor of the same class (`this`) or a constructor of the superclass (`super`).

C++ NOTE:

In a C++ constructor, you do not call `super`, but you use the initializer list syntax to construct the superclass. The `Manager` constructor would look like this in C++:

```
// C++
Manager::Manager(String name, double salary, int year, int
month, int day)
: Employee(name, salary, year, month, day)
{
   bonus = 0;
}
```

After you redefine the `getSalary` method for `Manager` objects, managers will *automatically* have the bonus added to their salaries.

Here's an example of this at work. We make a new manager and set the manager's bonus:

```
Manager boss = new Manager("Carl Cracker", 80000, 1987, 12,
15);
boss.setBonus(5000);
```

We make an array of three employees:

```
var staff = new Employee[3];
```

We populate the array with a mix of managers and employees:

```
staff[0] = boss;
staff[1] = new Employee("Harry Hacker", 50000, 1989, 10, 1);
staff[2] = new Employee("Tony Tester", 40000, 1990, 3, 15);
```

We print out everyone's salary:

```
for (Employee e : staff)
   System.out.println(e.getName() + " " + e.getSalary());
```

This loop prints the following data:

```
Carl Cracker 85000.0
Harry Hacker 50000.0
Tommy Tester 40000.0
```

Now `staff[1]` and `staff[2]` each print their base salary because they are `Employee` objects. However, `staff[0]` is a `Manager` object whose `getSalary` method adds the bonus to the base salary.

What is remarkable is that the call

```
e.getSalary()
```

picks out the *correct* `getSalary` method. Note that the *declared* type of `e` is `Employee`, but the *actual* type of the object to which `e` refers can be either `Employee` or `Manager`.

When `e` refers to an `Employee` object, the call `e.getSalary()` calls the `getSalary` method of the `Employee` class. However, when `e` refers to a `Manager` object, then the `getSalary` method of the `Manager` class is called instead. The virtual machine knows about the actual type of the object to which `e` refers, and therefore can invoke the correct method.

The fact that an object variable (such as the variable `e`) can refer to multiple actual types is called *polymorphism*. Automatically selecting the appropriate method at runtime is called *dynamic binding*. I discuss both topics in more detail in this chapter.

C++ NOTE:

In C++, you need to declare a member function as `virtual` if you want dynamic binding. In Java, dynamic binding is the default behavior; if you do *not* want a method to be virtual, you tag it as `final`. (I discuss the `final` keyword later in this chapter.)

Listing 5.1 contains a program that shows how the salary computation differs for `Employee` (Listing 5.2) and `Manager` (Listing 5.3) objects.

Listing 5.1 `inheritance/ManagerTest.java`

```
package inheritance;

/**
 * This program demonstrates inheritance.
 * @version 1.21 2004-02-21
 * @author Cay Horstmann
 */
public class ManagerTest
{
    public static void main(String[] args)
    {
        // construct a Manager object
        var boss = new Manager("Carl Cracker", 80000, 1987, 12, 15);
        boss.setBonus(5000);

        var staff = new Employee[3];

        // fill the staff array with Manager and Employee objects

        staff[0] = boss;
        staff[1] = new Employee("Harry Hacker", 50000, 1989, 10, 1);
        staff[2] = new Employee("Tommy Tester", 40000, 1990, 3, 15);

```

```
         // print out information about all Employee objects
         for (Employee e : staff)
            System.out.println("name=" + e.getName() +
",salary=" + e.getSalary());
      }
}
```

Listing 5.2 `inheritance/Employee.java`

```
package inheritance;

import java.time.*;

public class Employee
{
   private String name;
   private double salary;
   private LocalDate hireDay;

   public Employee(String name, double salary, int year, int
month, int day)
   {
      this.name = name;
      this.salary = salary;
      hireDay = LocalDate.of(year, month, day);
   }

   public String getName()
   {
      return name;
   }

   public double getSalary()
   {
      return salary;
   }

   public LocalDate getHireDay()
```

```
    {
       return hireDay;
    }

    public void raiseSalary(double byPercent)
    {
       double raise = salary * byPercent / 100;
       salary += raise;
    }
}
```

Listing 5.3 `inheritance/Manager.java`

```
package inheritance;

public class Manager extends Employee
{
   private double bonus;

   /**
    * @param name the employee's name
    * @param salary the salary
    * @param year the hire year
    * @param month the hire month
    * @param day the hire day
    */
   public Manager(String name, double salary, int year, int month, int day)
   {
     super(name, salary, year, month, day);
     bonus = 0;
   }

   public double getSalary()
   {
     double baseSalary = super.getSalary();
     return baseSalary + bonus;
   }
```

```

    public void setBonus(double b)
    {
      bonus = b;
    }
}
```

5.1.4 Inheritance Hierarchies

Inheritance need not stop at deriving one layer of classes. We could have an `Executive` class that extends `Manager`, for example. The collection of all classes extending a common superclass is called an *inheritance hierarchy,* as shown in Figure 5.1. The path from a particular class to its ancestors in the inheritance hierarchy is its *inheritance chain*.

There is usually more than one chain of descent from a distant ancestor class. You could form subclasses `Programmer` or `Secretary` that extend `Employee`, and they would have nothing to do with the `Manager` class (or with each other). This process can continue as long as is necessary.

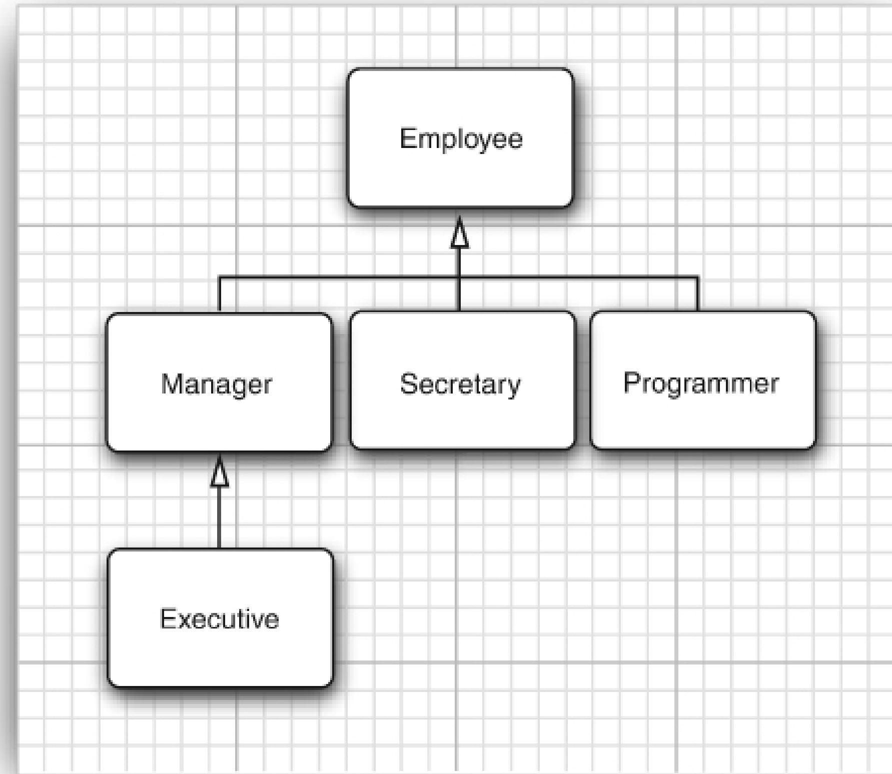


Figure 5.1 Employee inheritance hierarchy

C++ NOTE:

In C++, a class can have multiple superclasses. Java does not support multiple inheritance. For ways to recover much of the functionality of multiple inheritance, see Section 6.1, "Interfaces," on p. 312.

5.1.5 Polymorphism

A simple rule can help you decide whether or not inheritance is the right design for your data. The "is–a" rule states that every object of the subclass is an object of the superclass. For example, every manager is an employee.

Thus, it makes sense for the `Manager` class to be a subclass of the `Employee` class. Naturally, the opposite is not true—not every employee is a manager.

Another way of formulating the "is–a" rule is the *substitution principle*. That principle states that you can use a subclass object whenever the program expects a superclass object.

For example, you can assign a subclass object to a superclass variable.

```
Employee e;
e = new Employee(. . .);  // Employee object expected
e = new Manager(. . .); // OK, Manager can be used as well
```

In the Java programming language, object variables are *polymorphic*. A variable of type `Employee` can refer to an object of type `Employee` or to an object of any subclass of the `Employee` class (such as `Manager`, `Executive`, `Secretary`, and so on).

We took advantage of this principle in Listing 5.1:

```
Manager boss = new Manager(. . .);
Employee[] staff = new Employee[3];
staff[0] = boss;
```

In this case, the variables `staff[0]` and `boss` refer to the same object. However, `staff[0]` is considered to be only an `Employee` object by the compiler.

That means you can call

```
boss.setBonus(5000); // OK
```

but you can't call

```
staff[0].setBonus(5000); // ERROR
```

The declared type of `staff[0]` is `Employee`, and the `setBonus` method is not a method of the `Employee` class.

However, you cannot assign a superclass reference to a subclass variable. For example, it is not legal to make the assignment

```
Manager m = staff[i]; // ERROR
```

The reason is clear: Not all employees are managers. If this assignment were to succeed and `m` were to refer to an `Employee` object that is not a manager, then it would later be possible to call `m.setBonus(. . .)` and a runtime error would occur.

CAUTION:

In Java, arrays of subclass references can be converted to arrays of superclass references without a cast. For example, consider this array of managers:

```
Manager[] managers = new Manager[10];
```

It is legal to convert this array to an `Employee[]` array:

```
Employee[] staff = managers; // OK
```

Sure, why not, you may think. After all, if `managers[i]` is a `Manager`, it is also an `Employee`. But actually, something surprising is going on. Keep in mind that `managers` and `staff` are references to the same array. Now consider the statement

```
staff[0] = new Employee("Harry Hacker", . . .);
```

The compiler will cheerfully allow this assignment. But `staff[0]` and `managers[0]` are the same reference, so it looks as if we managed to smuggle a mere employee into the management ranks. That would be very bad—calling `managers[0].setBonus(1000)` would try to access a nonexistent instance field and would corrupt neighboring memory.

To make sure no such corruption can occur, all arrays remember the element type with which they were created, and they monitor that only compatible references are stored into them. For example, the array created as `new Manager[10]` remembers that it is an array of managers. Attempting to store an `Employee` reference causes an `ArrayStoreException`.

5.1.6 Understanding Method Calls

It is important to understand exactly how a method call is applied to an object. Let's say we call `x.f(args)`, and the implicit parameter `x` is declared to be an object of class `C`. Here is what happens:

1. The compiler looks at the declared type of the object and the method name. Note that there may be multiple methods, all with the same name, `f`, but with different parameter types. For example, there may be a method `f(int)` and a method `f(String)`. The compiler enumerates all methods called `f` in the class `C` and all accessible methods called `f` in the superclasses of `C`. (Private methods of the superclass are not accessible.)

   Now the compiler knows all possible candidates for the method to be called.
2. Next, the compiler determines the types of the arguments supplied in the method call. If among all the methods called `f` there is a unique method whose parameter types are a best match for the supplied arguments, that method is chosen to be called. This process is called *overloading resolution*. For example, in a call `x.f("Hello")`, the compiler picks `f(String)` and not `f(int)`. The situation can get complex because of type conversions (`int` to `double`, `Manager` to `Employee`, and so on). If the compiler cannot find any method with matching parameter types or if multiple methods all match after applying conversions, the compiler reports an error.

Now the compiler knows the name and parameter types of the method that needs to be called.

NOTE:

Recall that the name and parameter type list for a method is called the method's *signature*. For example, `f(int)` and `f(String)` are two methods with the same name but different signatures. If you define a method in a subclass that has the same signature as a superclass method, you override the superclass method.

The return type is not part of the signature. However, when you override a method, you need to keep the return type compatible. A subclass may change the return type to a subtype of the original type. For example, suppose the `Employee` class has a method

```
public Employee getBuddy() { . . . }
```

A manager would never want to have a lowly employee as a buddy. To reflect that fact, the `Manager` subclass can override this method as

```
public Manager getBuddy() { . . . } // OK to change return type
```

We say that the two `getBuddy` methods have *covariant* return types.

---

3. If the method is `private`, `static`, `final`, or a constructor, then the compiler knows exactly which method to call. (The `final` modifier is explained in the next section.) This is called *static binding*. Otherwise, the method to be called depends on the actual type of the implicit parameter, and dynamic binding must be used at runtime. In our example, the compiler would generate an instruction to call `f(String)` with dynamic binding.

4. When the program runs and uses dynamic binding to call a method, the virtual machine must call the version of the method that is appropriate for the *actual* type of the object to which `x` refers. Let's say the actual type is `D`, a subclass of `C`. If the class `D` defines a method `f(String)`, that method is called. If not, `D`'s superclass is searched for a method `f(String)`, and so on.

   It would be time-consuming to carry out this search every time a method is called. Instead, the virtual machine precomputes a *method table* for each class. The method table lists all method signatures and the actual methods to be called.

   The virtual machine can build the method table after loading a class, by combining the methods that it finds in the class file with the method table of the superclass.

   When a method is actually called, the virtual machine simply makes a table lookup. In our example, the virtual machine consults the method table for the class `D` and looks up the method to call for `f(String)`. That method may be `D.f(String)` or `X.f(String)`, where `X` is some superclass of `D`.

   There is one twist to this scenario. If the call is `super.f(param)`, then the virtual machine consults the method table of the superclass.

Let's look at this process in detail in the call `e.getSalary()` in Listing 5.1. The declared type of `e` is `Employee`. The `Employee` class has a single method, called `getSalary`, with no method parameters. Therefore, in this case, we don't worry about overloading resolution.

The `getSalary` method is not `private`, `static`, or `final`, so it is dynamically bound. The virtual machine produces method tables for the `Employee` and `Manager` classes. The `Employee` table shows that all methods are defined in the `Employee` class itself:

```
Employee:
   getName() -> Employee.getName()
   getSalary() -> Employee.getSalary()
   getHireDay() -> Employee.getHireDay()
   raiseSalary(double) -> Employee.raiseSalary(double)
```

Actually, that isn't the whole story—as you will see later in this chapter, the `Employee` class has a superclass `Object` from which it inherits a number of methods. I ignore the `Object` methods for now.

The `Manager` method table is slightly different. Three methods are inherited, one method is redefined, and one method is added.

```
Manager:
   getName() -> Employee.getName()
   getSalary() -> Manager.getSalary()
   getHireDay() -> Employee.getHireDay()
   raiseSalary(double) -> Employee.raiseSalary(double)
   setBonus(double) -> Manager.setBonus(double)
```

At runtime, the call `e.getSalary()` is resolved as follows:

1. First, the virtual machine fetches the method table for the actual type of `e`. That may be the table for `Employee`, `Manager`, or another subclass of `Employee`.
2. Then, the virtual machine looks up the defining class for the `getSalary()` signature. Now it knows which method to call.
3. Finally, the virtual machine calls the method.

Dynamic binding has a very important property: It makes programs *extensible* without the need for modifying existing code. Suppose a new class `Executive` is added and there is the possibility that the variable `e` refers to an object of that class. The code containing the call `e.getSalary()` need not be recompiled. The `Executive.getSalary()` method is called automatically if `e` happens to refer to an object of type `Executive`.

CAUTION:

When you override a method, the subclass method must be *at least as visible* as the superclass method. In particular, if the superclass method is `public`, the subclass method must also be declared `public`. It is a common error to accidentally omit the `public` specifier for the subclass method. The compiler then complains that you try to supply a more restrictive access privilege.

5.1.7 Preventing Inheritance: Final Classes and Methods

Occasionally, you want to prevent someone from forming a subclass of one of your classes. Classes that cannot be extended are called *final* classes, and you use the `final` modifier in the definition of the class to indicate this. For example, suppose we want to prevent others from subclassing the `Executive` class. Simply declare the class using the `final` modifier, as follows:

```
public final class Executive extends Manager
{
   . . .
}
```

You can also make a specific method in a class `final`. If you do this, then no subclass can override that method. (All methods in a `final` class are automatically `final`.) For example:

```
public class Employee
{
    . . .
    public final String getName()
    {
       return name;
    }
    . . .
}
```

NOTE:

Recall that fields can also be declared as `final`. A final field cannot be changed after the object has been constructed. However, if a class is declared `final`, only the methods, not the fields, are automatically `final`.

There is only one good reason to make a method or class `final`: to make sure its semantics cannot be changed in a subclass. For example, the `getTime` and `setTime` methods of the `Calendar` class are `final`. This indicates that the designers of the `Calendar` class have taken over responsibility for the conversion between the `Date` class and the calendar state. No subclass should be allowed to mess up this arrangement. Similarly, the `String` class is a `final` class. That means nobody can define a subclass of `String`. In other words, if you have a `String` reference, you know it refers to a `String` and nothing but a `String`.

Some programmers believe that you should declare all methods as `final` unless you have a good reason to want polymorphism. In fact, in C++ and C#, methods do not use polymorphism unless you specifically request it. That may be a bit extreme, but I agree that it is a good idea to think carefully about final methods and classes when you design a class hierarchy.

In the early days of Java, some programmers used the `final` keyword hoping to avoid the overhead of dynamic binding. If a method is not overridden, and it is short, then a compiler can optimize the method call away—a process called *inlining*. For example, inlining the call `e.getName()` replaces it with the field access `e.name`. This is a worthwhile improvement—CPUs hate branching because it interferes with their strategy of prefetching instructions while processing the current one. However, if `getName` can be overridden in another class, then the compiler cannot inline it because it has no way of knowing what the overriding code may do.

Fortunately, the just-in-time compiler in the virtual machine can do a better job than a traditional compiler. It knows exactly which classes extend a given class, and it can check whether any class actually overrides a given method. If a method is short, frequently called, and not actually overridden, the justin-time compiler can inline it. What happens if the virtual machine loads another subclass that overrides an inlined method? Then the optimizer must undo the inlining. That takes time, but it happens rarely.

NOTE:

Enumerations and records are always final—you cannot extend them.

5.1.8 Casting

Recall from Chapter 3 that the process of forcing a conversion from one type to another is called casting. The Java programming language has a special notation for casts. For example,

```
double x = 3.405;
int nx = (int) x;
```

converts the value of the expression `x` into an integer, discarding the fractional part.

Just as you occasionally need to convert a floating-point number to an integer, you may need to convert an object reference from one class to another. Let's again use the example of an array containing a mix of `Employee` and `Manager` objects:

```
var staff = new Employee[3];
staff[0] = new Manager("Carl Cracker", 80000, 1987, 12, 15);
staff[1] = new Employee("Harry Hacker", 50000, 1989, 10, 1);
staff[2] = new Employee("Tony Tester", 40000, 1990, 3, 15);
```

To actually make a cast of an object reference, use a syntax similar to what you use for casting numeric expressions. Surround the target class name with parentheses and place it before the object reference you want to cast. For example:

```
Manager boss = (Manager) staff[0];
```

There is only one reason why you would want to make a cast—to use an object in its full capacity after its actual type has been temporarily forgotten. For example, in the `ManagerTest` class, the `staff` array had to be an array of `Employee` objects because *some* of its elements were regular employees. We would need to cast the managerial elements of the array back to `Manager` to access any of its new variables. (Note that in the sample code for the first section, I made a special effort to avoid the cast. I initialized the `boss` variable with a `Manager` object before storing it in the array. I needed the correct type to set the bonus of the manager.)

As you know, in Java every variable has a type. The type describes the kind of object the variable refers to and what it can do. For example, `staff[i]` refers to an `Employee` object (so it can also refer to a `Manager` object).

The compiler checks that you do not promise too much when you store a value in a variable. If you assign a subclass reference to a superclass variable, you are promising less, and the compiler will simply let you do it. If you assign a superclass reference to a subclass variable, you are promising more. Then you must use a cast so that your promise can be checked at runtime.

What happens if you try to cast down an inheritance chain and are "lying" about what an object contains?

```
Manager boss = (Manager) staff[1]; // ERROR
```

When the program runs, the Java runtime system notices the broken promise and generates a `ClassCastException`. If you do not catch the exception, your program terminates. Thus, it is good programming practice to find out whether a cast will succeed before attempting it. Simply use the `instanceof` operator. For example:

```
if (staff[i] instanceof Manager)
{   boss = (Manager) staff[i];
   . . .
}
```

Finally, the compiler will not let you make a cast if there is no chance for the cast to succeed. For example, the cast

```
String c = (String) staff[i];
```

is a compile-time error because `String` is not a subclass of `Employee`.

To sum up:

- You can cast only within an inheritance hierarchy.
- Use `instanceof` to check before casting from a superclass to a subclass.

NOTE:

The test

```
x instanceof C
```

does not generate an exception if `x` is `null`. It simply returns `false`. That makes sense: `null` refers to no object, so it certainly doesn't refer to an object of type `C`.

Actually, converting the type of an object by a cast is not usually a good idea. In our example, you do not need to cast an `Employee` object to a `Manager` object for most purposes. The `getSalary` method will work correctly on both objects of both classes. The dynamic binding that makes polymorphism work locates the correct method automatically.

The only reason to make the cast is to use a method that is unique to managers, such as `setBonus`. If for some reason you find yourself wanting to call `setBonus` on `Employee` objects, ask yourself whether this is an indication of a design flaw in the superclass. It may make sense to redesign the superclass and add a `setBonus` method. Remember, it takes only one uncaught `ClassCastException` to terminate your program. In general, it is best to minimize the use of casts and the `instanceof` operator.

C++ NOTE:

Java uses the cast syntax from the “bad old days” of C, but it works like the safe `dynamic_cast` operation of C++. For example,

```
Manager boss = (Manager) staff[i]; // Java
```

is the same as

```
Manager* boss = dynamic_cast<Manager*>(staff[i]); // C++
```

with one important difference. If the cast fails, it does not yield a null object but throws an exception. In this sense, it is like a C++ cast of *references*. This is a pain in the neck. In C++, you can take care of the type test and type conversion in one operation.

```
Manager* boss = dynamic_cast<Manager*>(staff[i]); // C++
if (boss != NULL) . . .
```

In Java, you need to use a combination of the `instanceof` operator and a cast.

```
if (staff[i] instanceof Manager)
{
   Manager boss = (Manager) staff[i];
   . . .
}
```

5.1.9 Pattern Matching for `instanceof`

The code

```
if (staff[i] instanceof Manager)
{
   Manager boss = (Manager) staff[i];
   boss.setBonus(5000);
}
```

is rather verbose. Do we really need to mention the subclass `Manager` three times?

As of Java 16, there is an easier way. You can declare the subclass variable right in the `instanceof` test:

```
if (staff[i] instanceof Manager boss)
{
   boss.setBonus(5000);
}
```

If `staff[i]` is an instance of the `Manager` class, then the variable `boss` is set to `staff[i]`, and you can use it *as a* `Manager`. You skip the cast.

If `staff[i]` doesn't refer to a `Manager`, `boss` is not set, and the `instanceof` operator yields the value `false`. The body of the `if` statement is skipped.

TIP:

In most situations in which you use `instanceof`, you need to apply a subclass method. Then use this "pattern-matching" form of `instanceof` instead of a cast.

A useless `instanceof` pattern is an error:

```
Manager boss = . . .;
if (boss instanceof Employee e) . . . // ERROR: Of course it's
an Employee
```

NOTE:

The equally useless

```
if (boss instanceof Employee) . . .
```

is allowed, for backwards compatibility with Java 1.0.

When an `instanceof` pattern introduces a variable, you can use it right away, in the same expression:

```
Employee e;
if (e instanceof Manager m && m.getBonus() > 10000) . . .
```

This works because the right-hand side of an `&&` expression is only evaluated if the left-hand side is `true`. If the right-hand side is evaluated, `m` must have been bound to a `Manager` instance.

However, the following is a compile-time error:

```
if (e instanceof Manager m || m.getBonus() > 10000) . . . //
ERROR
```

The right-hand side of `||` is executed when the left-hand side is `false`, and then nothing is bound to the variable `m`.

Here is another example with the conditional operator:

```
double bonus = e instanceof Manager m ? m.getBonus() : 0;
```

The variable `m` is defined in the subexpression after the `?`, but not in the subexpression after the `:`.

NOTE:

The variable-declaring `instanceof` form is called "pattern-matching" because it is similar to type patterns in `switch`, a "preview" feature of Java 17. I don't discuss preview features in detail, but here is an example of the syntax:

```
String description = switch (e) {
   case Executive exec -> "An executive with a fancy title of "
+ exec.getTitle();
      case Manager m -> "A manager with a bonus of " +
m.getBonus();
      default -> "A lowly employee with a salary of " +
e.getSalary();
}
```

As with an `instanceof` pattern, each type pattern declares a variable.

CAUTION:

As any local variable, the local variable defined by an `instanceof` pattern can shadow a field. For example:

```
class Value
{
   private double v;
   public boolean equals(Value other)
   {
      if (other instanceof LabeledValue v)
```

```
            // v is the same as other
         else
            // v denotes the field
      }
      . . .
   }
```

5.1.10 Protected Access

As you know, fields in a class are best tagged as `private`, and methods are usually tagged as `public`. Any features declared `private` won't be accessible in other classes. As explained at the beginning of this chapter, this is also true for subclasses: A subclass cannot access the private fields of its superclass.

There are times, however, when you want to restrict a method to subclasses only or, less commonly, to allow subclass methods to access a superclass field. In that case, you declare a class feature as `protected`. For example, if the superclass `Employee` declares the `hireDay` field as `protected` instead of `private`, then the `Manager` methods can access it directly.

In Java, a protected field is accessible by any class in the same package. Now consider an `Administrator` subclass in a different package. The methods of the `Administrator` class can peek inside the `hireDay` field of `Administrator` objects only, not of other `Employee` objects. This restriction is made so that you can't abuse the `protected` mechanism by forming subclasses just to gain access to the protected fields.

In practice, use protected fields with caution. Suppose your class is used by other programmers and you designed it with protected fields. Unknown to you, other programmers may inherit classes from your class and start accessing your protected fields. In this case, you can no longer change the implementation of your class without upsetting those programmers. That is against the spirit of OOP, which encourages data encapsulation.

Protected methods make more sense. A class may declare a method as `protected` if it is tricky to use. This indicates that the subclasses (which, presumably, know their ancestor well) can be trusted to use the method correctly, but other classes cannot.

A good example of this kind of method is the `clone` method of the `Object` class—see Chapter 6 for more details.

C++ NOTE:

As already mentioned, protected features in Java are accessible to all subclasses as well as to all other classes in the same package. This is slightly different from the C++ meaning of protected, and it makes the notion of `protected` in Java even less safe than in C++.

Here is a summary of the four access control modifiers in Java:

1. Accessible in the class only (`private`).
2. Accessible by the world (`public`).
3. Accessible in the package and all subclasses (`protected`).
4. Accessible in the package—the (unfortunate) default. No modifiers are needed.

5.2 `Object`: The Cosmic Superclass

The `Object` class is the ultimate ancestor—every class in Java extends `Object`. However, you never have to write

```
public class Employee extends Object
```

The ultimate superclass `Object` is taken for granted if no superclass is explicitly mentioned. Since *every* class in Java extends `Object`, it is important to be familiar with the services provided by the `Object` class. I go over the basic ones in this chapter; consult the later chapters or view the online documentation for what is not covered here. (Several methods of `Object` come up only when dealing with concurrency—see Chapter 12.)

5.2.1 Variables of Type `Object`

You can use a variable of type `Object` to refer to objects of any type:

```
Object obj = new Employee("Harry Hacker", 35000);
```

Of course, a variable of type `Object` is only useful as a generic holder for arbitrary values. To do anything specific with the value, you need to have some knowledge about the original type and apply a cast:

```
Employee e = (Employee) obj;
```

In Java, only the values of *primitive types* (numbers, characters, and `boolean` values) are not objects.

All array types, no matter whether they are arrays of objects or arrays of primitive types, are class types that extend the `Object` class.

```
Employee[] staff = new Employee[10];
obj = staff; // OK
obj = new int[10]; // OK
```

C++ NOTE:

In C++, there is no cosmic root class. However, every pointer can be converted to a `void*` pointer.

5.2.2 The `equals` Method

The `equals` method in the `Object` class tests whether one object is considered equal to another. The `equals` method, as implemented in the `Object` class, determines whether two object references are identical. This is a pretty reasonable default—if two objects are identical, they should certainly be equal. For quite a few classes, nothing else is required. For example, it makes little sense to compare two `PrintStream` objects for equality. However, you will often want to implement state-based equality testing, in which two objects are considered equal when they have the same state.

For example, let us consider two employees equal if they have the same name, salary, and hire date. (In an actual employee database, it would be more sensible to compare IDs instead. I use this example to demonstrate the mechanics of implementing the `equals` method.)

```
public class Employee
{
   . . .
   public boolean equals(Object otherObject)
   {
      // a quick test to see if the objects are identical
      if (this == otherObject) return true;
      // must return false if the explicit parameter is null
      if (otherObject == null) return false;
      // if the classes don't match, they can't be equal
      if (getClass() != otherObject.getClass())
         return false;
      // now we know otherObject is a non-null Employee
      Employee other = (Employee) otherObject;
      // test whether the fields have identical values
      return name.equals(other.name)
         && salary == other.salary
         && hireDay.equals(other.hireDay);
   }
}
```

The `getClass` method returns the class of an object—we discuss this method in detail later in this chapter. In our test, two objects can only be equal when they belong to the same class.

TIP:

To guard against the possibility that `name` or `hireDay` are `null`, use the `Objects.equals` method. The call `Objects.equals(a, b)` returns `true` if both arguments are `null`, `false` if only one is `null`, and calls `a.equals(b)` otherwise. With that method, the last statement of the `Employee.equals` method becomes

```
return Objects.equals(name, other.name)
   && salary == other.salary
   && Objects.equals(hireDay, other.hireDay);
```

When you define the `equals` method for a subclass, first call `equals` on the super-class. If that test doesn't pass, then the objects can't be equal. If the superclass fields are equal, you are ready to compare the instance fields of the subclass.

```
public class Manager extends Employee
{
  . . .
  public boolean equals(Object otherObject)
  {
     if (!super.equals(otherObject)) return false;
     // super.equals checked that this and otherObject belong
to the same class
     Manager other = (Manager) otherObject;
     return bonus == other.bonus;
  }
}
```

NOTE:

Recall from Chapter 4 that a record is a special form of an immutable class whose state is entirely defined by the fields set in a "canonical" constructor. Records automatically define an `equals` method that compares the fields. Two record instances are equals when the corresponding field values are equal.

5.2.3 Equality Testing and Inheritance

How should the `equals` method behave if the implicit and explicit parameters don't belong to the same class? This has been an area of some controversy. In the preceding example, the `equals` method returns `false` if the classes don't match exactly. But many programmers use an `instanceof` test instead:

```
if (!(otherObject instanceof Employee)) return false;
```

This leaves open the possibility that `otherObject` can belong to a subclass. However, this approach can get you into trouble. Here is why. The Java Language Specification requires that the `equals` method has the following properties:

1. It is *reflexive*: For any non-null reference `x`, `x.equals(x)` should return `true`.
2. It is *symmetric*: For any references `x` and `y`, `x.equals(y)` should return `true` if and only if `y.equals(x)` returns `true`.
3. It is *transitive*: For any references `x`, `y`, and `z`, if `x.equals(y)` returns `true` and `y.equals(z)` returns `true`, then `x.equals(z)` should return `true`.
4. It is *consistent*: If the objects to which `x` and `y` refer haven't changed, then repeated calls to `x.equals(y)` return the same value.
5. For any non-null reference `x`, `x.equals(null)` should return `false`.

These rules are certainly reasonable. You wouldn't want a library implementor to ponder whether to call `x.equals(y)` or `y.equals(x)` when locating an element in a data structure.

However, the symmetry rule has subtle consequences when the parameters belong to different classes. Consider a call

```
e.equals(m)
```

where `e` is an `Employee` object and `m` is a `Manager` object, both of which happen to have the same name, salary, and hire date. If `Employee.equals` uses an `instanceof` test, the call returns `true`. But that means that the reverse call

```
m.equals(e)
```

also needs to return `true`—the symmetry rule does not allow it to return `false` or to throw an exception.

That leaves the `Manager` class in a bind. Its `equals` method must be willing to compare itself to any `Employee`, without taking manager-specific information into account! All of a sudden, the `instanceof` test looks less attractive.

Some authors have gone on record that the `getClass` test is wrong because it violates the substitution principle. A commonly cited example is the `equals` method in the `AbstractSet` class that tests whether two sets have the same elements. The `AbstractSet` class has two concrete subclasses, `TreeSet` and `HashSet`, that use different algorithms for locating set elements. You really want to be able to compare any two sets, no matter how they are implemented.

However, the set example is rather specialized. It would make sense to declare `AbstractSet.equals` as `final`, because nobody should redefine the semantics of set equality. (The method is not actually `final`. This allows a subclass to implement a more efficient algorithm for the equality test.)

The way I see it, there are two distinct scenarios:

- If subclasses can have their own notion of equality, then the symmetry requirement forces you to use the `getClass` test.
- If the notion of equality is fixed in the superclass, then you can use the `instanceof` test and allow objects of different subclasses to be equal to one

another.

In the example with employees and managers, we consider two objects to be equal when they have matching fields. If we have two `Manager` objects with the same name, salary, and hire date, but with different bonuses, we want them to be different. Therefore, we use the `getClass` test.

But suppose we used an employee ID for equality testing. This notion of equality makes sense for all subclasses. Then we could use the `instanceof` test, and we should have declared `Employee.equals` as `final`.

NOTE:

The standard Java library contains over 150 implementations of `equals` methods, with a mishmash of using `instanceof`, calling `getClass`, catching a `ClassCastException`, or doing nothing at all. Check out the API documentation of the `java.sql.Timestamp` class, where the implementors note with some embarrassment that they have painted themselves in a corner. The `Timestamp` class inherits from `java.util.Date`, whose `equals` method uses an `instanceof` test, and it is impossible to override `equals` to be both symmetric and accurate.

Here is a recipe for writing the perfect `equals` method:

1. Name the explicit parameter `otherObject`—later, you will need to cast it to another variable that you should call `other`.
2. Test whether `this` happens to be identical to `otherObject`:

   ```
   if (this == otherObject) return true;
   ```

   This statement is just an optimization. In practice, this is a common case. It is much cheaper to check for identity than to compare the fields.
3. Test whether `otherObject` is `null` and return `false` if it is. This test is required.

   ```
   if (otherObject == null) return false;
   ```

4. Compare the classes of `this` and `otherObject`. If the semantics of `equals` can change in subclasses, use the `getClass` test:

   ```
   if (getClass() != otherObject.getClass()) return false;
   ClassName other = (ClassName) otherObject;
   ```

   If the same semantics holds for *all* subclasses, you can use an `instanceof` test:

   ```
   if (!(otherObject instanceof ClassName other)) return false;
   ```

   Note that the `instanceof` test sets `other` to `otherObject` if it succeeds. No cast is necessary.
5. Now compare the fields, as required by your notion of equality. Use `==` for primitive type fields, `Objects.equals` for object fields. Return `true` if all fields match, `false` otherwise.

   ```
   return field1 == other.field1
      && Objects.equals(field2, other.field2)
      && . . .;
   ```

   If you redefine `equals` in a subclass, include a call to `super.equals(other)`.

TIP:

If you have fields of array type, you can use the static `Arrays.equals` method to check that the corresponding array elements are equal. Use the `Arrays.deepEquals` method for multidimensional arrays.

CAUTION:

Here is a common mistake when implementing the `equals` method. Can you spot the problem?

```
public class Employee
{
  public boolean equals(Employee other)
  {
     return other != null
        && getClass() == other.getClass()
        && Objects.equals(name, other.name)
        && salary == other.salary
        && Objects.equals(hireDay, other.hireDay);
  }
  . . .
}
```

This method declares the explicit parameter type as `Employee`. As a result, it does not override the `equals` method of the `Object` class but defines a completely unrelated method.

You can protect yourself against this type of error by tagging methods that are intended to override superclass methods with `@Override`:

```
@Override public boolean equals(Object other)
```

If you made a mistake and are defining a new method, the compiler reports an error. For example, suppose you add the following declaration to the `Employee` class:

```
@Override public boolean equals(Employee other)
```

An error is reported because this method doesn't override any method from the `Object` superclass.

---

java.util.Arrays 1.2

- `static boolean equals(`*xxx*`[] a, `*xxx*`[] b)` 5

  returns `true` if the arrays have equal lengths and equal elements in corresponding positions. The component type *xxx* of the array can be `Object`, `int`, `long`, `short`, `char`, `byte`, `boolean`, `float`, or `double`.

`java.util.Objects` 7

- `static boolean equals(Object a, Object b)`

  returns `true` if `a` and `b` are both `null`, `false` if exactly one of them is `null`, and `a.equals(b)` otherwise.

5.2.4 The `hashCode` Method

A hash code is an integer that is derived from an object. Hash codes should be scrambled—if `x` and `y` are two distinct objects, there should be a high probability that `x.hashCode()` and `y.hashCode()` are different. Table 5.1 lists a few examples of hash codes that result from the `hashCode` method of the `String` class.

The `String` class uses the following algorithm to compute the hash code:

```
int hash = 0;
for (int i = 0; i < length(); i++)
   hash = 31 * hash + charAt(i);
```

Table 5.1 Hash Codes Resulting from the `hashCode` Method

String	Hash Code
Hello	69609650
Harry	69496448
Hacker	-2141031506

The `hashCode` method is defined in the `Object` class. Therefore, every object has a default hash code. That hash code is derived from the object's memory address. Consider this example:

```
var s = "Ok";
var sb = new StringBuilder(s);
System.out.println(s.hashCode() + " " + sb.hashCode());
var t = new String("Ok");
var tb = new StringBuilder(t);
System.out.println(t.hashCode() + " " + tb.hashCode());
```

Table 5.2 shows the result.

Table 5.2 Hash Codes of Strings and String Builders

Object	Hash Code	Object	Hash Code
s	2556	t	2556
sb	20526976	tb	20527144

Note that the strings `s` and `t` have the same hash code because, for strings, the hash codes are derived from their *contents*. The string builders `sb` and `tb` have different hash codes because no `hashCode` method has been defined for the `StringBuilder` class and the default `hashCode` method in the `Object` class derives the hash code from the object's memory address.

If you redefine the `equals` method, you will also need to redefine the `hashCode` method for objects that users might insert into a hash table. (I discuss hash tables in Chapter 9.)

The `hashCode` method should return an integer (which can be negative). Just combine the hash codes of the instance fields so that the hash codes for different objects are likely to be widely scattered.

For example, here is a `hashCode` method for the `Employee` class:

```
public class Employee
{
  public int hashCode()
  {
     return 7 * name.hashCode()
        + 11 * Double.valueOf(salary).hashCode()
        + 13 * hireDay.hashCode();
  }
  . . .
}
```

However, you can do better. First, use the null-safe method `Objects.hashCode`. It returns `0` if its argument is `null` and the result of calling `hashCode` on the argument otherwise. Also, use the static `Double.hashCode` method to avoid creating a `Double` object:

```
public int hashCode()
{
  return 7 * Objects.hashCode(name)
     + 11 * Double.hashCode(salary)
     + 13 * Objects.hashCode(hireDay);
}
```

Even better, when you need to combine multiple hash values, call `Objects.hash` with all of them. It will call `Objects.hashCode` for each argument and combine the values. Then the `Employee.hashCode` method is simply

```
public int hashCode()
{
```

```
    return Objects.hash(name, salary, hireDay);
  }
```

Your definitions of `equals` and `hashCode` must be compatible: If `x.equals(y)` is `true`, then `x.hashCode()` must return the same value as `y.hashCode()`. For example, if you define `Employee.equals` to compare employee IDs, then the `hashCode` method needs to hash the IDs, not employee names or memory addresses.

TIP:

If you have fields of an array type, you can use the static `Arrays.hashCode` method to compute a hash code composed of the hash codes of the array elements.

NOTE:

A `record` type automatically provides a `hashCode` method that derives a hash code from the hash codes of the field values.

CAUTION:

If the instance variables have small ranges of possible values, you need to achieve as many distinct hash codes as possible. Consider hashing calendar dates. Computing `7 * year + 11 * month + 13 * day` yields many collisions. In contrast, `31 * 12 * year + 31 * month + day` is a "perfect hash function." Assuming a reasonable year range, no two dates have the same hash code. (The actual `hashCode` method of the `LocalDate` class, which supports a range of ±999,999,999 years, is a bit more complex.)

---

java.lang.Object 1.0

- `int hashCode()`

  returns a hash code for this object. A hash code can be any integer, positive or negative. Equal objects need to return identical hash codes.

java.util.Objects 7

- `static int hash(Object... objects)`

  returns a hash code that is combined from the hash codes of all supplied objects.

- `static int hashCode(Object a)`

  returns `0` if `a` is `null` or `a.hashCode()` otherwise.

java.lang.(Integer|Long|Short|Byte|Double|Float|Character|Boolean) 1.0

- `static int hashCode(`*xxx* `value)` 8

  returns the hash code of the given value. Here *xxx* is the primitive type corresponding to the given wrapper type.

java.util.Arrays 1.2

- `static int hashCode(`*xxx*`[] a)` 5

computes the hash code of the array `a`. The component type *xxx* of the array can be `Object`, `int`, `long`, `short`, `char`, `byte`, `boolean`, `float`, or `double`.

5.2.5 The `toString` Method

Another important method in `Object` is the `toString` method that returns a string representing the value of this object. Here is a typical example. The `toString` method of the `Point` class returns a string like this:

```
java.awt.Point[x=10,y=20]
```

Most (but not all) `toString` methods follow this format: the name of the class, then the field values enclosed in square brackets. Here is an implementation of the `toString` method for the `Employee` class:

```
public String toString()
{
   return "Employee[name=" + name
      + ",salary=" + salary
      + ",hireDay=" + hireDay
      + "]";
}
```

Actually, you can do a little better. Instead of hardwiring the class name into the `toString` method, call `getClass().getName()` to obtain a string with the class name.

```
public String toString()
{
  return getClass().getName()
     + "[name=" + name
     + ",salary=" + salary
     + ",hireDay=" + hireDay
     + "]";
}
```

Such `toString` method will also work for subclasses.

Of course, the subclass programmer should define its own `toString` method and add the subclass fields. If the superclass uses `getClass().getName()`, then the subclass can simply call `super.toString()`. For example, here is a `toString` method for the `Manager` class:

```
public class Manager extends Employee
{
  . . .
  public String toString()
  {
     return super.toString()
        + "[bonus=" + bonus
        + "]";
  }
}
```

Now a `Manager` object is printed as

```
Manager[name=. . .,salary=. . .,hireDay=. . .][bonus=. . .]
```

The `toString` method is ubiquitous for an important reason: Whenever an object is concatenated with a string by the "+" operator, the Java compiler automatically invokes the `toString` method to obtain a string representation of the object. For example:

```
var p = new Point(10, 20);
String message = "The current position is " + p;
  // automatically invokes p.toString()
```

TIP:

Instead of writing `x.toString()`, you can write `"" + x`. This statement concatenates the empty string with the string representation of `x` that is exactly `x.toString()`. Unlike `toString`, this statement even works if `x` is of primitive type.

If `x` is any object and you call

```
System.out.println(x);
```

then the `println` method simply calls `x.toString()` and prints the resulting string.

The `Object` class defines the `toString` method to print the class name and the hash code of the object. For example, the call

```
System.out.println(System.out)
```

produces an output that looks like this:

```
java.io.PrintStream@2f6684
```

The reason is that the implementor of the `PrintStream` class didn't bother to override the `toString` method.

CAUTION:

Annoyingly, arrays inherit the `toString` method from `Object`, with the added twist that the array type is printed in an archaic format. For example,

```
int[] luckyNumbers = { 2, 3, 5, 7, 11, 13 };
String s = "" + luckyNumbers;
```

yields the string `"[I@1a46e30"`. (The prefix `[I` denotes an array of integers.) The remedy is to call the static `Arrays.toString` method instead. The code

```
String s = Arrays.toString(luckyNumbers);
```

yields the string `"[2, 3, 5, 7, 11, 13]"`.

To correctly print multidimensional arrays (that is, arrays of arrays), use `Arrays.deepToString`.

The `toString` method is a great tool for logging. Many classes in the standard class library define the `toString` method so that you can get useful information about the state of an object. This is particularly useful in logging messages like this:

```
System.out.println("Current position = " + position);
```

As explained in Chapter 7, an even better solution is to use an object of the

```
Logger class and call
Logger.global.info("Current position = " + position);
```

✔ **TIP:**

I strongly recommend that you add a `toString` method to each class that you write. You, as well as other programmers who use your classes, will be grateful for the logging support.

However, for `record` types, a `toString` method is already provided. It simply lists the class name and the names and stringified values of the fields.

The program in Listing 5.4 tests the `equals`, `hashCode`, and `toString` methods for the classes `Employee` (Listing 5.5) and `Manager` (Listing 5.6).

Listing 5.4 `equals/EqualsTest.java`

```
package equals;

/**
 * This program demonstrates the equals method.
 * @version 1.12 2012-01-26
 * @author Cay Horstmann
 */
public class EqualsTest
{
   public static void main(String[] args)
   {
      var alice1 = new Employee("Alice Adams", 75000, 1987,
12, 15);
      var alice2 = alice1;
      var alice3 = new Employee("Alice Adams", 75000, 1987,
12, 15);
      var bob = new Employee("Bob Brandson", 50000, 1989, 10,
1);

       System.out.println("alice1 == alice2: " + (alice1 ==
alice2));

       System.out.println("alice1 == alice3: " + (alice1 ==
alice3));

       System.out.println("alice1.equals(alice3): " +
alice1.equals(alice3));

       System.out.println("alice1.equals(bob): " +
alice1.equals(bob));

      System.out.println("bob.toString(): " + bob);

      var carl = new Manager("Carl Cracker", 80000, 1987, 12,
```

```
15);
        var boss = new Manager("Carl Cracker", 80000, 1987, 12, 15);
        boss.setBonus(5000);
        System.out.println("boss.toString(): " + boss);
        System.out.println("carl.equals(boss): " + carl.equals(boss));
        System.out.println("alice1.hashCode(): " + alice1.hashCode());
        System.out.println("alice3.hashCode(): " + alice3.hashCode());
        System.out.println("bob.hashCode(): " + bob.hashCode());
        System.out.println("carl.hashCode(): " + carl.hashCode());
   }
}
```

Listing 5.5 `equals/Employee.java`

```
package equals;

import java.time.*;
import java.util.Objects;

public class Employee
{
   private String name;
   private double salary;
   private LocalDate hireDay;

   public Employee(String name, double salary, int year, int month, int day)
   {
      this.name = name;
      this.salary = salary;
      hireDay = LocalDate.of(year, month, day);
   }

```

```java
public String getName()
{
   return name;
}

public double getSalary()
{
   return salary;
}

public LocalDate getHireDay()
{
   return hireDay;
}

public void raiseSalary(double byPercent)
{
   double raise = salary * byPercent / 100;
   salary += raise;
}

public boolean equals(Object otherObject)
{
   // a quick test to see if the objects are identical
   if (this == otherObject) return true;

   // must return false if the explicit parameter is null
   if (otherObject == null) return false;

   // if the classes don't match, they can't be equal
   if (getClass() != otherObject.getClass()) return false;

   // now we know otherObject is a non-null Employee
   var other = (Employee) otherObject;

   // test whether the fields have identical values
   return Objects.equals(name, other.name)
      && salary == other.salary && Objects.equals(hireDay, other.hireDay);
```

```java
   }

   public int hashCode()
   {
      return Objects.hash(name, salary, hireDay);
   }

   public String toString()
   {
      return getClass().getName() + "[name=" + name + ",salary=" + salary + ",hireDay="
         + hireDay + "]";
   }
}
```

Listing 5.6 `equals/Manager.java`

```java
package equals;

public class Manager extends Employee
{
   private double bonus;

   public Manager(String name, double salary, int year, int month, int day)
   {
      super(name, salary, year, month, day);
      bonus = 0;
   }

   public double getSalary()
   {
      double baseSalary = super.getSalary();
      return baseSalary + bonus;
   }

   public void setBonus(double bonus)
   {
```

```java
      this.bonus = bonus;
   }

   public boolean equals(Object otherObject)
   {
      if (!super.equals(otherObject)) return false;
      var other = (Manager) otherObject;
      // super.equals checked that this and other belong to the same class
      return bonus == other.bonus;
   }

   public int hashCode()
   {
      return java.util.Objects.hash(super.hashCode(), bonus);
   }

   public String toString()
   {
      return super.toString() + "[bonus=" + bonus + "]";
   }
}
```

`java.lang.Object` 1.0

- `Class getClass()`

  returns a class object that contains information about the object. As you will see later in this chapter, Java has a runtime representation for classes that is encapsulated in the `Class` class.

- `boolean equals(Object otherObject)`

  compares two objects for equality; returns `true` if the objects point to the same area of memory, and `false` otherwise. You should override this method in your own classes.

- `String toString()`

returns a string that represents the value of this object. You should override this method in your own classes.

java.lang.Class 1.0

- `String getName()`

  returns the name of this class.

- `Class getSuperclass()`

  returns the superclass of this class as a `Class` object.

5.3 Generic Array Lists

In some programming languages—in particular, in C and C++—you have to fix the sizes of all arrays at compile time. Programmers hate this because it forces them into uncomfortable tradeoffs. How many employees will be in a department? Surely no more than 100. What if there is a humongous department with 150 employees? Do we want to waste 90 entries for every department with just 10 employees?

In Java, the situation is somewhat better. You can set the size of an array at runtime.

```
int actualSize = . . .;
var staff = new Employee[actualSize];
```

Of course, this code does not completely solve the problem of dynamically modifying arrays at runtime. Once you set the array size, you cannot change it easily. Instead, in Java you can deal with this common situation by using another Java class, called `ArrayList`. The `ArrayList` class is similar to an array, but it automatically adjusts its capacity as you add and remove elements, without any additional code.

ArrayList is a *generic class* with a *type parameter*. To specify the type of the element objects that the array list holds, you append a class name enclosed in angle brackets, such as ArrayList<Employee>. You will see in Chapter 8 how to define your own generic class, but you don't need to know any of those technicalities to use the ArrayList type.

The following sections show you how to work with array lists.

5.3.1 Declaring Array Lists

Here is how to declare and construct an array list that holds Employee objects:

```
ArrayList<Employee> staff = new ArrayList<Employee>();
```

As of Java 10, it is a good idea to use the var keyword to avoid duplicating the class name:

```
var staff = new ArrayList<Employee>();
```

It you don't use the var keyword, you can omit the type parameter on the right-hand side:

```
ArrayList<Employee> staff = new ArrayList<>();
```

This is called the "diamond" syntax because the empty brackets <> resemble a diamond. Use the diamond syntax together with the new operator. The compiler checks what happens to the new value. If it is assigned to a variable, passed into a method, or returned from a method, then the compiler checks the generic type of the variable, parameter, or method. It then places that type into the <>. In our example, the new ArrayList<>() is assigned to a variable of type ArrayList<Employee>. Therefore, the generic type is Employee.

CAUTION:

If you declare an `ArrayList` with `var`, do *not* use the diamond syntax. The declaration

```
var elements = new ArrayList<>();
```

yields an `ArrayList<Object>`.

NOTE:

Before Java 5, there were no generic classes. Instead, there was a single `ArrayList` class, a one-size-fits-all collection holding elements of type `Object`. You can still use `ArrayList` without a `<. . .>` suffix. It is considered a “raw” type, with the type parameter erased.

NOTE:

In even older versions of Java, programmers used the `Vector` class for dynamic arrays. However, the `ArrayList` class is more efficient, and there is no longer any good reason to use the `Vector` class.

Use the `add` method to add new elements to an array list. For example, here is how you populate an array list with `Employee` objects:

```
staff.add(new Employee("Harry Hacker", . . .));
staff.add(new Employee("Tony Tester", . . .));
```

The array list manages an internal array of object references. Eventually, that array will run out of space. This is where array lists work their magic: If you call `add` and the internal array is full, the array list automatically creates a bigger array and copies all the objects from the smaller to the bigger array.

If you already know, or have a good guess, how many elements you want to store, call the `ensureCapacity` method before filling the array list:

```
staff.ensureCapacity(100);
```

That call allocates an internal array of 100 objects. Then, the first 100 calls to `add` will not involve any costly reallocation.

You can also pass an initial capacity to the `ArrayList` constructor:

```
ArrayList<Employee> staff = new ArrayList<>(100);
```

CAUTION:

Allocating an array list as

```
new ArrayList<>(100) // capacity is 100
```

is *not* the same as allocating a new array as

```
new Employee[100] // size is 100
```

There is an important distinction between the capacity of an array list and the size of an array. If you allocate an array with 100 entries, then the array has 100 slots, ready for use. An array list with a capacity of 100 elements has the *potential* of holding 100 elements (and, in fact, more than 100, at the cost of additional reallocations)—but at the beginning, even after its initial construction, an array list holds no elements at all.

The size method returns the actual number of elements in the array list. For example,

```
staff.size()
```

returns the current number of elements in the staff array list. This is the equivalent of

```
a.length
```

for an array a.

Once you are reasonably sure that the array list is at its permanent size, you can call the trimToSize method. This method adjusts the size of the memory block to use exactly as much storage space as is required to hold the current number of elements. The garbage collector will reclaim any excess memory.

Once you trim the size of an array list, adding new elements will move the block again, which takes time. You should only use trimToSize when you are sure you won't add any more elements to the array list.

C++ NOTE:

The ArrayList class is similar to the C++ vector template. Both ArrayList and vector are generic types. But the C++ vector template overloads the [] operator for convenient element access. Java does not have operator overloading, so it must use explicit method calls instead. Moreover, C++ vectors are copied by value. If a and b are two vectors, then the assignment a = b makes a into a new vector with the same length as b, and all elements are copied from b to a. The same assignment in Java makes both a and b refer to the same array list.

java.util.ArrayList<E> 1.2

- `ArrayList<E>()`

  constructs an empty array list.

- `ArrayList<E>(int initialCapacity)`

  constructs an empty array list with the specified capacity.

- `boolean add(E obj)`

  appends `obj` at the end of the array list. Always returns `true`.

- `int size()`

  returns the number of elements currently stored in the array list. (Of course, this is never larger than the array list's capacity.)

- `void ensureCapacity(int capacity)`

  ensures that the array list has the capacity to store the given number of elements without reallocating its internal storage array.

- `void trimToSize()`

  reduces the storage capacity of the array list to its current size.

5.3.2 Accessing Array List Elements

Unfortunately, nothing comes for free. The automatic growth convenience of array lists requires a more complicated syntax for accessing the elements. The reason is that the `ArrayList` class is not a part of the Java programming language; it is just a utility class programmed by someone and supplied in the standard library.

Instead of the pleasant `[]` syntax to access or change the element of an array, you use the `get` and `set` methods.

For example, to set the `i`th element, use

```
staff.set(i, harry);
```

This is equivalent to

```
a[i] = harry;
```

for an array a. (As with arrays, the index values are zero-based.)

CAUTION:

Do not call `list.set(i, x)` until the *size* of the array list is larger than `i`. For example, the following code is wrong:

```
var list = new ArrayList<Employee>(100); // capacity 100, size
0
list.set(0, x); // no element 0 yet
```

Use the `add` method instead of `set` to fill up an array, and use `set` only to replace a previously added element.

To get an array list element, use

```
Employee e = staff.get(i);
```

This is equivalent to

```
Employee e = a[i];
```

NOTE:

When there were no generic classes, the `get` method of the raw `ArrayList` class had no choice but to return an `Object`. Consequently, callers of `get` had to cast the returned value to the desired type:

```
Employee e = (Employee) staff.get(i);
```

The raw `ArrayList` is also a bit dangerous. Its `add` and `set` methods accept objects of any type. A call

```
staff.set(i, "Harry Hacker");
```

compiles without so much as a warning, and you run into grief only when you retrieve the object and try to cast it. If you use an `ArrayList<Employee>` instead, the compiler will detect this error.

You can sometimes get the best of both worlds—flexible growth and convenient element access—with the following trick. First, make an array list and add all the elements:

```
var list = new ArrayList<X>();
while (. . .)
{
  x = . . .;
  list.add(x);
}
```

When you are done, use the `toArray` method to copy the elements into an array:

```
var a = new X[list.size()];
list.toArray(a);
```

Sometimes, you need to add elements in the middle of an array list. Use the `add` method with an index parameter:

```
int n = staff.size() / 2;
staff.add(n, e);
```

The elements at locations `n` and above are shifted up to make room for the new entry. If the new size of the array list after the insertion exceeds the capacity, the array list reallocates its storage array.

Similarly, you can remove an element from the middle of an array list:

```
Employee e = staff.remove(n);
```

The elements located above it are copied down, and the size of the array is reduced by one.

Inserting and removing elements is not terribly efficient. It is probably not worth worrying about for small array lists. But if you store many elements and frequently insert and remove in the middle of a collection, consider using a linked list instead. I explain how to program with linked lists in Chapter 9.

You can use the "for each" loop to traverse the contents of an array list:

```
for (Employee e : staff)
   do something with e
```

This loop has the same effect as

```
for (int i = 0; i < staff.size(); i++)
{
   Employee e = staff.get(i);
   do something with e
}
```

Listing 5.7 is a modification of the `EmployeeTest` program of Chapter 4. The `Employee[]` array is replaced by an `ArrayList<Employee>`. Note the following changes:

- You don't have to specify the array size.
- You use `add` to add as many elements as you like.
- You use `size()` instead of `length` to count the number of elements.

- You use `a.get(i)` instead of `a[i]` to access an element.

Listing 5.7 `arrayList/ArrayListTest.java`

```java
package arrayList;

import java.util.*;

/**
 * This program demonstrates the ArrayList class.
 * @version 1.11 2012-01-26
 * @author Cay Horstmann
 */
public class ArrayListTest
{
   public static void main(String[] args)
   {
      // fill the staff array list with three Employee objects
      var staff = new ArrayList<Employee>();

      staff.add(new Employee("Carl Cracker", 75000, 1987, 12, 15));
      staff.add(new Employee("Harry Hacker", 50000, 1989, 10, 1));
      staff.add(new Employee("Tony Tester", 40000, 1990, 3, 15));

       // raise everyone's salary by 5%
       for (Employee e : staff)
          e.raiseSalary(5);

       // print out information about all Employee objects
       for (Employee e : staff)
          System.out.println("name=" + e.getName() + ",salary=" + e.getSalary() + ",hireDay="
             + e.getHireDay());
  }
}
```

java.util.ArrayList<E> 1.2

- `E set(int index, E obj)`

  puts the value `obj` in the array list at the specified index, returning the previous contents.

- `E get(int index)`

  gets the value stored at a specified index.

- `void add(int index, E obj)`

  shifts up elements to insert `obj` at the specified index.

- `E remove(int index)`

  removes the element at the given index and shifts down all elements above it. The removed element is returned.

5.3.3 Compatibility between Typed and Raw Array Lists

In your own code, you will always want to use type parameters for added safety. In this section, you will see how to interoperate with legacy code that does not use type parameters.

Suppose you have the following legacy class:

```
public class EmployeeDB
{
  public void update(ArrayList list) { . . . }
  public ArrayList find(String query) { . . . }
}
```

You can pass a typed array list to the `update` method without any casts.

```
ArrayList<Employee> staff = . . .;
employeeDB.update(staff);
```

The `staff` object is simply passed to the `update` method.

CAUTION:

Even though you get no error or warning from the compiler, this call is not completely safe. The `update` method might add elements into the array list that are not of type `Employee`. When these elements are retrieved, an exception occurs. This sounds scary, but if you think about it, the behavior is simply as it was before generics were added to Java. The integrity of the virtual machine is never jeopardized. In this situation, you do not lose security, but you also do not benefit from the compile-time checks.

Conversely, when you assign a raw `ArrayList` to a typed one, you get a warning.

```
ArrayList<Employee> result = employeeDB.find(query);// yields
warning
```

NOTE:

To see the text of the warning, compile with the option `-Xlint:unchecked`.

Using a cast does not make the warning go away.

```
ArrayList<Employee> result = (ArrayList<Employee>)
employeeDB.find(query);
   // yields another warning
```

Instead, you get a different warning, telling you that the cast is misleading.

This is the consequence of a somewhat unfortunate limitation of generic types in Java. For compatibility, the compiler translates all typed array lists into raw ArrayList objects after checking that the type rules were not violated. In a running program, all array lists are the same—there are no type parameters in the virtual machine. Thus, the casts (ArrayList) and (ArrayList<Employee>) carry out identical runtime checks.

There isn't much you can do about that situation. When you interact with legacy code, study the compiler warnings and satisfy yourself that the warnings are not serious.

Once you are satisfied, you can tag the variable that receives the cast with the @SuppressWarnings("unchecked") annotation, like this:

```
@SuppressWarnings("unchecked") ArrayList<Employee> result
      = (ArrayList<Employee>) employeeDB.find(query); // yields
another warning
```

5.4 Object Wrappers and Autoboxing

Occasionally, you need to convert a primitive type like int to an object. All primitive types have class counterparts. For example, a class Integer corresponds to the primitive type int. These kinds of classes are usually called *wrappers*. The wrapper classes have obvious names: Integer, Long, Float, Double, Short, Byte, Character, and Boolean. (The first six inherit from the common superclass Number.) The wrapper classes are immutable—you cannot change a wrapped value after the wrapper has been constructed. They are also final, so you cannot subclass them.

Suppose we want an array list of integers. Unfortunately, the type parameter inside the angle brackets cannot be a primitive type. It is not possible to form an ArrayList<**int**>. Here, the Integer wrapper class comes in. It is OK to declare an array list of Integer objects.

```
var list = new ArrayList<Integer>();
```

CAUTION:

An `ArrayList<Integer>` is far less efficient than an `int[]` array because each value is separately wrapped inside an object. You would only want to use this construct for small collections when programmer convenience is more important than efficiency.

Fortunately, there is a useful feature that makes it easy to add an element of type `int` to an `ArrayList<Integer>`. The call

```
list.add(3);
```

is automatically translated to

```
list.add(Integer.valueOf(3));
```

This conversion is called *autoboxing*.

NOTE:

You might think that *autowrapping* would be more consistent, but the “boxing” metaphor was taken from C#.

Conversely, when you assign an `Integer` object to an `int` value, it is automatically unboxed. That is, the compiler translates

```
int n = list.get(i);
```

into

```
int n = list.get(i).intValue();
```

Automatic boxing and unboxing even works with arithmetic expressions. For example, you can apply the increment operator to a wrapper reference:

```
Integer n = 3;
n++;
```

The compiler automatically inserts instructions to unbox the object, increment the resulting value, and box it back.

In most cases, you get the illusion that the primitive types and their wrappers are one and the same. There is just one point in which they differ considerably: identity. As you know, the == operator, applied to wrapper objects, only tests whether the objects have identical memory locations. The following comparison would therefore probably fail:

```
Integer a = 1000;
Integer b = 1000;
if (a == b) . . .
```

However, a Java implementation *may*, if it chooses, wrap commonly occurring values into identical objects, and thus the comparison might succeed. This ambiguity is not what you want. The remedy is to call the `equals` method when comparing wrapper objects.

NOTE:

The autoboxing specification requires that `boolean`, `byte`, `char` <= `127`, `short`, and `int` between `-128` and `127` are wrapped into fixed objects. For example, if `a` and `b` had been initialized with `100` in the preceding example, then the comparison would have had to succeed.

TIP:

Never rely on the identity of wrapper objects. Don't compare them with `==` and don't use them as locks (see Chapter 14).

Don't use the wrapper class constructors. They are deprecated and scheduled for removal. For example, use `Integer.valueOf(1000)`, never `new Integer(1000)`. Or, simply rely on auto-boxing: `Integer a = 1000`.

There are a couple of other subtleties about autoboxing. First off, since wrapper class references can be `null`, it is possible for autounboxing to throw a `NullPointerException`:

```
Integer n = null;
System.out.println(2 * n); // throws NullPointerException
```

Also, if you mix `Integer` and `Double` types in a conditional expression, then the `Integer` value is unboxed, promoted to `double`, and boxed into a `Double`:

```
Integer n = 1;
Double x = 2.0;
System.out.println(true ? n : x); // prints 1.0
```

Finally, let us emphasize that boxing and unboxing is a courtesy of the *compiler*, not the virtual machine. The compiler inserts the necessary calls when it generates the bytecodes of a class. The virtual machine simply executes those bytecodes.

NOTE:

A future version of Java will allow user-defined types that are like primitive types—with values that are not stored inside objects. For example, a value of a primitive type `Point` with `double` fields `x` and `y` is simply a 16-byte block in memory, with two adjacent `double` values. You can copy it, but you can't have a reference to it.

If you need a reference, use an automatically generated companion class (named `Point.ref` in current proposals). Boxing and unboxing is automatic, as with primitive types today.

At some point, the primitive wrapper classes will be unified with those classes. For example, `Double` will be an alias for `double.ref`.

You will often see the number wrappers for another reason. The designers of Java found the wrappers a convenient place to put certain basic methods, such as those for converting strings of digits to numbers.

To convert a string to an integer, use the following statement:

```
int x = Integer.parseInt(s);
```

This has nothing to do with `Integer` objects—`parseInt` is a static method. But the `Integer` class was a good place to put it.

The API notes show some of the more important methods of the `Integer` class. The other number classes implement corresponding methods.

CAUTION:

Some people think that the wrapper classes can be used to implement methods that can modify numeric parameters. However, that is not correct. Recall from Chapter 4 that it is impossible to write a Java method that increments an integer parameter because parameters to Java methods are always passed by value.

```
public static void triple(int x) // won't work
{
  x = 3 * x; // modifies local variable
}
```

Could we overcome this by using an `Integer` instead of an int?

```
public static void triple(Integer x) // won't work
{
  . . .
}
```

The problem is that `Integer` objects are *immutable*: The information contained inside the wrapper can't change. You cannot use these wrapper classes to create a method that modifies numeric parameters.

`java.lang.Integer` 1.0

- `int intValue()`

  returns the value of this `Integer` object as an `int` (overrides the `intValue` method in the `Number` class).

- `static String toString(int i)`

  returns a new `String` object representing the number `i` in base 10.

- `static String toString(int i, int radix)`

  lets you return a representation of the number `i` in the base specified by the `radix` parameter.

- `static int parseInt(String s)`
- `static int parseInt(String s, int radix)`

  returns the integer whose digits are contained in the string `s`. The string must represent an integer in base 10 (for the first method) or in the base given by the `radix` parameter (for the second method).

- `static Integer valueOf(String s)`
- `static Integer valueOf(String s, int radix)`

returns a new `Integer` object initialized to the integer whose digits are contained in the string `s`. The string must represent an integer in base 10 (for the first method) or in the base given by the `radix` parameter (for the second method).

`java.text.NumberFormat` 1.1

- `Number parse(String s)`

  returns the numeric value, assuming the specified `String` represents a number.

5.5 Methods with a Variable Number of Parameters

It is possible to provide methods that can be called with a variable number of parameters. (These are sometimes called "varargs" methods.)

You have already seen such a method: `printf`. For example, the calls

```
System.out.printf("%d", n);
```

and

```
System.out.printf("%d %s", n, "widgets");
```

both call the same method, even though one call has two parameters and the other has three.

The `printf` method is defined like this:

```
public class PrintStream
{
  public PrintStream printf(String fmt, Object... args)
  {
```

```
        return format(fmt, args);
      }
    }
```

Here, the ellipsis `...` is part of the Java code. It denotes that the method can receive an arbitrary number of objects (in addition to the `fmt` parameter).

The `printf` method actually receives two parameters: the format string and an `Object[]` array that holds all other parameters. (If the caller supplies integers or other primitive type values, autoboxing turns them into objects.) It now faces the unenviable task of scanning the `fmt` string and matching up the `i`th format specifier with the value `args[i]`.

In other words, for the implementor of `printf`, the `Object...` parameter type is exactly the same as `Object[]`.

The compiler needs to transform each call to `printf`, bundling the parameters into an array and autoboxing as necessary:

```
System.out.printf("%d %s", new Object[] { Integer.valueOf(n),
"widgets" } );
```

You can define your own methods with variable parameters, and you can specify any type for the parameters, even a primitive type. Here is a simple example: a function that computes the maximum of a variable number of values.

```
public static double max(double... values)
{
  double largest = Double.NEGATIVE_INFINITY;
  for (double v : values) if (v > largest) largest = v;
  return largest;
}
```

Simply call the function like this:

```
double m = max(3.1, 40.4, -5);
```

The compiler passes a `new double[] { 3.1, 40.4, -5 }` to the `max` function.

NOTE:

It is legal to pass an array as the last parameter of a method with variable parameters. For example:

```
System.out.printf("%d %s", new Object[] { Integer.valueOf(1),
"widgets" } );
```

Therefore, you can redefine an existing function whose last parameter is an array to a method with variable parameters, without breaking any existing code. For example, `MessageFormat.format` was enhanced in this way in Java 5. If you like, you can even declare the `main` method as

```
public static void main(String... args)
```

5.6 Abstract Classes

As you move up the inheritance hierarchy, classes become more general and probably more abstract. At some point, the ancestor class becomes *so* general that you think of it more as a basis for other classes than as a class with specific instances you want to use. Consider, for example, an extension of our `Employee` class hierarchy. An employee is a person, and so is a student. Let us extend our class hierarchy to include classes `Person` and `Student`. Figure 5.2 shows the inheritance relationships between these classes.

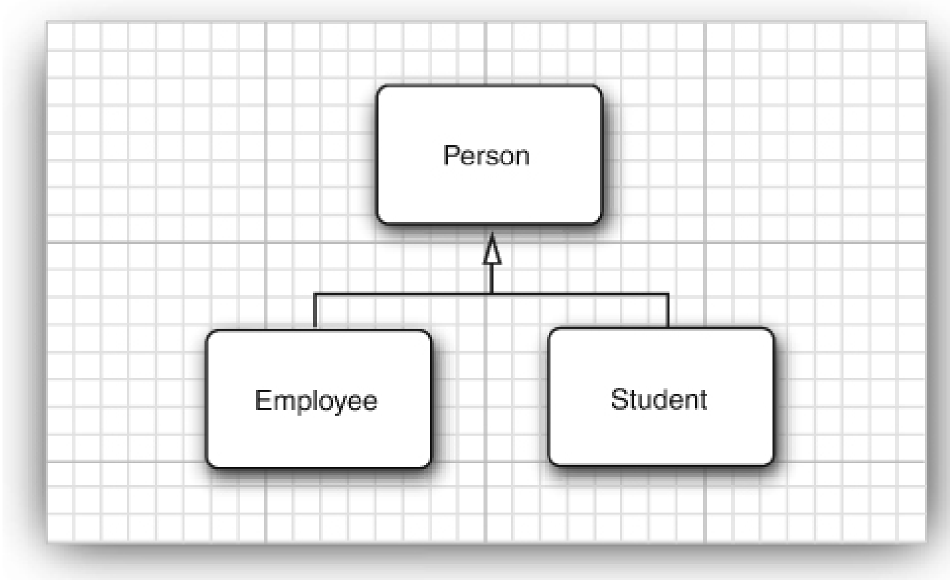


Figure 5.2 Inheritance diagram for `Person` and its subclasses

Why bother with so high a level of abstraction? There are some attributes that make sense for every person, such as a name. Both students and employees have names, and introducing a common superclass lets us factor out the `getName` method to a higher level in the inheritance hierarchy.

Now let's add another method, `getDescription`, whose purpose is to return a brief description of the person, such as

```
an employee with a salary of $50,000.00
a student majoring in computer science
```

It is easy to implement this method for the `Employee` and `Student` classes. But what information can you provide in the `Person` class? The `Person` class knows nothing about the person except the name. Of course, you could implement `Person.getDescription()` to return an empty string. But there is a better way. If you use the `abstract` keyword, you do not need to implement the method at all.

```
public abstract String getDescription();
    // no implementation required
```

For added clarity, a class with one or more abstract methods must itself be declared abstract.

```
public abstract class Person
{
  . . .
  public abstract String getDescription();
}
```

In addition to abstract methods, abstract classes can have fields and concrete methods. For example, the `Person` class stores the name of the person and has a concrete method that returns it.

```
public abstract class Person
{
  private String name;
  public Person(String name)
  {
     this.name = name;
  }
  public abstract String getDescription();
  public String getName()
  {
     return name;
  }
}
```

TIP:

Some programmers don't realize that abstract classes can have concrete methods. You should always move common fields and methods (whether abstract or not) to the superclass (whether abstract or not).

Abstract methods act as placeholders for methods that are implemented in the subclasses. When you extend an abstract class, you have two choices. You can leave some or all of the abstract methods undefined; then, you must tag the subclass as abstract as well. Or, you can define all methods, and the subclass is no longer abstract.

For example, we will define a `Student` class that extends the abstract `Person` class and implements the `getDescription` method. None of the methods of the `Student` class are abstract, so it does not need to be declared as an abstract class.

A class can even be declared as `abstract` though it has no abstract methods.

Abstract classes cannot be instantiated. That is, if a class is declared as `abstract`, no objects of that class can be created. For example, the expression

```
new Person("Vince Vu")
```

is an error. However, you can create objects of concrete subclasses.

Note that you can still create *object variables* of an abstract class, but such a variable must refer to an object of a nonabstract subclass. For example:

```
Person p = new Student("Vince Vu", "Economics");
```

Here `p` is a variable of the abstract type `Person` that refers to an instance of the nonabstract subclass `Student`.

C++ NOTE:

In C++, an abstract method is called a *pure virtual function* and is tagged with a trailing `= 0`, such as in

```
class Person // C++
{
```

```
public:
   virtual string getDescription() = 0;
   . . .
};
```

A C++ class is abstract if it has at least one pure virtual function. In C++, there is no special keyword to denote abstract classes.

Let us define a concrete subclass `Student` that extends the abstract class `Person`:

```
public class Student extends Person
{
  private String major;
  public Student(String name, String major)
  {
     super(name);
     this.major = major;
  }
  public String getDescription()
  {
     return "a student majoring in " + major;
  }
}
```

The `Student` class defines the `getDescription` method. Therefore, all methods in the `Student` class are concrete, and the class is no longer an abstract class.

The program shown in Listing 5.8 defines the abstract superclass `Person` (Listing 5.9) and two concrete subclasses, `Employee` (Listing 5.10) and `Student` (Listing 5.11). We fill an array of `Person` references with employee and student objects:

```
var people = new Person[2];
people[0] = new Employee(. . .);
```

```
people[1] = new Student(. . .);
```

We then print the names and descriptions of these objects:

```
for (Person p : people)
   System.out.println(p.getName() + ", " + p.getDescription());
```

Some people are baffled by the call

```
p.getDescription()
```

Isn't this a call to an undefined method? Keep in mind that the variable `p` never refers to a `Person` object because it is impossible to construct an object of the abstract `Person` class. The variable `p` always refers to an object of a concrete subclass such as `Employee` or `Student`. For these objects, the `getDescription` method is defined.

Could you have omitted the abstract method altogether from the `Person` super-class, simply defining the `getDescription` methods in the `Employee` and `Student` sub-classes? If you did that, you wouldn't have been able to invoke the `getDescription` method on the variable `p`. The compiler ensures that you invoke only methods that are declared in the class.

Abstract methods are an important concept in the Java programming language. You will encounter them most commonly inside *interfaces*. For more information about interfaces, turn to Chapter 6.

Listing 5.8 `abstractClasses/PersonTest.java`

```
package abstractClasses;

/**
 * This program demonstrates abstract classes.
 * @version 1.01 2004-02-21
 * @author Cay Horstmann
 */
public class PersonTest
```

```java
{
    public static void main(String[] args)
    {
        var people = new Person[2];

        // fill the people array with Student and Employee objects
        people[0] = new Employee("Harry Hacker", 50000, 1989, 10, 1);
        people[1] = new Student("Maria Morris", "computer science");

        // print out names and descriptions of all Person objects
        for (Person p : people)
            System.out.println(p.getName() + ", " + p.getDescription());
    }
}
```

Listing 5.9 `abstractClasses/Person.java`

```java
package abstractClasses;

public abstract class Person
{
   public abstract String getDescription();
   private String name;

   public Person(String name)
   {
      this.name = name;
   }

   public String getName()
   {
      return name;
```

```
   }
}
```

Listing 5.10 `abstractClasses/Employee.java`

```
package abstractClasses;

import java.time.*;

public class Employee extends Person
{
   private double salary;
   private LocalDate hireDay;

   public Employee(String name, double salary, int year, int month, int day)
   {
      super(name);
      this.salary = salary;
      hireDay = LocalDate.of(year, month, day);
   }

   public double getSalary()
   {
      return salary;
   }

   public LocalDate getHireDay()
   {
      return hireDay;
   }

   public String getDescription()
   {
      return "an employee with a salary of $%.2f".formatted(salary);
   }

```

```
    public void raiseSalary(double byPercent)
    {
       double raise = salary * byPercent / 100;
       salary += raise;
    }
 }
```

Listing 5.11 `abstractClasses/Student.java`

```
package abstractClasses;

public class Student extends Person
{
   private String major;

  /**
  * @param name the student's name
  * @param major the student's major
  */
  public Student(String name, String major)
  {
     // pass name to superclass constructor
     super(name);
     this.major = major;
  }

  public String getDescription()
  {
     return "a student majoring in " + major;
  }
}
```

5.7 Enumeration Classes

You saw in Chapter 3 how to define enumerated types. Here is a typical example:

```
public enum Size { SMALL, MEDIUM, LARGE, EXTRA_LARGE }
```

The type defined by this declaration is actually a class. The class has exactly four instances—it is not possible to construct new objects.

Therefore, you never need to use `equals` for values of enumerated types. Simply use == to compare them.

You can, if you like, add constructors, methods, and fields to an enumerated type. Of course, the constructors are only invoked when the enumerated constants are constructed. Here is an example:

```
public enum Size
{
   SMALL("S"), MEDIUM("M"), LARGE("L"), EXTRA_LARGE("XL");
   private String abbreviation;
   Size(String abbreviation) { this.abbreviation =
abbreviation; }
       // automatically private
   public String getAbbreviation() { return abbreviation; }
}
```

The constructor of an enumeration is always private. You can omit the `private` modifier, as in the preceding example. It is a syntax error to declare an enum constructor as `public` or `protected`.

All enumerated types are subclasses of the abstract class `Enum`. They inherit a number of methods from that class. The most useful one is `toString`, which returns the name of the enumerated constant. For example, `Size.SMALL.toString()` returns the string `"SMALL"`.

The converse of `toString` is the static `valueOf` method. For example, the statement

```
Size s = Enum.valueOf(Size.class, "SMALL");
```

sets `s` to `Size.SMALL`.

Each enumerated type has a static values method that returns an array of all values of the enumeration. For example, the call

```
Size[] values = Size.values();
```

returns the array with elements Size.SMALL, Size.MEDIUM, Size.LARGE, and Size.EXTRA_LARGE.

The ordinal method yields the position of an enumerated constant in the enum declaration, counting from zero. For example, Size.MEDIUM.ordinal() returns 1.

The short program in Listing 5.12 demonstrates how to work with enumerated types.

NOTE:

The Enum class has a type parameter that I have ignored for simplicity. For example, the enumerated type Size actually extends Enum<Size>. The type parameter is used in the compareTo method. (I discuss the compareTo method in Chapter 6 and type parameters in Chapter 8.)

Listing 5.12 enums/EnumTest.java

```
package enums;

import java.util.*;

/**
 * This program demonstrates enumerated types.
 * @version 1.0 2004-05-24
 * @author Cay Horstmann
 */
public class EnumTest
{
```

```java
    public static void main(String[] args)
    {
        var in = new Scanner(System.in);
        System.out.print("Enter a size: (SMALL, MEDIUM, LARGE, EXTRA_LARGE) ");
        String input = in.next().toUpperCase();
        Size size = Enum.valueOf(Size.class, input);
        System.out.println("size=" + size);
        System.out.println("abbreviation=" + size.getAbbreviation());
        if (size == Size.EXTRA_LARGE)
           System.out.println("Good job--you paid attention to the _.");
   }
}

enum Size
{
   SMALL("S"), MEDIUM("M"), LARGE("L"), EXTRA_LARGE("XL");

   private Size(String abbreviation) { this.abbreviation = abbreviation; }
   public String getAbbreviation() { return abbreviation; }

   private String abbreviation;
}
```

java.lang.Enum<E> 5

- `static Enum valueOf(Class enumClass, String name)`

  returns the enumerated constant of the given class with the given name.

- `String toString()`

  returns the name of this enumerated constant.

- `int ordinal()`

returns the zero-based position of this enumerated constant in the `enum` declaration.

- `int compareTo(E other)`

  returns a negative integer if this enumerated constant comes before `other`, zero if `this == other`, and a positive integer otherwise. The ordering of the constants is given by the `enum` declaration.

5.8 Sealed Classes

Unless a class is declared final, anyone can form a subclass of it. What if you want to have more control? For example, suppose you need to write your own JSON library because none of the existing ones does exactly what you need.

The JSON standard says that a JSON value is an array, number, string, Boolean value, object, or null. An obvious approach is to model this with classes `JSONArray`, `JSONNumber`, and so on that extend an abstract class `JSONValue`:

```
public abstract class JSONValue
{
  // Methods that apply to all JSON values
}
public final class JSONArray extends JSONValue
{
  . . .
}
public final class JSONNumber extends JSONValue
{
  . . .
}
```

By declaring the classes `JSONArray`, `JSONNumber`, and so on as `final`, we can ensure that nobody forms a subclass. But we cannot stop anyone from forming another subclass of `JSONValue`.

Why might we want that control? Consider this code:

```
JSONValue v = . . .;
if (v instanceof JSONArray a) . . .
else if (v instanceof JSONNumber n) . . .
else if (v instanceof JSONString s) . . .
else if (v instanceof JSOBoolean b) . . .
else if (v instanceof JSONObject o) . . .
else . . . // Must be JSONNull
```

Here, the control flow implies that we know all direct subclasses of `JSONValue`. This is not an open-ended hierarchy. The JSON standard won't change; if it does, we as the library implementors will add a seventh subclass. We don't want anyone else out there mess with the class hierarchy.

In Java, a *sealed* class controls which classes may inherit from it. Sealed classes were added as a preview feature in Java 15 and finalized in Java 17.

Here is how to declare the `JSONValue` class as sealed:

```
public abstract sealed class JSONValue
   permits JSONArray, JSONNumber, JSONString, JSONBoolean,
JSONObject, JSONNull
{
   . . .
}
```

It is an error to define a non-permitted subclass:

```
public class JSONComment extends JSONValue { . . . } // Error
```

That's just as well, since JSON doesn't allow for comments. Sealed classes thus allow for accurate modeling of domain constraints.

The permitted subclasses of a sealed class must be accessible. They cannot be private classes that are nested in another class, or package-visible classes from another package.

For permitted subclasses that are public, the rules are more stringent. They must be in the same package as the sealed class. However, if you use modules (see Chapter 9 of Volume II), then they must only be in the same module.

NOTE:

A sealed class can be declared without a `permits` clause. Then all of its direct subclasses must be declared in the same file. Programmers without access to that file cannot form subclasses.

A file can have at most one `public` class, so this arrangement appears to be only useful if the subclasses are not for use by the public.

However, as you will see in the next chapter, you can use inner classes as public subclasses.

An important motivation for sealed classes is compile-time checking. Consider this method of the `JSONValue` class, which uses a `switch` expression with pattern matching (a preview feature in Java 17):

```
public String type()
{
   return switch (this)
   {
      case JSONArray j -> "array";
      case JSONNumber j -> "number";
      case JSONString j -> "string";
      case JSONBoolean j -> "boolean";
      case JSONObject j -> "object";
      case JSONNull j -> "null";
      // No default needed here
   };
}
```

The compiler can check that no `default` clause is needed since all direct subclasses of `JSONValue` occur as cases.

NOTE:

The preceding `type` method doesn't look very object-oriented. It would be in the spirit of OOP to have each of the six classes provide its own `type` method, relying on polymorphism instead of a switch. For an open-ended hierarchy, that is a good approach. But when there is a fixed set of classes, it is often more convenient to have all alternatives in one method.

At first glance, it appears as if a subclass of a sealed class must be final. But for exhaustiveness testing, we only need to know all direct subclasses. It is not a problem if those classes have further subclasses. For example, we can reorganize our JSON hierarchy as shown in Figure 5.3.

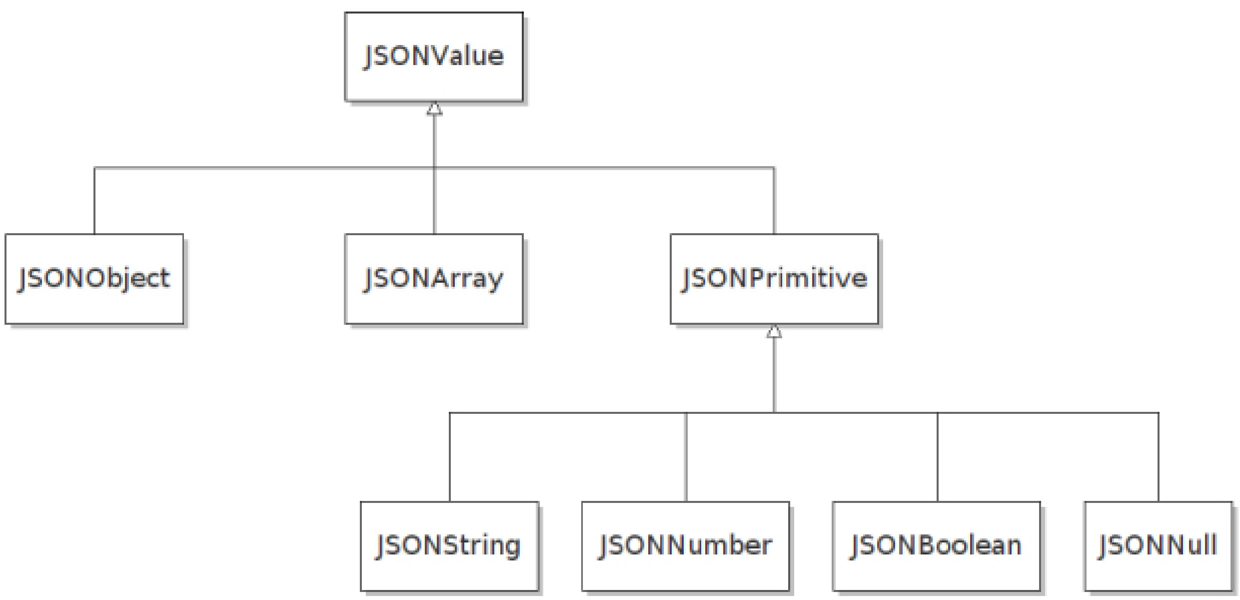


Figure 5.3 The complete hierarchy of classes for representing JSON values

In this hierarchy, `JSONValue` permits three subclasses:

```
public abstract sealed class JSONValue permits JSONObject,
JSONArray, JSONPrimitive
{
  . . .
}
```

The `JSONPrimitive` class is sealed as well:

```
public abstract sealed class JSONPrimitive extends JSONValue
      permits JSONString, JSONNumber, JSONBoolean, JSONNull
{
  . . .
}
```

A subclass of a sealed class must specify whether it is `sealed`, `final`, or open for subclassing. In the latter case, it must be declared as `non-sealed`.

NOTE:

The `non-sealed` keyword is the first Java keyword with a hyphen. This may well be a future trend. Adding keywords to the language always comes with a risk. Existing code may no longer compile. For that reason, `sealed` is a "contextual" keyword. You can still declare variables or methods named `sealed`:

```
int sealed = 1; // OK to use contextual keyword as identifier
```

With a hyphenated keyword, one doesn't have to worry about this. The only ambiguity is with subtraction:

```
int non = 0;
non = non-sealed; // Subtraction, not keyword
```

Why would you ever want a `non-sealed` subclass? Consider an XML node class with six direct subclasses:

```
public abstract sealed class Node permits Element, Text,
Comment,
      CDATASection, EntityReference, ProcessingInstruction
{
  . . .
}
```

We allow arbitrary subclasses of `Element`:

```
public non-sealed class Element extends Node
{
  . . .
}
public class HTMLDivElement extends Element
{
  . . .
}
```

In this section, you learned about sealed *classes*. In the next chapter, you will learn about *interfaces*, a generalization of abstract classes. Java interfaces can also have subtypes. Sealed interfaces work exactly the same as sealed classes, controlling the direct subtypes.

The following sample program fleshes out the JSON hierarchy. The implementation of `JSONObject` uses a `HashMap`, which will be covered in Chapter 9. In the example, we use interfaces instead of abstract classes so that `JSONNumber` and `JSONString` can be records and the `JSONBoolean` and `JSONNull` classes can be enumerations. Records and enumerations can implement interfaces, but they cannot extend classes.

Listing 5.13 `sealed/SealedTest.java`

```
package sealed;

```

```java
import java.util.*;

sealed interface JSONValue permits JSONArray, JSONObject, JSONPrimitive
{
   public default String type()
   {
       if (this instanceof JSONArray) return "array";
       else if (this instanceof JSONObject) return "object";
       else if (this instanceof JSONNumber) return "number";
       else if (this instanceof JSONString) return "string";
       else if (this instanceof JSONBoolean) return "boolean";
       else return "null";
    }
}

final class JSONArray extends ArrayList<JSONValue>  implements JSONValue {}

final class JSONObject extends HashMap<String, JSONValue> implements JSONValue
{
    public String toString()
    {
       StringBuilder result = new StringBuilder();
       result.append("{");
       for (Map.Entry<String, JSONValue> entry : entrySet())
       {
          if (result.length() > 1) result.append(",");
          result.append(" \"");
          result.append(entry.getKey());
          result.append("\": ");
          result.append(entry.getValue());
       }
       result.append(" }");
       return result.toString();
    }
}
```

```
sealed interface JSONPrimitive extends JSONValue
       permits JSONNumber, JSONString, JSONBoolean, JSONNull
{
}

final record JSONNumber(double value) implements JSONPrimitive
{
   public String toString() { return "" + value; }
}

final record JSONString(String value) implements JSONPrimitive
{
 public String toString() { return "\"" + value.translateEscapes() + "\""; }
}

enum JSONBoolean implements JSONPrimitive
{
   FALSE, TRUE;
   public String toString() { return super.toString().toLowerCase(); }
}

enum JSONNull implements JSONPrimitive
{
   INSTANCE;
   public String toString() { return "null"; }
}

public class SealedTest
{
   public static void main(String[] args)
   {
      JSONObject obj = new JSONObject();
      obj.put("name", new JSONString("Harry"));
      obj.put("salary", new JSONNumber(90000));
      obj.put("married", JSONBoolean.FALSE);
      JSONArray arr = new JSONArray();
      arr.add(new JSONNumber(13));
```

```
      arr.add(JSONNull.INSTANCE);

      obj.put("luckyNumbers", arr);
      System.out.println(obj);
      System.out.println(obj.type());
 }
}
```

5.9 Reflection

The *reflection library* gives you a very rich and elaborate toolset to write programs that manipulate Java code dynamically. Using reflection, Java can support user interface builders, object-relational mappers, and many other development tools that dynamically inquire about the capabilities of classes.

A program that can analyze the capabilities of classes is called *reflective*. The reflection mechanism is extremely powerful. As the next sections show, you can use it to

- Analyze the capabilities of classes at runtime
- Inspect objects at runtime—for example, to write a single `toString` method that works for *all* classes
- Implement generic array manipulation code
- Take advantage of `Method` objects that work just like function pointers in languages such as C++

Reflection is a powerful and complex mechanism; however, it is of interest mainly to tool builders, not application programmers. If you are interested in programming applications rather than tools for other Java programmers, you can safely skip the remainder of this chapter and return to it later.

5.9.1 The `Class` Class

While your program is running, the Java runtime system always maintains what is called *runtime type identification* on all objects. This information keeps track of the class to which each object belongs. Runtime type information is used by the virtual machine to select the correct methods to execute.

However, you can also access this information by working with a special Java class. The class that holds this information is called, somewhat confusingly, `Class`. The `getClass()` method in the `Object` class returns an instance of `Class` type.

```
Employee e; . . .
Class cl = e.getClass();
```

Just like an `Employee` object describes the properties of a particular employee, a `Class` object describes the properties of a particular class. Probably the most commonly used method of `Class` is `getName`. This returns the name of the class. For example, the statement

```
System.out.println(e.getClass().getName() + " " + e.getName());
```

prints

```
Employee Harry Hacker
```

if `e` is an employee, or

```
Manager Harry Hacker
```

if `e` is a manager.

If the class is in a package, the package name is part of the class name:

```
var generator = new Random();
Class cl = generator.getClass();
String name = cl.getName(); // name is set to
"java.util.Random"
```

You can obtain a Class object corresponding to a class name by using the static forName method.

```
String className = "java.util.Random";
Class cl = Class.forName(className);
```

Use this method if the class name is stored in a string that varies at runtime. This works if className is the name of a class or interface. Otherwise, the forName method throws a *checked exception*. See Section 5.9.2, “A Primer on Declaring Exceptions,” on p. 283 for how to supply an *exception handler* whenever you use this method.

A third method for obtaining an object of type Class is a convenient shorthand. If T is any Java type (or the void keyword), then T.class is the matching class object. For example:

```
Class cl1 = Random.class; // if you import java.util.*;
Class cl2 = int.class;
Class cl3 = Double[].class;
```

Note that a Class object really describes a *type*, which may or may not be a class. For example, int is not a class, but int.class is nevertheless an object of type Class.

NOTE:

The Class class is actually a generic class. For example, Employee.class is of type Class<Employee>. I’m not dwelling on this issue because it would further complicate an already abstract concept. For most practical purposes, you can ignore the type parameter and work with the raw Class type. See Chapter 8 for more information on this issue.

CAUTION:

For historical reasons, the `getName` method returns somewhat strange names for array types:

- `Double[].class.getName()` returns `"[Ljava.lang.Double;"`.
- `int[].class.getName()` returns `"[I"`.

The virtual machine manages a unique `Class` object for each type. Therefore, you can use the == operator to compare class objects. For example:

```
if (e.getClass() == Employee.class) . . .
```

This test passes if `e` is an instance of `Employee`. Unlike the condition `e instanceof Employee`, this test fails if `e` is an instance of a subclass such as `Manager`.

If you have an object of type `Class`, you can use it to construct instances of the class. Call the `getConstructor` method to get an object of type `Constructor`, then use the `newInstance` method to construct an instance. For example:

```
var className = "java.util.Random"; // or any other name of a
class with
                                  // a no-arg constructor
Class cl = Class.forName(className);
Object obj = cl.getConstructor().newInstance();
```

If the class doesn't have a constructor without arguments, the `getConstructor` method throws an exception. You will see in Section 5.9.7, "Invoking Arbitrary Methods and Constructors," on p. 304 how to invoke other constructors.

NOTE:

There is a deprecated `Class.toInstance` method that also constructs an instance with the no-argument constructor. However, if the constructor throws a checked exception, the exception is rethrown without being checked. This violates the compile-time checking of exceptions. In contrast, `Constructor. newInstance` wraps any constructor exception into an `InvocationTargetException`.

C++ NOTE:

The `newInstance` method corresponds to the idiom of a *virtual constructor* in C++. However, virtual constructors in C++ are not a language feature but just an idiom that needs to be supported by a specialized library. The `Class` class is similar to the `type_info` class in C++, and the `getClass` method is equivalent to the `typeid` operator. The Java `Class` is quite a bit more versatile than `type_info`, though. The C++ `type_info` can only reveal a string with the name of the type, not create new objects of that type.

`java.lang.Class` 1.0

- `static Class forName(String className)`

  returns the `Class` object representing the class with name `className`.

- `Constructor getConstructor(Class... parameterTypes)` 1.1

  yields an object describing the constructor with the given parameter types. See Section 5.9.7, "Invoking Arbitrary Methods and Constructors," on p. 304 for more information on how to supply parameter types.

`java.lang.reflect.Constructor` 1.1

- `Object newInstance(Object... params)`

  constructs a new instance of the constructor's declaring class, passing `params` to the constructor. See Section 5.9.7, "Invoking Arbitrary Methods and Constructors," on p. 304 for more information on how to supply parameters.

`java.lang.Throwable` 1.0

- `void printStackTrace()`

  prints the `Throwable` object and the stack trace to the standard error stream.

5.9.2 A Primer on Declaring Exceptions

I cover exception handling fully in Chapter 7, but in the meantime you will occasionally encounter methods that threaten to throw exceptions.

When an error occurs at runtime, a program can "throw an exception." Throwing an exception is more flexible than terminating the program because you can provide a *handler* that "catches" the exception and deals with it.

If you don't provide a handler, the program terminates and prints a message to the console, giving the type of the exception. You may have already seen exception reports when you accidentally used a `null` reference or overstepped the bounds of an array.

There are two kinds of exceptions: *unchecked* exceptions and *checked* exceptions. With checked exceptions, the compiler checks that you, the programmer, are aware of the exception and are prepared to deal with the consequences. However, many common exceptions, such as bounds errors, or accessing a null reference, are unchecked. The compiler does not expect that you provide a handler—after all, you should spend your mental energy on avoiding these mistakes rather than coding handlers for them.

But not all errors are avoidable. If an exception can occur despite your best efforts, then most Java APIs will throw a checked exception. One example is the `Class.forName` method. There is no way for you to ensure that a class with the given name exists. In Chapter 7, you will see several strategies for exception handling. For now, I just show you the simplest strategy.

Whenever a method contains a statement that might throw a checked exception, add a `throws` clause to the method name.

```
public static void doSomethingWithClass(String name)
      throws ReflectiveOperationException
{
   Class cl = Class.forName(name); // might throw exception
   do something with cl
}
```

Any method that calls this method also needs a `throws` declaration. This includes the `main` method. If an exception actually occurs, the `main` method terminates with a stack trace. (You will learn in Chapter 7 how to catch exceptions instead of having them terminate your programs.)

You only need to supply a `throws` clause for checked exceptions. It is easy to find out which methods throw checked exceptions—the compiler will complain whenever you call a method that threatens to throw a checked exception and you don't supply a handler.

5.9.3 Resources

Classes often have associated data files, such as:

- Image and sound files
- Text files with message strings and button labels

In Java, such an associated file is called a *resource*.

For example, consider a dialog box that displays a message such as the one in Figure 5.4.

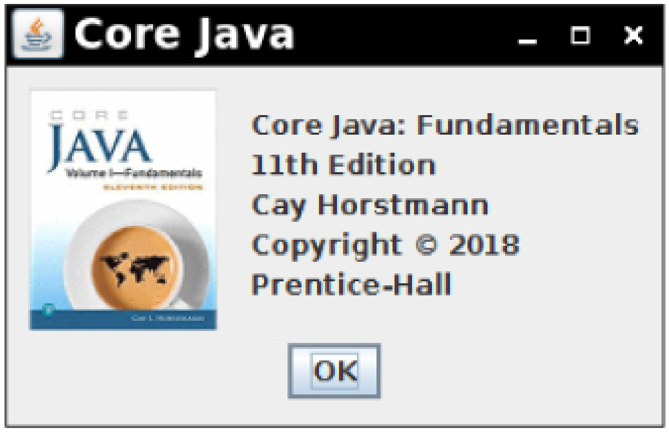


Figure 5.4 Displaying image and text resources

Of course, the book title and copyright year in the panel will change for the next edition of the book. To make it easy to track this change, we will put the text inside a file and not hardcode it as a string.

But where should you put a file such as `about.txt`? Of course, it would be convenient to simply place it with the rest of the program files inside a JAR file.

The `Class` class provides a useful service for locating resource files. Here are the necessary steps:

1. Get the `Class` object of the class that has a resource—for example, `ResourceTest.class`.
2. Some methods, such as the `getImage` method of the `ImageIcon` class, accept URLs that describe resource locations. Then you call

```
URL url = cl.getResource("about.gif");
```

3. Otherwise, use the `getResourceAsStream` method to obtain an input stream for reading the data in the file.

The point is that the Java virtual machine knows how to locate a class, so it can then search for the associated resource *in the same location*. For example, suppose the `ResourceTest` class is in a package `resources`. Then the `ResourceTest.class` file is located in a `resources` directory, and you place an icon file into the same directory.

Instead of placing a resource file inside the same directory as the class file, you can provide a relative or absolute path such as

```
data/about.txt
/corejava/title.txt
```

Automating the loading of files is all the resource loading feature does. There are no standard methods for interpreting the contents of resource files. Each program must have its own way of interpreting its resource files.

Another common application of resources is the internationalization of programs. Language-dependent strings, such as messages and user interface labels, are stored in resource files, with one file per language. The *internationalization API*, which is discussed in Chapter 7 of Volume II, supports a standard method for organizing and accessing these localization files.

Listing 5.13 is a program that demonstrates resource loading. (Do not worry about the code for reading text and displaying dialogs—we cover those details later.) Compile, build a JAR file, and execute it:

```
javac resource/ResourceTest.java
jar cvfe ResourceTest.jar resources.ResourceTest \
   resources/*.class resources/*.gif resources/data/*.txt
corejava/*.txt
java -jar ResourceTest.jar
```

Move the JAR file to a different directory and run it again to check that the program reads the resource files from the JAR file, not from the current directory.

Listing 5.14 resources/ResourceTest.java

```java
package resources;

import java.io.*;
import java.net.*;
import java.nio.charset.*;
import javax.swing.*;

/**
 * @version 1.5 2018-03-15
 * @author Cay Horstmann
 */
public class ResourceTest
{
   public static void main(String[] args) throws IOException
   {
     Class cl = ResourceTest.class;
     URL aboutURL = cl.getResource("about.gif");
     var icon = new ImageIcon(aboutURL);

     InputStream stream = cl.getResourceAsStream("data/about.txt");
     var about = new String(stream.readAllBytes(), "UTF-8");

     InputStream stream2 = cl.getResourceAsStream("/corejava/title.txt");
     var title = new String(stream2.readAllBytes(), StandardCharsets.UTF_8).strip();

     JOptionPane.showMessageDialog(
        null, about, title, JOptionPane.INFORMATION_MESSAGE, icon);
   }
}
```

java.lang.Class 1.0

- `URL getResource(String name)` **1.1**
- `InputStream getResourceAsStream(String name)` **1.1**

  finds the resource in the same place as the class and then returns a URL or input stream that you can use for loading the resource. Returns `null` if the resource isn't found, so does not throw an exception for an I/O error.

5.9.4 Using Reflection to Analyze the Capabilities of Classes

Here is a brief overview of the most important parts of the reflection mechanism for letting you examine the structure of a class.

The three classes `Field`, `Method`, and `Constructor` in the `java.lang.reflect` package describe the fields, methods, and constructors of a class, respectively. All three classes have a method called `getName` that returns the name of the item. The `Field` class has a method `getType` that returns an object, again of type `Class`, that describes the field type. The `Method` and `Constructor` classes have methods to report the types of the parameters, and the `Method` class also reports the return type. All three of these classes also have a method called `getModifiers` that returns an integer, with various bits turned on and off, that describes the modifiers used, such as `public` and `static`. You can then use the static methods in the `Modifier` class in the `java.lang.reflect` package to analyze the integer that `getModifiers` returns. Use methods like `isPublic`, `isPrivate`, or `isFinal` in the `Modifier` class to tell whether a method or constructor was `public`, `private`, or `final`. All you have to do is have the appropriate method in the `Modifier` class work on the integer that `getModifiers` returns. You can also use the `Modifier.toString` method to print the modifiers.

The `getFields`, `getMethods`, and `getConstructors` methods of the `Class` class return arrays of the *public* fields, methods, and constructors that the class supports. This includes public members of superclasses. The `getDeclaredFields`, `getDeclaredMethods`, and `getDeclaredConstructors` methods of the `Class` class return arrays consisting of all fields, methods, and constructors that are declared in the class. This includes private, package, and protected members, as well as members with package access, but not members of superclasses.

Listing 5.15 shows you how to print out all information about a class. The program prompts you for the name of a class and writes out the signatures of all methods and constructors as well as the names of all instance fields of a class. For example, if you enter

```
java.lang.Double
```

the program prints

```
public final class java.lang.Double extends java.lang.Number
{
   public java.lang.Double(double);
   public java.lang.Double(java.lang.String);
   public boolean equals(java.lang.Object);
   public static java.lang.String toString(double);
   public java.lang.String toString();
   public static int hashCode(double);
   public int hashCode();
   public static double min(double, double);
   public static double max(double, double);
   public static native long doubleToRawLongBits(double);
   public static long doubleToLongBits(double);
   public static native double longBitsToDouble(long);
   public int compareTo(java.lang.Double);
   public volatile int compareTo(java.lang.Object);
   public static int compare(double, double);
   public byte byteValue();
   public short shortValue();
   public int intValue();
   public long longValue();
   public float floatValue();
   public double doubleValue();
   public static java.lang.Double valueOf(java.lang.String);
   public static java.lang.Double valueOf(double);
   public static java.lang.String toHexString(double);
```

```
   public volatile java.lang.Object resolveConstantDesc(
     java.lang.invoke.MethodHandles$Lookup);
   public java.lang.Double
resolveConstantDesc(java.lang.invoke.MethodHandles$Lookup);
   public java.util.Optional describeConstable();
   public boolean isNaN();
   public static boolean isNaN(double);
   public static double sum(double, double);
   public boolean isInfinite();
   public static boolean isInfinite(double);
   public static boolean isFinite(double);
   public static double parseDouble(java.lang.String);
   public static final double POSITIVE_INFINITY;
   public static final double NEGATIVE_INFINITY;
   public static final double NaN;
   public static final double MAX_VALUE;
   public static final double MIN_NORMAL;
   public static final double MIN_VALUE;
   public static final int MAX_EXPONENT;
   public static final int MIN_EXPONENT;
   public static final int SIZE;
   public static final int BYTES;
   public static final java.lang.Class TYPE;
   private final double value;
   private static final long serialVersionUID;
}
```

What is remarkable about this program is that it can analyze any class that the Java interpreter can load, not just the classes that were available when the program was compiled. We will use this program in the next chapter to peek inside the inner classes that the Java compiler generates automatically.

Listing 5.15 `reflection/ReflectionTest.java`

```
package reflection;

import java.util.*;
import java.lang.reflect.*;
```

```java
/**
 * This program uses reflection to print all features of a class.
 * @version 1.12 2021-06-15
 * @author Cay Horstmann
 */
public class ReflectionTest
{
   public static void main(String[] args)
         throws ReflectiveOperationException
   {
      // read class name from command line args or user input
      String name;
      if (args.length > 0) name = args[0];
      else
      {
         var in = new Scanner(System.in);
         System.out.println("Enter class name (e.g. java.util.Date): ");
         name = in.next();
      }

      // print class modifiers, name and superclass name (if != Object)
      Class cl = Class.forName(name);
      String modifiers = Modifier.toString(cl.getModifiers());
      if (modifiers.length() > 0) System.out.print(modifiers + " ");
      if (cl.isSealed())
         System.out.print("sealed ");
      if (cl.isEnum())
         System.out.print("enum " + name);
      else if (cl.isRecord())
         System.out.print("record " + name);
      else if (cl.isInterface())
         System.out.print("interface " + name);
      else
         System.out.print("class " + name);
      Class supercl = cl.getSuperclass();
```

```java
        if (supercl != null && supercl != Object.class) System.out.print(" extends "
              + supercl.getName());

        printInterfaces(cl);
        printPermittedSubclasses(cl);

       System.out.print("\n{\n");
       printConstructors(cl);
       System.out.println();
       printMethods(cl);
       System.out.println();
       printFields(cl);
       System.out.println("}");
   }

   /**
   * Prints all constructors of a class
   * @param cl a class
   */
   public static void printConstructors(Class cl)
   {
     Constructor[] constructors = cl.getDeclaredConstructors();

     for (Constructor c : constructors)
     {
        String name = c.getName();
        System.out.print("   ");
        String modifiers = Modifier.toString(c.getModifiers());
        if (modifiers.length() > 0) System.out.print(modifiers + " ");
        System.out.print(name + "(");

        // print parameter types
        Class[] paramTypes = c.getParameterTypes();
        for (int j = 0; j < paramTypes.length; j++)
        {
           if (j > 0) System.out.print(", ");
           System.out.print(paramTypes[j].getName());
```

```
         }
         System.out.println(");");
      }
   }

   /**
   * Prints all methods of a class
   * @param cl a class
   */
   public static void printMethods(Class cl)
   {
      Method[] methods = cl.getDeclaredMethods();

      for (Method m : methods)
      {
         Class retType = m.getReturnType();
         String name = m.getName();

         System.out.print("  ");
         // print modifiers, return type and method name
         String modifiers = Modifier.toString(m.getModifiers());
         if (modifiers.length() > 0) System.out.print(modifiers
+ " ");
         System.out.print(retType.getName() + " " + name + "(");

         // print parameter types
         Class[] paramTypes = m.getParameterTypes();
         for (int j = 0; j < paramTypes.length; j++)
         {
            if (j > 0) System.out.print(", ");
            System.out.print(paramTypes[j].getName());
         }
         System.out.println(");");
      }
   }

   /**
   * Prints all fields of a class
   * @param cl a class
```

```java
*/
public static void printFields(Class cl)
{
   Field[] fields = cl.getDeclaredFields();

   for (Field f : fields)
   {
      Class type = f.getType();
      String name = f.getName();
      System.out.print("  ");
      String modifiers = Modifier.toString(f.getModifiers());
      if (modifiers.length() > 0) System.out.print(modifiers + " ");
      System.out.println(type.getName() + " " + name + ";");
   }
}

/**
* Prints all permitted subtypes of a sealed class
* @param cl a class
*/
public static void printPermittedSubclasses(Class cl)
{
   if (cl.isSealed())
   {
      Class<?>[] permittedSubclasses = cl.getPermittedSubclasses();
      for (int i = 0; i < permittedSubclasses.length; i++)
      {
         if (i == 0)
            System.out.print(" permits ");
         else
            System.out.print(", ");
         System.out.print(permittedSubclasses[i].getName());
      }
   }
}
```

```java
/**
* Prints all directly implemented interfaces of a class
* @param cl a class
*/
public static void printInterfaces(Class cl)
{
   Class<?>[] interfaces = cl.getInterfaces();
   for (int i = 0; i < interfaces.length; i++)
   {
      if (i == 0)
         System.out.print(cl.isInterface() ? " extends " : " implements ");
      else
         System.out.print(", ");
      System.out.print(interfaces[i].getName());
   }
}
}
```

`java.lang.Class` 1.0

- `Field[] getFields()` 1.1
- `Field[] getDeclaredFields()` 1.1

  `getFields` returns an array containing `Field` objects for the public fields of this class or its superclasses; `getDeclaredField` returns an array of `Field` objects for all fields of this class. The methods return an array of length 0 if there are no such fields or if the `Class` object represents a primitive or array type.

- `Method[] getMethods()` 1.1
- `Method[] getDeclaredMethods()` 1.1

  returns an array containing `Method` objects: `getMethods` returns public methods and includes inherited methods; `getDeclaredMethods` returns all methods of this class or interface but does not include inherited methods.

- `Constructor[] getConstructors()` 1.1
- `Constructor[] getDeclaredConstructors()` 1.1

  returns an array containing `Constructor` objects that give you all the public constructors (for `getConstructors`) or all constructors (for `getDeclaredConstructors`) of the class represented by this `Class` object.

- `isInterface()`

  returns `true` if this `Class` object describes an `interface`. (See Chapter 6 for interfaces.)

- `isEnum()` 1.5

  returns `true` if this `Class` object describes an `enum`.

- `isRecord()` 16

  returns `true` if this `Class` object describes a `record`.

- `RecordComponent[] getRecordComponents()` 16

  returns an array of `RecordComponent` objects that describe the record fields, or `null` if this class is not a record.

- `String getPackageName()` 9

  gets the name of the package containing this type, or the package of the element type if this type is an array type, or `"java.lang"` if this type is a primitive type.

---

java.lang.reflect.Field 1.1

---

java.lang.reflect.Method 1.1

java.lang.reflect.Constructor 1.1

- `Class getDeclaringClass()`

returns the `Class` object for the class that defines this constructor, method, or field.

- `Class[] getExceptionTypes()` (in `Constructor` and `Method` classes)

  returns an array of `Class` objects that represent the types of the exceptions thrown by the method.

- `int getModifiers()`

  returns an integer that describes the modifiers of this constructor, method, or field. Use the methods in the `Modifier` class to analyze the return value.

- `String getName()`

  returns a string that is the name of the constructor, method, or field.

- `Class[] getParameterTypes()` (in `Constructor` and `Method` classes)

  returns an array of `Class` objects that represent the types of the parameters.

- `Class getReturnType()` (in `Method` class)

  returns a `Class` object that represents the return type.

java.lang.reflect.RecordComponent 16

- `String getName()`

  `Class<?> getType()`

  get the name and type of this record component

- `Method getAccessor()`

  returns the `Method` object for accessing this record component

java.lang.reflect.Modifier 1.1

- `static String toString(int modifiers)`

  returns a string with the modifiers that correspond to the bits set in `modifiers`.

- `static boolean isAbstract(int modifiers)`
- `static boolean isFinal(int modifiers)`
- `static boolean isInterface(int modifiers)`
- `static boolean isNative(int modifiers)`
- `static boolean isPrivate(int modifiers)`
- `static boolean isProtected(int modifiers)`
- `static boolean isPublic(int modifiers)`
- `static boolean isStatic(int modifiers)`
- `static boolean isStrict(int modifiers)`
- `static boolean isSynchronized(int modifiers)`
- `static boolean isVolatile(int modifiers)`

  tests the bit in the `modifiers` value that corresponds to the modifier in the method name.

5.9.5 Using Reflection to Analyze Objects at Runtime

In the preceding section, we saw how we can find out the *names* and *types* of the instance fields of any object:

- Get the corresponding `Class` object.
- Call `getDeclaredFields` on the `Class` object.

In this section, we will go one step further and actually look at the *contents* of the fields. Of course, it is easy to look at the contents of a specific field of an object whose name and type are known when you write a program. But reflection lets you look at fields of objects that were not known at compile time.

The key method to achieve this is the `get` method in the `Field` class. If `f` is an object of type `Field` (for example, one obtained from `getDeclaredFields`) and `obj` is an object of the class of which `f` is a field, then `f.get(obj)` returns an object whose value is the current value of the field of `obj`. This is all a bit abstract, so let's run through an example.

```
var harry = new Employee("Harry Hacker", 50000, 10, 1, 1989);
Class cl = harry.getClass();
   // the class object representing Employee
Field f = cl.getDeclaredField("name");
   // the name field of the Employee class
Object v = f.get(harry);
   // the value of the name field of the harry object, i.e.,
   // the String object "Harry Hacker"
```

Of course, you can also set the values that you can get. The call `f.set(obj, value)` sets the field represented by `f` of the object `obj` to the new value.

Actually, there is a problem with this code. Since the `name` field is a private field, the `get` and `set` methods will throw an `IllegalAccessException`. You can only use `get` and `set` with accessible fields. The security mechanism of Java lets you find out what fields an object has, but it won't let you read and write the values of those fields unless you have permission.

The default behavior of the reflection mechanism is to respect Java access control. However, you can override access control by invoking the `setAccessible` method on a `Field`, `Method`, or `Constructor` object. For example:

```
f.setAccessible(true); // now OK to call f.get(harry)
```

The `setAccessible` method is a method of the `AccessibleObject` class, the common superclass of the `Field`, `Method`, and `Constructor` classes. This feature is provided for debuggers, persistent storage, and similar mechanisms. We will use it for a generic `toString` method later in this section.

The call to `setAccessible` throws an exception if the access is not granted. The access can be denied by the module system (Chapter 9 of Volume II) or a security manager (Chapter 10 of Volume II). The use of security managers is not common, and they are deprecated since Java 17. However, as of Java 9, every program contains modules since the Java API is modularized.

For example, the sample program at the end of this section looks into the internals of `ArrayList` and `Integer` objects. When you run it with Java 9 to Java 16, the following ominous message appears:

```
WARNING: An illegal reflective access operation has occurred
WARNING: Illegal reflective access by
objectAnalyzer.ObjectAnalyzer (file:/home/cay
   /books/cj11/code/v1ch05/bin/) to field
java.util.ArrayList.serialVersionUID
WARNING: Please consider reporting this to the maintainers of
   objectAnalyzer.ObjectAnalyzer
WARNING: Use --illegal-access=warn to enable warnings of
further illegal
   reflective access operations
WARNING: All illegal access operations will be denied in a
future release
```

When you run the program with Java 17, an `InaccessibleObjectException` exception occurs.

To keep the program running, "open" the `java.util` and `java.lang` packages in the `java.base` module to the "unnamed module." The details are in Chapter 9 of Volume II. Here is the syntax:

```
java --add-opens java.base/java.util=ALL-UNNAMED \
    --add-opens java.base/java.lang=ALL-UNNAMED \
    objectAnalyzer.ObjectAnalyzerTest
```

NOTE:

It is possible that future libraries will use *variable handles* instead of reflection for reading and writing fields. A `VarHandle` is similar to a `Field`. You can use it to read or write a specific field of any instance of a specific class. However, to obtain a `VarHandle`, the library code needs a `Lookup` object:

```
public Object getFieldValue(Object obj, String fieldName,
Lookup lookup)
      throws NoSuchFieldException, IllegalAccessException
{
   Class<?> cl = obj.getClass();
   Field field = cl.getDeclaredField(fieldName);
   VarHandle handle = MethodHandles.privateLookupIn(cl, lookup)
      .unreflectVarHandle(field);
   return handle.get(obj);
}
```

This works provided the `Lookup` object is generated in the module that has the permission to access the field. Some method in the module simply calls `MethodHandles.lookup()`, which yields an object encapsulating the access rights of the caller. In this way, one module can give permission for accessing private members to another module. The practical issue is how those permissions can be given with a minimum of hassle.

While we can still do so, let us look at a generic `toString` method that works for *any* class (see Listing 5.16). The generic `toString` method uses `getDeclaredFields` to obtain all instance fields and the `setAccessible` convenience method to make all fields accessible. For each field, it obtains the name and the value. Each value is turned into a string by recursively invoking `toString`.

The generic `toString` method needs to address a couple of complexities. Cycles of references could cause an infinite recursion. Therefore, the `ObjectAnalyzer` keeps track of objects that were already visited. Also, to peek inside arrays, you need a different approach. You'll learn about the details in the next section.

You can use this `toString` method to peek inside any object. For example, the call

```
var squares = new ArrayList<Integer>();
for (int i = 1; i <= 5; i++) squares.add(i * i);
System.out.println(new ObjectAnalyzer().toString(squares));
```

yields the printout

```
java.util.ArrayList[elementData=class java.lang.Object[]
{java.lang.Integer[value=1][][],
java.lang.Integer[value=4][][],java.lang.Integer[value=9][][],
   java.lang.Integer[value=16][][],
java.lang.Integer[value=25][]
[],null,null,null,null,null},size=5][modCount=5][][]
```

You can use this generic `toString` method to implement the `toString` methods of your own classes, like this:

```
public String toString()
{
  return new ObjectAnalyzer().toString(this);
}
```

This is a hassle-free and undoubtedly useful method for supplying a universal `toString` method. However, before you get too excited about never having to implement `toString` again, remember that the days of uncontrolled access to internals are numbered.

Listing 5.16 `objectAnalyzer/ObjectAnalyzerTest.java`

```
package objectAnalyzer;

import java.util.*;

/**
```

```
 * This program uses reflection to spy on objects.
 * @version 1.13 2018-03-16
 * @author Cay Horstmann
 */
public class ObjectAnalyzerTest
{
   public static void main(String[] args)
        throws ReflectiveOperationException
   {
      var squares = new ArrayList<Integer>();
      for (int i = 1; i <= 5; i++)
        squares.add(i * i);
      System.out.println(new
ObjectAnalyzer().toString(squares));
   }
}
```

Listing 5.17 `objectAnalyzer/ObjectAnalyzer.java`

```
package objectAnalyzer;

import java.lang.reflect.AccessibleObject;
import java.lang.reflect.Array;
import java.lang.reflect.Field;
import java.lang.reflect.Modifier;
import java.util.ArrayList;

public class ObjectAnalyzer
{
   private ArrayList<Object> visited = new ArrayList<>();

   /**
    * Converts an object to a string representation that lists
all fields.
    * @param obj an object
    * @return a string with the object's class name and all
field names and values
    */
```

```java
   public String toString(Object obj)
         throws ReflectiveOperationException
   {
      if (obj == null) return "null";
      if (visited.contains(obj)) return "...";
      visited.add(obj);
      Class cl = obj.getClass();
      if (cl == String.class) return (String) obj;
      if (cl.isArray())
      {
         String r = cl.getComponentType() + "[]{";
         for (int i = 0; i < Array.getLength(obj); i++)
         {
            if (i > 0) r += ",";
            Object val = Array.get(obj, i);
            if (cl.getComponentType().isPrimitive()) r += val;
            else r += toString(val);
         }
         return r + "}";
      }

      String r = cl.getName();
      // inspect the fields of this class and all superclasses
      do
      {
         r += "[";
         Field[] fields = cl.getDeclaredFields();
         AccessibleObject.setAccessible(fields, true);
         // get the names and values of all fields
         for (Field f : fields)
         {
             if (!Modifier.isStatic(f.getModifiers()))
             {
                 if (!r.endsWith("[")) r += ",";
                 r += f.getName() + "=";
                 Class t = f.getType();
                 Object val = f.get(obj);
                 if (t.isPrimitive()) r += val;
                 else r += toString(val);
```

```
            }
         }
         r += "]";
         cl = cl.getSuperclass();
      }
      while (cl != null);

      return r;
   }
}
```

---

java.lang.reflect.AccessibleObject 1.2

- `void setAccessible(boolean flag)`

  sets or clears the accessibility flag for this accessible object, or throws an `IllegalAccessException` if the access is denied.

- `boolean trySetAccessible()` 9

  sets the accessibility flag for this accessible object, or returns `false` if the access is denied.

- `boolean canAccess(Object obj)` 9

  checks if the caller can access `obj` through this field, method, or constructor object. Pass `null` for a static field or method, or for a constructor.

- `static void setAccessible(AccessibleObject[] array, boolean flag)`

  is a convenience method to set the accessibility flag for an array of objects.

java.lang.Class 1.1

- `Field getField(String name)`
- `Field[] getFields()`

  gets the public field with the given name, or an array of all fields.

- `Field getDeclaredField(String name)`
- `Field[] getDeclaredFields()`

  gets the field that is declared in this class with the given name, or an array of all fields.

`java.lang.reflect.Field` 1.1

- `Object get(Object obj)`

  gets the value of the field described by this `Field` object in the object `obj`.

- `void set(Object obj, Object newValue)`

  sets the field described by this `Field` object in the object `obj` to a new value.

5.9.6 Using Reflection to Write Generic Array Code

The `Array` class in the `java.lang.reflect` package allows you to create arrays dynamically. This is used, for example, in the implementation of the `copyOf` method in the `Arrays` class. Recall how this method can be used to grow an array that has become full.

```
var a = new Employee[100];
. . .
// array is full
a = Arrays.copyOf(a, 2 * a.length);
```

How can one write such a generic method? It helps that an `Employee[]` array can be converted to an `Object[]` array. That sounds promising. Here is a first attempt:

```
public static Object[] badCopyOf(Object[] a, int newLength) //
not useful
{
  var newArray = new Object[newLength];
  System.arraycopy(a, 0, newArray, 0, Math.min(a.length,
newLength));
  return newArray;
}
```

However, there is a problem with actually *using* the resulting array. The type of array that this code returns is an array of *objects* (`Object[]`) because we created the array using the line of code

```
new Object[newLength]
```

An array of objects *cannot* be cast to an array of employees (`Employee[]`). The virtual machine would generate a `ClassCastException` at runtime. The point is that, as mentioned earlier, a Java array remembers the type of its entries—that is, the element type used in the `new` expression that created it. It is legal to cast an `Employee[]` temporarily to an `Object[]` array and then cast it back, but an array that started its life as an `Object[]` array can never be cast into an `Employee[]` array. To write this kind of generic array code, we need to be able to make a new array of the *same* type as the original array. For this, we need the methods of the `Array` class in the `java.lang.reflect` package. The key is the static `newInstance` method of the `Array` class that constructs a new array. You must supply the type for the entries and the desired length as parameters to this method.

```
Object newArray = Array.newInstance(componentType, newLength);
```

To actually carry this out, we need to get the length and the component type of the new array.

We obtain the length by calling `Array.getLength(a)`. The static `getLength` method of the `Array` class returns the length of an array. To get the component type of the new array:

1. First, get the class object of `a`.
2. Confirm that it is indeed an array.
3. Use the `getComponentType` method of the `Class` class (which is defined only for class objects that represent arrays) to find the right type for the array.
4. Conversely, for any `Class` object representing a class *C*, the `arrayType` method yields the `Class` object representing *C*`[]`.

Why is `getLength` a method of `Array` but `getComponentType` a method of `Class`? I don't know—the distribution of the reflection methods seems a bit ad hoc at times.

Here's the code:

```
public static Object goodCopyOf(Object a, int newLength)
{
  Class cl = a.getClass();
  if (!cl.isArray()) return null;
  Class componentType = cl.getComponentType();
  int length = Array.getLength(a);
  Object newArray = Array.newInstance(componentType,
newLength);
  System.arraycopy(a, 0, newArray, 0, Math.min(length,
newLength));
  return newArray;
}
```

Note that this `copyOf` method can be used to grow arrays of any type, not just arrays of objects.

```
int[] a = { 1, 2, 3, 4, 5 };
a = (int[]) goodCopyOf(a, 10);
```

To make this possible, the parameter of `goodCopyOf` is declared to be of type `Object`, *not an array of objects* (`Object[]`). The integer array type `int[]` can be converted to an `Object`, but not to an array of objects!

Listing 5.18 shows both methods in action. Note that the cast of the return value of `badcopyOf` will throw an exception.

Listing 5.18 `arrays/CopyOfTest.java`

```
package arrays;

import java.lang.reflect.*;
import java.util.*;

/**
 * This program demonstrates the use of reflection for manipulating arrays.
 * @version 1.2 2012-05-04
 * @author Cay Horstmann
 */
public class CopyOfTest
{
   public static void main(String[] args)
   {
     int[] a = { 1, 2, 3 };
     a = (int[]) goodCopyOf(a, 10);
     System.out.println(Arrays.toString(a));

     String[] b = { "Tom", "Dick", "Harry" };
     b = (String[]) goodCopyOf(b, 10);
     System.out.println(Arrays.toString(b));

     System.out.println("The following call will generate an exception.");
     b = (String[]) badCopyOf(b, 10);
}

 /**
 * This method attempts to grow an array by allocating a new
```

```
array and
    * copying all elements.
    * @param a the array to grow
    * @param newLength the new length
    * @return a larger array that contains all elements of a. However, the returned
    * array has type Object[], not the same type as a
    */
   public static Object[] badCopyOf(Object[] a, int newLength) // not useful
   {
      var newArray = new Object[newLength];
      System.arraycopy(a, 0, newArray, 0, Math.min(a.length, newLength));
      return newArray;
   }

   /**
    * This method grows an array by allocating a new array of the same type and
    * copying all elements.
    * @param a the array to grow. This can be an object array or a primitive
    * type array
    * @return a larger array that contains all elements of a.
    */
   public static Object goodCopyOf(Object a, int newLength)
   {
      Class cl = a.getClass();
      if (!cl.isArray()) return null;
      Class componentType = cl.getComponentType();
      int length = Array.getLength(a);
      Object newArray = Array.newInstance(componentType, newLength);
      System.arraycopy(a, 0, newArray, 0, Math.min(length, newLength));
      return newArray;
   }
}
```

java.lang.Class 1.1

- boolean isArray()

  returns true if this object represents an array type.

- Class<?> getComponentType()

  Class<?> componentType() 12

  returns the Class describing the component type if this object represents an array type, or null otherwise.

- Class<?> arrayType() 12

  returns the Class describing the array type whose component type is represented by this object.

java.lang.reflect.Array 1.1

- static Object get(Object array, int index)

- static *xxx* get*Xxx*(Object array, int index)

  (*xxx* is one of the primitive types boolean, byte, char, double, float, int, long, or short.) These methods return the value of the given array that is stored at the given index.

- static void set(Object array, int index, Object newValue)

- static set*Xxx*(Object array, int index, *xxx* newValue)

  (*xxx* is one of the primitive types boolean, byte, char, double, float, int, long, or short.) These methods store a new value into the given array at the given index.

- static int getLength(Object array)

  returns the length of the given array.

- static Object newInstance(Class componentType, int length)

- `static Object newInstance(Class componentType, int[] lengths)`

  returns a new array of the given component type with the given dimensions.

5.9.7 Invoking Arbitrary Methods and Constructors

In C and C++, you can execute an arbitrary function through a function pointer. On the surface, Java does not have method pointers—that is, ways of giving the location of a method to another method, so that the second method can invoke it later. In fact, the designers of Java have said that method pointers are dangerous and error-prone, and that Java interfaces and lambda expressions (discussed in the next chapter) are a superior solution. However, the reflection mechanism allows you to call arbitrary methods.

Recall that you can inspect a field of an object with the `get` method of the `Field` class. Similarly, the `Method` class has an `invoke` method that lets you call the method that is wrapped in the current `Method` object. The signature for the `invoke` method is

```
Object invoke(Object obj, Object... args)
```

The first parameter is the implicit parameter, and the remaining objects provide the explicit parameters.

For a static method, the first parameter is ignored—you can set it to `null`.

For example, if `m1` represents the `getName` method of the `Employee` class, the following code shows how you can call it:

```
String n = (String) m1.invoke(harry);
```

If the return type is a primitive type, the `invoke` method will return the wrapper type instead. For example, suppose that `m2` represents the `getSalary` method of the `Employee` class. Then, the returned object is actually a `Double`, and you must cast it accordingly. Use automatic unboxing to turn it into a `double`:

```
double s = (Double) m2.invoke(harry);
```

How do you obtain a `Method` object? You can, of course, call `getDeclaredMethods` and search through the returned array of `Method` objects until you find the method you want. Or, you can call the `getMethod` method of the `Class` class. This is similar to the `getField` method that takes a string with the field name and returns a `Field` object. However, there may be several methods with the same name, so you need to be careful that you get the right one. For that reason, you must also supply the parameter types of the desired method. The signature of `getMethod` is

```
Method getMethod(String name, Class... parameterTypes)
```

For example, here is how you can get method pointers to the `getName` and `raiseSalary` methods of the `Employee` class:

```
Method m1 = Employee.class.getMethod("getName");
Method m2 = Employee.class.getMethod("raiseSalary",
double.class);
```

Use a similar approach for invoking arbitrary constructors. Supply the constructor's parameter types to the `Class.getConstructor` method, and supply the parameter values to the `Constructor.newInstance` method:

```
Class cl = Random.class; // or any other class with a
constructor that
                        // accepts a long parameter
Constructor cons = cl.getConstructor(long.class);
Object obj = cons.newInstance(42L);
```

NOTE:

The `Method` and `Constructor` classes extend the `Executable` class. As of Java 17, the `Executable` class is sealed, permitting only `Method` and `Constructor` as subclasses.

Now that you have seen the rules for using `Method` objects, let's put them to work. Listing 5.19 is a program that prints a table of values for a mathematical function such as `Math.sqrt` or `Math.sin`. The printout looks like this:

```
public static native double java.lang.Math.sqrt(double)
      1.0000 |   1.0000
      2.0000 |   1.4142
      3.0000 |   1.7321
      4.0000 |   2.0000
      5.0000 |   2.2361
      6.0000 |   2.4495
      7.0000 |   2.6458
      8.0000 |   2.8284
      9.0000 |   3.0000
     10.0000 |   3.1623
```

The code for printing a table is, of course, independent of the actual function that is being tabulated.

```
double dx = (to - from) / (n - 1);
for (double x = from; x <= to; x += dx)
{
  double y = (Double) f.invoke(null, x);
  System.out.printf("%10.4f | %10.4f%n", x, y);
}
```

Here, `f` is an object of type `Method`. The first parameter of `invoke` is `null` because we are calling a static method.

To tabulate the `Math.sqrt` function, we set `f` to

```
Math.class.getMethod("sqrt", double.class)
```

That is the method of the `Math` class that has the name `sqrt` and a single parameter of type `double`.

Listing 5.19 shows the complete code of the generic tabulator and a couple of test runs.

Listing 5.19 `methods/MethodTableTest.java`

```
package methods;

import java.lang.reflect.*;

/**
 * This program shows how to invoke methods through reflection.
 * @version 1.2 2012-05-04
 * @author Cay Horstmann
 */
public class MethodTableTest
{
   public static void main(String[] args)
         throws ReflectiveOperationException
   {
      // get method pointers to the square and sqrt methods
      Method square = MethodTableTest.class.getMethod("square", double.class);
      Method sqrt = Math.class.getMethod("sqrt", double.class);

      // print tables of x- and y-values
      printTable(1, 10, 10, square);
      printTable(1, 10, 10, sqrt);
   }

```

```
   /**
    * Returns the square of a number
    * @param x a number
    * @return x squared
    */
   public static double square(double x)
   {
      return x * x;
   }

   /**
    * Prints a table with x- and y-values for a method
    * @param from the lower bound for the x-values
    * @param to the upper bound for the x-values
    * @param n the number of rows in the table
    * @param f a method with a double parameter and double return value
    */
 public static void printTable(double from, double to, int n, Method f)
       throws ReflectiveOperationException
 {
    // print out the method as table header
    System.out.println(f);

    double dx = (to - from) / (n - 1);

    for (double x = from; x <= to; x += dx)
    {
        double y = (Double) f.invoke(null, x);
        System.out.printf("%10.4f | %10.4f%n", x, y);
    }
 }
}
```

As this example clearly shows, you can do anything with `Method` objects that you can do with function pointers in C (or delegates in C#). Just as in C, this style of programming is usually quite inconvenient, and always error-prone.

What happens if you invoke a method with the wrong parameters? The `invoke` method throws an exception.

Also, the parameters and return values of `invoke` are necessarily of type `Object`. That means you must cast back and forth a lot. As a result, the compiler is deprived of the chance to check your code, so errors surface only during testing, when they are more tedious to find and fix. Moreover, code that uses reflection to get at method pointers is significantly slower than code that simply calls methods directly.

For that reason, I suggest that you use `Method` objects in your own programs only when absolutely necessary. Using interfaces and, as of Java 8, lambda expressions (the subject of the next chapter) is almost always a better idea. In particular, I echo the developers of Java and suggest not using `Method` objects for callback functions. Using interfaces for the callbacks leads to code that runs faster and is a lot more maintainable.

`java.lang.reflect.Method` 1.1

- `public Object invoke(Object implicitParameter, Object[] explicitParameters)`

  invokes the method described by this object, passing the given parameters and returning the value that the method returns. For static methods, pass `null` as the implicit parameter. Pass primitive type values by using wrappers. Primitive type return values must be unwrapped.

5.10 Design Hints for Inheritance

I want to end this chapter with some hints that I have found useful when using inheritance.

1. *Place common operations and fields in the superclass.*

   This is why we put the name field into the `Person` class instead of replicating it in the `Employee` and `Student` classes.

2. *Don't use protected fields.*

   Some programmers think it is a good idea to define most instance fields as `protected`, "just in case," so that subclasses can access these fields if they need to. However, the `protected` mechanism doesn't give much protection, for two reasons. First, the set of subclasses is unbounded—anyone can form a subclass of your classes and then write code that directly accesses `protected` instance fields, thereby breaking encapsulation. And second, in Java, all classes in the same package have access to `protected` fields, whether or not they are subclasses.

   However, `protected` methods can be useful to indicate methods that are not ready for general use and should be redefined in subclasses.

3. *Use inheritance to model the "is–a" relationship.*

   Inheritance is a handy code-saver, but sometimes people overuse it. For example, suppose we need a `Contractor` class. Contractors have names and hire dates, but they do not have salaries. Instead, they are paid by the hour, and they do not stay around long enough to get a raise. There is the temptation to form a subclass `Contractor` from `Employee` and add an `hourlyWage` field.

```
public class Contractor extends Employee
{
   private double hourlyWage;
   . . .
}
```

   This is *not* a good idea, however, because now each contractor object has both a salary and hourly wage field. It will cause you no end of grief when you implement methods for printing paychecks or tax forms. You will end up writing more code than you would have written by not inheriting in the first place.

   The contractor-employee relationship fails the "is–a" test. A contractor is not a special case of an employee.

4. *Don't use inheritance unless all inherited methods make sense.*

   Suppose we want to write a `Holiday` class. Surely every holiday is a day, and days can be expressed as instances of the `GregorianCalendar` class, so we can use inheritance.

```
class Holiday extends GregorianCalendar { . . . }
```

Unfortunately, the set of holidays is not *closed* under the inherited operations. One of the public methods of `GregorianCalendar` is `add`. And `add` can turn holidays into nonholidays:

```
Holiday christmas;
christmas.add(Calendar.DAY_OF_MONTH, 12);
```

Therefore, inheritance is not appropriate in this example.

Note that this problem does not arise if you extend an immutable class. Suppose you have an immutable date class, similar to `LocalDate` but not `final`. If you form a `Holiday` subclass, there is no method that can turn a holiday into a nonholiday.

5. *Don't change the expected behavior when you override a method.*

The substitution principle applies not just to syntax but, more importantly, to behavior. When you override a method, you should not unreasonably change its behavior. The compiler can't help you—it cannot check whether your redefinitions make sense. For example, you can "fix" the issue of the `add` method in the `Holiday` class by redefining `add`, perhaps to do nothing, or to throw an exception, or to move on to the next holiday.

However, such a fix violates the substitution principle. The sequence of statements

```
int d1 = x.get(Calendar.DAY_OF_MONTH);
x.add(Calendar.DAY_OF_MONTH, 1);
int d2 = x.get(Calendar.DAY_OF_MONTH);
System.out.println(d2 - d1);
```

should have the *expected behavior*, no matter whether `x` is of type `GregorianCalendar` or `Holiday`.

Of course, therein lies the rub. Reasonable and unreasonable people can argue at length about what the expected behavior is. For example, some authors argue that the substitution principle requires `Manager.equals` to ignore the `bonus` field because `Employee.equals` ignores it. These discussions are pointless if they occur in a vacuum. Ultimately, what matters is that you do not circumvent the intent of the original design when you override methods in subclasses.

6. *Use polymorphism, not type information.*

   Whenever you find code of the form

   ```
   if (x is of type 1)
       $$$action1(x);
   else if (x is of type 2)
       $$$action2(x);
   ```

   think polymorphism.

   Do $action_1$ and $action_2$ represent a common concept? If so, make the concept a method of a common superclass or interface of both types. Then, you can simply call

   ```
   x.action();
   ```

   and have the dynamic dispatch mechanism inherent in polymorphism launch the correct action.

   Code that uses polymorphic methods or interface implementations is much easier to maintain and extend than code using multiple type tests.

7. *Don't overuse reflection.*

   The reflection mechanism lets you write programs with amazing generality, by detecting fields and methods at runtime. This capability can be extremely useful for systems programming, but it is usually not appropriate in applications. Reflection is fragile—with it, the compiler cannot help you find programming errors. Any errors are found at runtime and result in exceptions.

You have now seen how Java supports the fundamentals of object-oriented programming: classes, inheritance, and polymorphism. In the next chapter, I will tackle two advanced topics that are very important for using Java effectively: interfaces and lambda expressions.

Chapter 6. Interfaces, Lambda Expressions, and Inner Classes

In this chapter

You have now learned about classes and inheritance, the key concepts of object-oriented programming in Java. This chapter shows you several advanced techniques that are commonly used. Despite their less obvious nature, you will need to master them to complete your Java tool chest.

The first technique, called *interfaces*, is a way of describing *what* classes should do, without specifying *how* they should do it. A class can *implement* one or more interfaces. You can then use objects of these implementing classes whenever conformance to the interface is required. After discussing interfaces, we move on to *lambda expressions*, a concise way to create blocks of code that can be executed at a later point in time. Using lambda expressions, you can express code that uses callbacks or variable behavior in an elegant and concise fashion.

We then discuss the mechanism of *inner classes*. Inner classes are technically somewhat complex—they are defined inside other classes, and their methods can access the fields of the surrounding class. Inner classes are useful when you design collections of cooperating classes.

This chapter concludes with a discussion of *proxies*, objects that implement arbitrary interfaces. A proxy is a very specialized construct that is useful for building system-level tools. You can safely skip that section on first reading.

6.1 Interfaces

In the following sections, you will learn what Java interfaces are and how to use them. You will also find out how interfaces have been made more powerful in recent versions of Java.

6.1.1 The Interface Concept

In the Java programming language, an interface is not a class but a set of *requirements* for the classes that want to conform to the interface.

Typically, the supplier of some service states: “If your class conforms to a particular interface, then I’ll perform the service.” Let’s look at a concrete example. The `sort` method of the `Arrays` class promises to sort an array of objects, but under one condition: The objects must belong to classes that *implement* the `Comparable` interface.

Here is what the `Comparable` interface looks like:

```
public interface Comparable
{
  int compareTo(Object other);
}
```

In the interface, the `compareTo` method is *abstract*—it has no implementation. A class that implements the `Comparable` interface needs to have a `compareTo` method, and the method must take an `Object` parameter and return an integer. Otherwise, the class is also abstract—that is, you cannot construct any objects.

NOTE:

As of Java 5, the Comparable interface has been enhanced to be a generic type.

```
public interface Comparable<T>
{
  int compareTo(T other); // parameter has type T
}
```

For example, a class that implements Comparable<Employee> must supply a method

```
int compareTo(Employee other)
```

You can still use the “raw” Comparable type without a type parameter. Then the compareTo method has a parameter of type Object, and you have to manually cast that parameter of the compareTo method to the desired type. I will do just that for a little while so that you don’t have to worry about two new concepts at the same time.

All methods of an interface are automatically public. For that reason, it is not necessary to supply the keyword public when declaring a method in an interface.

Of course, there is an additional requirement that the interface cannot spell out: When calling x.compareTo(y), the compareTo method must actually be able to *compare* the two objects and return an indication whether x or y is larger. The method is supposed to return a negative number if x is smaller than y, zero if they are equal, and a positive number otherwise.

This particular interface has a single method. Some interfaces have multiple methods. As you will see later, interfaces can also define constants. What is more important, however, is what interfaces *cannot* supply. Interfaces never have instance fields. Before Java 8, all methods in an interface were abstract. As you will see in Section 6.1.4, “Static and Private Methods,” on p. 322 and Section 6.1.5, “Default Methods,” on p. 323, it is now possible to have other methods in interfaces. Of course, those methods cannot refer to instance fields—interfaces don't have any.

Now, suppose we want to use the `sort` method of the `Arrays` class to sort an array of `Employee` objects. Then the `Employee` class must *implement* the `Comparable` interface.

To make a class implement an interface, you carry out two steps:

1. You declare that your class intends to implement the given interface.
2. You supply definitions for all methods in the interface.

To declare that a class implements an interface, use the `implements` keyword:

```
class Employee implements Comparable
```

Of course, now the `Employee` class needs to supply the `compareTo` method. Let's suppose that we want to compare employees by their salary. Here is an implementation of the `compareTo` method:

```
public int compareTo(Object otherObject)
{
  Employee other = (Employee) otherObject;
  return Double.compare(salary, other.salary);
}
```

Here, we use the static `Double.compare` method that returns a negative if the first argument is less than the second argument, `0` if they are equal, and a positive value otherwise.

CAUTION:

In the interface declaration, the `compareTo` method was not declared `public` because all methods in an *interface* are automatically public. However, when implementing the interface, you must declare the method as `public`.

Otherwise, the compiler assumes that the method has package access—the default for a *class*. The compiler then complains that you're trying to supply a more restrictive access privilege.

We can do a little better by supplying a type parameter for the generic `Comparable` interface:

```
class Employee implements Comparable<Employee>
{
  public int compareTo(Employee other)
  {
  return Double.compare(salary, other.salary);
  }
  . . .
}
```

Note that the unsightly cast of the `Object` parameter has gone away.

TIP:

The `compareTo` method of the `Comparable` interface returns an integer. If the objects are not equal, it does not matter what negative or positive value you return. This flexibility can be useful when you are comparing integer fields. For example, suppose each employee has a unique integer `id` and you want to sort by the employee ID number. Then you can simply return `id - other.id`. That value will be some negative value if the first ID number is less than the other, `0` if they are the same ID, and some positive value otherwise. However, there is one caveat: The range of the integers must be small enough so that the subtraction does not overflow. If you know that the IDs are not negative or that their absolute value is at most `(Integer.MAX_VALUE - 1) / 2`, you are safe. Otherwise, call the static `Integer.compare` method.

Of course, the subtraction trick doesn't work for floating-point numbers. The difference `salary - other.salary` can round to `0` if the salaries are close together but not identical. The call `Double.compare(x, y)` simply returns `-1` if `x < y` or `1` if `x > y`.

NOTE:

The documentation of the `Comparable` interface suggests that the `compareTo` method should be compatible with the `equals` method. That is, `x.compareTo(y)` should be zero exactly when `x.equals(y)`. Most classes in the Java API that implement `Comparable` follow this advice. A notable exception is `BigDecimal`. Consider `x = new BigDecimal("1.0")` and `y = new BigDecimal("1.00")`. Then `x.equals(y)` is `false` because the numbers differ in precision. But `x.compareTo(y)` is zero. Ideally, it shouldn't be, but there was no obvious way of deciding which one should come first.

Now you saw what a class must do to avail itself of the sorting service—it must implement a `compareTo` method. That's eminently reasonable. There needs to be some way for the `sort` method to compare objects. But why can't the `Employee` class simply provide a `compareTo` method without implementing the `Comparable` interface?

The reason for interfaces is that the Java programming language is *strongly typed*. When making a method call, the compiler needs to be able to check that the method actually exists. Somewhere in the `sort` method will be statements like this:

```
if (a[i].compareTo(a[j]) > 0)
{
  // rearrange a[i] and a[j]
  . . .
}
```

The compiler must know that `a[i]` actually has a `compareTo` method. If `a` is an array of `Comparable` objects, then the existence of the method is assured because every class that implements the `Comparable` interface must supply the method.

NOTE:

You would expect that the `sort` method in the `Arrays` class is defined to accept a `Comparable[]` array so that the compiler can complain if anyone ever calls `sort` with an array whose element type doesn't implement the `Comparable` interface. Sadly, that is not the case. Instead, the `sort` method accepts an `Object[]` array and uses a clumsy cast:

```
// approach used in the standard library--not recommended
if (((Comparable) a[i]).compareTo(a[j]) > 0)
{
  // rearrange a[i] and a[j]
  . . .
}
```

If `a[i]` does not belong to a class that implements the `Comparable` interface, the virtual machine throws an exception.

Listing 6.1 presents the full code for sorting an array of instances of the class `Employee` (Listing 6.2).

Listing 6.1 `interfaces/EmployeeSortTest.java`

```
package interfaces;

import java.util.*;

/**
 * This program demonstrates the use of the Comparable interface.
 * @version 1.30 2004-02-27
 * @author Cay Horstmann
```

```
 */
public class EmployeeSortTest
{
   public static void main(String[] args)
   {
      var staff = new Employee[3];

      staff[0] = new Employee("Harry Hacker", 35000);
      staff[1] = new Employee("Carl Cracker", 75000);
      staff[2] = new Employee("Tony Tester", 38000);

      Arrays.sort(staff);

      // print out information about all Employee objects
      for (Employee e : staff)
         System.out.println("name=" + e.getName() + ",salary="
+ e.getSalary());
   }
}
```

Listing 6.2 `interfaces/Employee.java`

```
package interfaces;

public class Employee implements Comparable<Employee>
{
   private String name;
   private double salary;

   public Employee(String name, double salary)
   {
      this.name = name;
      this.salary = salary;
   }

   public String getName()
   {
      return name;
```

```java
    }

    public double getSalary()
    {
      return salary;
    }

    public void raiseSalary(double byPercent)
    {
      double raise = salary * byPercent / 100;
      salary += raise;
    }

  /**
  * Compares employees by salary
  * @param other another Employee object
  * @return a negative value if this employee has a lower salary than
  * otherObject, 0 if the salaries are the same, a positive value otherwise
  */
  public int compareTo(Employee other)
  {
     return Double.compare(salary, other.salary);
  }
}
```

java.lang.Comparable<T> 1.0

- `int compareTo(T other)`

  compares this object with `other` and returns a negative integer if this object is less than `other`, zero if they are equal, and a positive integer otherwise.

java.util.Arrays 1.2

- `static void sort(Object[] a)`

  sorts the elements in the array `a`. All elements in the array must belong to classes that implement the `Comparable` interface, and they must all be comparable to each other.

`java.lang.Integer` 1.0

- `static int compare(int x, int y)` 7

  returns a negative integer if `x < y`, zero if `x` and `y` are equal, and a positive integer otherwise.

`java.lang.Double` 1.0

- `static int compare(double x, double y)` 1.4

  returns a negative integer if `x < y`, zero if `x` and `y` are equal, and a positive integer otherwise.

NOTE:

According to the language standard: “The implementor must ensure `sgn(x.compareTo(y)) = -sgn(y.compareTo(x))` for all `x` and `y`. (This implies that `x.compareTo(y)` must throw an exception if `y.compareTo(x)` throws an exception.)” Here, `sgn` is the *sign* of a number: `sgn(`*n*`)` is –1 if *n* is negative, `0` if *n* equals `0`, and `1` if *n* is positive. In plain English, if you flip the parameters of `compareTo`, the sign (but not necessarily the actual value) of the result must also flip.

As with the `equals` method, problems can arise when inheritance comes into play.

Since Manager extends Employee, it implements Comparable<Employee> and not Comparable<Manager>. If Manager chooses to override compareTo, it must be prepared to compare managers to employees. It can't simply cast an employee to a manager:

```
class Manager extends Employee
{
    public int compareTo(Employee other)
    {
       Manager otherManager = (Manager) other; // NO
       . . .
    }
    . . .
}
```

That violates the "antisymmetry" rule. If x is an Employee and y is a Manager, then the call x.compareTo(y) doesn't throw an exception—it simply compares x and y as employees. But the reverse, y.compareTo(x), throws a ClassCastException.

This is the same situation as with the equals method discussed in Chapter 5, and the remedy is the same. There are two distinct scenarios.

If subclasses have different notions of comparison, then you should outlaw comparison of objects that belong to different classes. Each compareTo method should start out with the test

```
if (getClass() != other.getClass()) throw new
ClassCastException();
```

If there is a common algorithm for comparing subclass objects, simply provide a single compareTo method in the superclass and declare it as final.

For example, suppose you want managers to be better than regular employees, regardless of salary. What about other subclasses such as Executive and Secretary? If you need to establish a pecking order, supply a method such as rank in the Employee class. Have each subclass override `rank`, and implement a single `compareTo` method that takes the `rank` values into account.

6.1.2 Properties of Interfaces

Interfaces are not classes. In particular, you can never use the `new` operator to instantiate an interface:

```
x = new Comparable(. . .); // ERROR
```

However, even though you can't construct interface objects, you can still declare interface variables.

```
Comparable x; // OK
```

An interface variable must refer to an object of a class that implements the interface:

```
x = new Employee(. . .); // OK provided Employee implements
Comparable
```

Next, just as you use `instanceof` to check whether an object is of a specific class, you can use `instanceof` to check whether an object implements an interface:

```
if (anObject instanceof Comparable) { . . . }
```

Just as you can build hierarchies of classes, you can extend interfaces. This allows for multiple chains of interfaces that go from a greater degree of generality to a greater degree of specialization. For example, suppose you had an interface called `Moveable`.

```
public interface Moveable
{
```

```
  void move(double x, double y);
}
```

Then, you could imagine an interface called `Powered` that extends it:

```
public interface Powered extends Moveable
{
  double milesPerGallon();
}
```

Although you cannot put instance fields in an interface, you can supply constants in them. For example:

```
public interface Powered extends Moveable
{
  double milesPerGallon();
  double SPEED_LIMIT = 95; // a public static final constant
}
```

Just as methods in an interface are automatically `public`, fields are always `public static final`.

NOTE:

It is legal to tag interface methods as `public`, and fields as `public static final`. Some programmers do that, either out of habit or for greater clarity. However, the Java Language Specification recommends that the redundant keywords not be supplied, and I follow that recommendation.

While each class can have only one superclass, classes can implement *multiple* interfaces. This gives you the maximum amount of flexibility in defining a class's behavior. For example, the Java programming language has an important interface built into it, called `Cloneable`. (This interface is discussed in detail in Section 6.1.9, "Object Cloning," on p. 330.) If your class implements `Cloneable`, the `clone` method in the `Object` class will make an exact copy of your class's objects. If you want both cloneability and comparability, simply implement both interfaces. Use commas to separate the interfaces that you want to implement:

```
class Employee implements Cloneable, Comparable
```

NOTE:

Records and enumeration classes cannot extend other classes (since they implicitly extend the `Record` and `Enum` class). However, they can implement interfaces.

NOTE:

Interfaces can be `sealed`. As with sealed classes, the direct subtypes (which can be classes or interfaces) must be declared in a `permits` clause or be located in the same source file.

6.1.3 Interfaces and Abstract Classes

If you read the section about abstract classes in Chapter 5, you may wonder why the designers of the Java programming language bothered with introducing the concept of interfaces. Why can't `Comparable` simply be an abstract class:

```
abstract class Comparable // why not?
{
  public abstract int compareTo(Object other);
}
```

The `Employee` class would then simply extend this abstract class and supply the `compareTo` method:

```
class Employee extends Comparable // why not?
{
  public int compareTo(Object other) { . . . }
}
```

There is, unfortunately, a major problem with using an abstract base class to express a generic property. A class can only extend a single class. Suppose the `Employee` class already extends a different class, say, `Person`. Then it can't extend a second class.

```
class Employee extends Person, Comparable // ERROR
```

But each class can implement as many interfaces as it likes:

```
class Employee extends Person implements Comparable // OK
```

Other programming languages, in particular C++, allow a class to have more than one superclass. This feature is called *multiple inheritance*. The designers of Java chose not to support multiple inheritance, because it makes the language either very complex (as in C++) or less efficient (as in Eiffel).

Instead, interfaces afford most of the benefits of multiple inheritance while avoiding the complexities and inefficiencies.

C++ NOTE:

C++ has multiple inheritance and all the complications that come with it, such as virtual base classes, dominance rules, and transverse pointer casts. Few C++ programmers use multiple inheritance, and some say it should never be used. Other programmers recommend using multiple inheritance only for the "mix-in" style of inheritance. In the mix-in style, a primary base class describes the parent object, and additional base classes (the so-called mix-ins) may supply auxiliary characteristics. That style is similar to a Java class with a single superclass and additional interfaces.

TIP:

You have seen the `CharSequence` interface in chapter 3. Both `String` and `StringBuilder` (as well as a few more esoteric string-like classes) implement this interface. The interface contains methods that are common to all classes that manage sequences of characters. A common interface encourages programmers to write methods that use the `CharSequence` interface. Those methods work with instances of `String`, `StringBuilder`, and the other string-like classes.

Sadly, the `CharSequence` interface is rather paltry. You can get the length, iterate over the code points or code units, extract subsequences, and lexicographically compare two sequences. Java 17 adds an `isEmpty` method.

If you process strings, and those operations suffice for your tasks, accept `CharSequence` instances instead of strings.

6.1.4 Static and Private Methods

As of Java 8, you are allowed to add static methods to interfaces. There was never a technical reason why this should be outlawed. It simply seemed to be against the spirit of interfaces as abstract specifications.

Up to now, it has been common to place static methods in companion classes. In the standard library, you'll find pairs of interfaces and utility classes such as `Collection`/`Collections` or `Path`/`Paths`.

You can construct a path to a file or directory from a URI, or from a sequence of strings, such as `Paths.get("jdk-17", "conf", "security")`. In Java 11, equivalent methods are provided in the `Path` interface:

```
public interface Path
{
  public static Path of(URI uri) { . . . }
  public static Path of(String first, String... more) { . . . }
  . . .
}
```

Then the `Paths` class is no longer necessary.

Similarly, when you implement your own interfaces, there is no longer a reason to provide a separate companion class for utility methods.

As of Java 9, methods in an interface can be `private`. A `private` method can be `static` or an instance method. Since private methods can only be used in the methods of the interface itself, their use is limited to being helper methods for the other methods of the interface.

6.1.5 Default Methods

You can supply a *default* implementation for any interface method. You must tag such a method with the `default` modifier.

```
public interface Comparable<T>
{
   default int compareTo(T other) { return 0; }
       // by default, all elements are the same
}
```

Of course, that is not very useful since every realistic implementation of `Comparable` would override this method. But there are other situations where default methods can be useful. For example, in Chapter 9 you will see an `Iterator` interface for visiting elements in a data structure. It declares a `remove` method as follows:

```
public interface Iterator<E>
{
  boolean hasNext();
```

```
  E next();
  default void remove() { throw new
UnsupportedOperationException("remove"); }
  . . .
}
```

If you implement an iterator, you need to provide the `hasNext` and `next` methods. There are no defaults for these methods—they depend on the data structure that you are traversing. But if your iterator is read-only, you don't have to worry about the `remove` method.

A default method can call other methods. For example, a `Collection` interface can define a convenience method

```
public interface Collection
{
  int size(); // an abstract method
  default boolean isEmpty() { return size() == 0; }
  . . .
}
```

Then a programmer implementing `Collection` doesn't have to worry about implementing an `isEmpty` method.

NOTE:

The `Collection` interface in the Java API does not actually do this. Instead, there is a class `AbstractCollection` that implements `Collection` and defines `isEmpty` in terms of `size`. Implementors of a collection are advised to extend `AbstractCollection`. That technique is obsolete. Just implement the methods in the interface.

An important use for default methods is *interface evolution*. Consider, for example, the `Collection` interface that has been a part of Java for many years. Suppose that a long time ago, you provided a class

```
public class Bag implements Collection
```

Later, in Java 8, a `stream` method was added to the interface.

Suppose the `stream` method was not a default method. Then the `Bag` class would no longer compile since it doesn't implement the new method. Adding a nondefault method to an interface is not *source-compatible*.

But suppose you don't recompile the class and simply use an old JAR file containing it. The class will still load, even with the missing method. Programs can still construct `Bag` instances, and nothing bad will happen. (Adding a method to an interface is *binary compatible*.) However, if a program calls the `stream` method on a `Bag` instance, an `AbstractMethodError` occurs.

Making the method a `default` method solves both problems. The `Bag` class will again compile. And if the class is loaded without being recompiled and the `stream` method is invoked on a `Bag` instance, the `Collection.stream` method is called.

6.1.6 Resolving Default Method Conflicts

What happens if the exact same method is defined as a default method in one interface and then again as a method of a superclass or another interface? Languages such as Scala and C++ have complex rules for resolving such ambiguities. Fortunately, the rules in Java are much simpler. Here they are:

1. Superclasses win. If a superclass provides a concrete method, default methods with the same name and parameter types are simply ignored.
2. Interfaces clash. If an interface provides a default method, and another interface contains a method with the same name and parameter types (default or not), then you must resolve the conflict by overriding that method.

Let's look at the second rule. Consider two interfaces with a `getName` method:

```
interface Person
{
  default String getName() { return ""; };
}
interface Named
{
  default String getName() { return getClass().getName() + "_"
+ hashCode(); }
}
```

What happens if you form a class that implements both of them?

```
class Student implements Person, Named { . . . }
```

The class inherits two inconsistent `getName` methods provided by the `Person` and `Named` interfaces. Instead of choosing one over the other, the Java compiler reports an error and leaves it up to the programmer to resolve the ambiguity. Simply provide a `getName` method in the `Student` class. In that method, you can choose one of the two conflicting methods, like this:

```
class Student implements Person, Named
{
  public String getName() { return Person.super.getName(); }
  . . .
}
```

Now assume that the `Named` interface does not provide a default implementation for `getName`:

```
interface Named
{
  String getName();
}
```

Can the `Student` class inherit the default method from the `Person` interface? This might be reasonable, but the Java designers decided in favor of uniformity. It doesn't matter how two interfaces conflict. If at least one interface provides an implementation, the compiler reports an error, and the programmer must resolve the ambiguity.

NOTE:

Of course, if neither interface provides a default for a shared method, then we are in the situation before Java 8, and there is no conflict. An implementing class has two choices: implement the method, or leave it unimplemented. In the latter case, the class is itself abstract.

We just discussed name clashes between two interfaces. Now consider a class that extends a superclass and implements an interface, inheriting the same method from both. For example, suppose that `Person` is a class and `Student` is defined as

```
class Student extends Person implements Named { . . . }
```

In that case, only the superclass method matters, and any default method from the interface is simply ignored. In our example, `Student` inherits the `getName` method from `Person`, and it doesn't make any difference whether the `Named` interface provides a default for `getName` or not. This is the "class wins" rule.

The "class wins" rule ensures compatibility with Java 7. If you add default methods to an interface, it has no effect on code that worked before there were default methods.

CAUTION:

You can never make a default method that redefines one of the methods in the `Object` class. For example, you can't define a default method for `toString` or `equals`, even though that might be attractive for interfaces such as `List`. As a consequence of the “class wins” rule, such a method could never win against `Object.toString` or `Object.equals`.

6.1.7 Interfaces and Callbacks

A common pattern in programming is the *callback* pattern. In this pattern, you specify the action that should occur whenever a particular event happens. For example, you may want a particular action to occur when a button is clicked or a menu item is selected. However, as you have not yet seen how to implement user interfaces, we will consider a similar but simpler situation.

The `javax.swing` package contains a `Timer` class that is useful if you want to be notified whenever a time interval has elapsed. For example, if a part of your program contains a clock, you can ask to be notified every second so that you can update the clock face.

When you construct a timer, you set the time interval and tell it what it should do whenever the time interval has elapsed.

How do you tell the timer what it should do? In many programming languages, you supply the name of a function that the timer should call periodically. However, the classes in the Java standard library take an object-oriented approach. You pass an object of some class. The timer then calls one of the methods on that object. Passing an object is more flexible than passing a function because the object can carry additional information.

Of course, the timer needs to know what method to call. The timer requires that you specify an object of a class that implements the `ActionListener` interface of the `java.awt.event` package. Here is that interface:

```
public interface ActionListener
{
  void actionPerformed(ActionEvent event);
}
```

The timer calls the `actionPerformed` method when the time interval has expired.

Suppose you want to print a message “At the tone, the time is . . .”, followed by a beep, once every second. You would define a class that implements the `ActionListener` interface. You would then place whatever statements you want to have executed inside the `actionPerformed` method.

```
class TimePrinter implements ActionListener
{
   public void actionPerformed(ActionEvent event)
   {
      System.out.println("At the tone, the time is "
          + Instant.ofEpochMilli(event.getWhen()));
      Toolkit.getDefaultToolkit().beep();
   }
}
```

Note the `ActionEvent` parameter of the `actionPerformed` method. This parameter gives information about the event, such as the time when the event happened. The call `event.getWhen()` returns the event time, measured in milliseconds since the “epoch” (January 1, 1970). By passing it to the static `Instant.ofEpochMilli` method, we get a more readable description.

Next, construct an object of this class and pass it to the `Timer` constructor.

```
var listener = new TimePrinter();
Timer t = new Timer(1000, listener);
```

The first parameter of the `Timer` constructor is the time interval that must elapse between notifications, measured in milliseconds. We want to be notified every second. The second parameter is the listener object.

Finally, start the timer.

```
t.start();
```

Every second, a message like

```
At the tone, the time is 2017-12-16T05:01:49.550Z
```

is displayed, followed by a beep.

CAUTION:

Be sure to import `javax.swing.Timer`. There is also a `java.util.Timer` class that is slightly different.

Listing 6.3 puts the timer and its action listener to work. After the timer is started, the program puts up a message dialog and waits for the user to click the OK button to stop. While the program waits for the user, the current time is displayed every second. (If you omit the dialog, the program would terminate as soon as the `main` method exits.)

Listing 6.3 `timer/TimerTest.java`

```
package timer;

/**
  @version 1.02 2017-12-14
  @author Cay Horstmann
*/

import java.awt.*;
import java.awt.event.*;
import java.time.*;
import javax.swing.*;

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

```
      var listener = new TimePrinter();

      // construct a timer that calls the listener once every second
      var timer = new Timer(1000, listener);
      timer.start();

      // keep program running until the user selects "OK"
      JOptionPane.showMessageDialog(null, "Quit program?");
      System.exit(0);
   }
}

class TimePrinter implements ActionListener
{
   public void actionPerformed(ActionEvent event)
   {
      System.out.println("At the tone, the time is " + Instant.ofEpochMilli(event.getWhen()));
      Toolkit.getDefaultToolkit().beep();
   }
}
```

javax.swing.JOptionPane 1.2

- `static void showMessageDialog(Component parent, Object message)`

  displays a dialog box with a message prompt and an OK button. The dialog is centered over the `parent` component. If `parent` is `null`, the dialog is centered on the screen.

javax.swing.Timer 1.2

- `Timer(int interval, ActionListener listener)` constructs a timer that notifies `listener` whenever `interval` milliseconds have elapsed.

- `void start()`

  starts the timer. Once started, the timer calls `actionPerformed` on its listeners.

- `void stop()`

  stops the timer. Once stopped, the timer no longer calls `actionPerformed` on its listeners.

`java.awt.Toolkit` 1.0

- `static Toolkit getDefaultToolkit()`

  gets the default toolkit. A toolkit contains information about the GUI environment.

- `void beep()`

  emits a beep sound.

6.1.8 The `Comparator` Interface

In Section 6.1.1, "The Interface Concept," on p. 312, you have seen how you can sort an array of objects, provided they are instances of classes that implement the `Comparable` interface. For example, you can sort an array of strings since the `String` class implements `Comparable<String>`, and the `String.compareTo` method compares strings in dictionary order.

Now suppose we want to sort strings by increasing length, not in dictionary order. We can't have the `String` class implement the `compareTo` method in two ways—and at any rate, the `String` class isn't ours to modify.

To deal with this situation, there is a second version of the `Arrays.sort` method whose parameters are an array and a *comparator*—an instance of a class that implements the `Comparator` interface.

```
public interface Comparator<T>
{
  int compare(T first, T second);
}
```

To compare strings by length, define a class that implements `Comparator<String>`:

```
class LengthComparator implements Comparator<String>
{
    public int compare(String first, String second)
    {
       return first.length() - second.length();
    }
}
```

To actually do the comparison, you need to make an instance:

```
var comp = new LengthComparator();
if (comp.compare(words[i], words[j]) > 0) . . .
```

Contrast this call with `words[i].compareTo(words[j])`. The `compare` method is called on the comparator object, not the string itself.

NOTE:

Even though the `LengthComparator` object has no state, you still need to make an instance of it. You need the instance to call the `compare` method—it is not a static method.

To sort an array, pass a `LengthComparator` object to the `Arrays.sort` method:

```
String[] friends = { "Peter", "Paul", "Mary" };
Arrays.sort(friends, new LengthComparator());
```

Now the array is either `["Paul", "Mary", "Peter"]` or `["Mary", "Paul", "Peter"]`.

You will see in Section 6.2, "Lambda Expressions," on p. 338 how to use a `Comparator` much more easily with a lambda expression.

6.1.9 Object Cloning

In this section, we discuss the `Cloneable` interface that indicates that a class has provided a safe `clone` method. Since cloning is not all that common, and the details are quite technical, you may just want to glance at this material until you need it.

To understand what cloning means, recall what happens when you make a copy of a variable holding an object reference. The original and the copy are references to the same object (see Figure 6.1). This means a change to either variable also affects the other.

```
var original = new Employee("John Public", 50000);
Employee copy = original;
copy.raiseSalary(10); // oops--also changed original
```

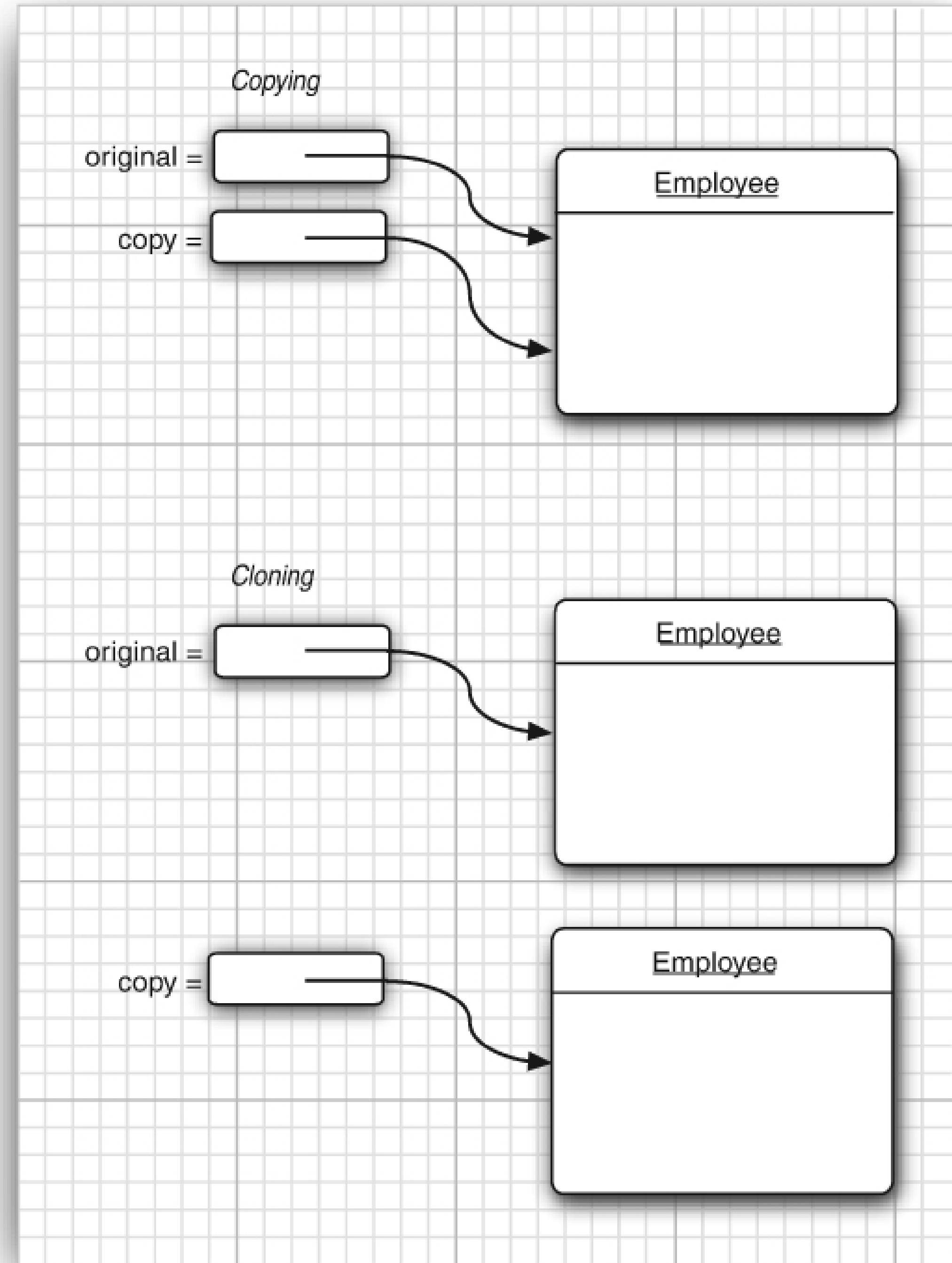


Figure 6.1 Copying and cloning

If you would like `copy` to be a new object that begins its life being identical to `original` but whose state can diverge over time, use the `clone` method.

```
Employee copy = original.clone();
copy.raiseSalary(10); // OK--original unchanged
```

But it isn't quite so simple. The `clone` method is a `protected` method of `Object`, which means that your code cannot simply call it. Only the `Employee` class can clone `Employee` objects. There is a reason for this restriction. Think about the way in which the `Object` class can implement `clone`. It knows nothing about the object at all, so it can make only a field-by-field copy. If all instance fields in the object are numbers or other basic types, copying the fields is just fine. But if the object contains references to subobjects, then copying the field gives you another reference to the same subobject, so the original and the cloned objects still share some information.

To visualize that, consider the `Employee` class that was introduced in Chapter 4. Figure 6.2 shows what happens when you use the `clone` method of the `Object` class to clone such an `Employee` object. As you can see, the default cloning operation is "shallow"—it doesn't clone objects that are referenced inside other objects. (The figure shows a shared `Date` object. For reasons that will become clear shortly, this example uses a version of the `Employee` class in which the hire day is represented as a `Date`.)

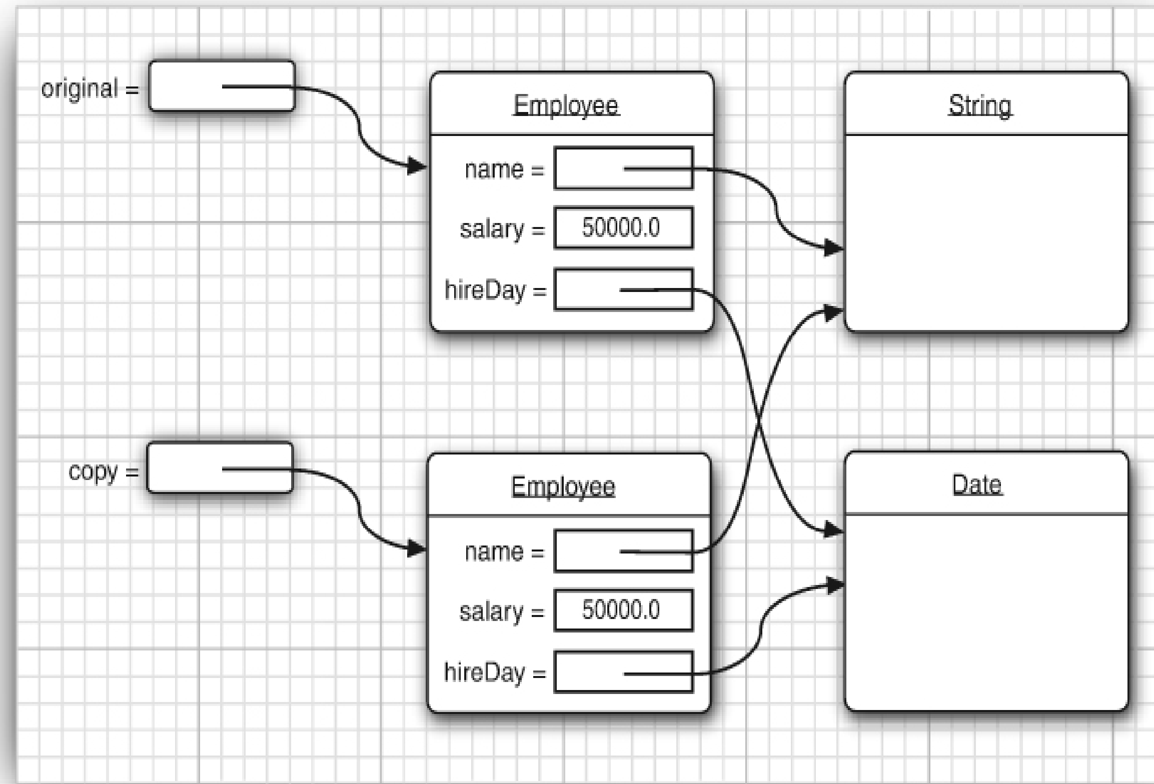


Figure 6.2 A shallow copy

Does it matter if the copy is shallow? It depends. If the subobject shared between the original and the shallow clone is *immutable*, then the sharing is safe. This certainly happens if the subobject belongs to an immutable class, such as `String`. Alternatively, the subobject may simply remain constant throughout the lifetime of the object, with no mutators touching it and no methods yielding a reference to it.

Quite frequently, however, subobjects are mutable, and you must redefine the `clone` method to make a *deep copy* that clones the subobjects as well. In our example, the `hireDay` field is a `Date`, which is mutable, so it too must be cloned. (For that reason, this example uses a field of type `Date`, not `LocalDate`, to demonstrate the cloning process. Had `hireDay` been an instance of the immutable `LocalDate` class, no further action would have been required.)

For every class, you need to decide whether

1. The default `clone` method is good enough;
2. The default `clone` method can be patched up by calling `clone` on the mutable subobjects; or
3. `clone` should not be attempted.

The third option is actually the default. To choose either the first or the second option, a class must

1. Implement the `Cloneable` interface; and
2. Redefine the `clone` method with the `public` access modifier.

NOTE:

The `clone` method is declared `protected` in the `Object` class, so that your code can't simply call `anObject.clone()`. But aren't protected methods accessible from any subclass, and isn't every class a subclass of `Object`? Fortunately, the rules for protected access are more subtle (see Chapter 5). A subclass can call a protected `clone` method only to clone *its own* objects. You must redefine `clone` to be public to allow objects to be cloned by any method.

In this case, the appearance of the `Cloneable` interface has nothing to do with the normal use of interfaces. In particular, it does *not* specify the `clone` method—that method is inherited from the `Object` class. The interface merely serves as a tag, indicating that the class designer understands the cloning process. Objects are so paranoid about cloning that they generate a checked exception if an object requests cloning but does not implement that interface.

NOTE:

The `Cloneable` interface is one of a handful of *tagging interfaces* that Java provides. (Some programmers call them *marker interfaces*.) Recall that the usual purpose of an interface such as `Comparable` is to ensure that a class implements a particular method or set of methods. A tagging interface has no methods; its only purpose is to allow the use of `instanceof` in a type inquiry:

```
if (obj instanceof Cloneable) . . .
```

I recommend that you do not use tagging interfaces in your own programs.

Even if the default (shallow copy) implementation of `clone` is adequate, you still need to implement the `Cloneable` interface, redefine `clone` to be public, and call `super.clone()`. Here is an example:

```
class Employee implements Cloneable
{
   // public access, change return type
   public Employee clone() throws CloneNotSupportedException
   {
     return (Employee) super.clone();
   }
   . . .
}
```

NOTE:

Up to Java 1.4, the `clone` method always had return type `Object`. Nowadays, you can specify the correct return type for your `clone` methods. This is an example of covariant return types (see Chapter 5).

The `clone` method that you just saw adds no functionality to the shallow copy provided by `Object.clone`. It merely makes the method public. To make a deep copy, you have to work harder and clone the mutable instance fields.

Here is an example of a `clone` method that creates a deep copy:

```
class Employee implements Cloneable
{
  . . .
  public Employee clone() throws CloneNotSupportedException
  {
    // call Object.clone()
    Employee cloned = (Employee) super.clone();
    // clone mutable fields
    cloned.hireDay = (Date) hireDay.clone();
    return cloned;

  }
}
```

The `clone` method of the `Object` class threatens to throw a `CloneNotSupportedException`—it does that whenever `clone` is invoked on an object whose class does not implement the `Cloneable` interface. Of course, the `Employee` and `Date` classes implement the `Cloneable` interface, so the exception won't be thrown. However, the compiler does not know that. Therefore, we declared the exception:

```
public Employee clone() throws CloneNotSupportedException
```

NOTE:

Would it be better to catch the exception instead? (See Chapter 7 for details on catching exceptions.)

```
public Employee clone()
{
  try
  {
     Employee cloned = (Employee) super.clone();
     . . .
```

```
      }
      catch (CloneNotSupportedException e) { return null; }
      // this won't happen, since we are Cloneable
   }
```

This is appropriate for `final` classes. Otherwise, it is better to leave the `throws` specifier in place. That gives subclasses the option of throwing a `CloneNotSupportedException` if they can't support cloning.

You have to be careful about cloning of subclasses. For example, once you have defined the `clone` method for the `Employee` class, anyone can use it to clone `Manager` objects. Can the `Employee` clone method do the job? It depends on the fields of the `Manager` class. In our case, there is no problem because the `bonus` field has primitive type. But `Manager` might have acquired fields that require a deep copy or are not cloneable. There is no guarantee that the implementor of the subclass has fixed `clone` to do the right thing. For that reason, the `clone` method is declared as `protected` in the `Object` class. But you don't have that luxury if you want the users of your classes to invoke `clone`.

Should you implement `clone` in your own classes? If your clients need to make deep copies, then you probably should. Some authors feel that you should avoid `clone` altogether and instead implement another method for the same purpose. I agree that `clone` is rather awkward, but you'll run into the same issues if you shift the responsibility to another method. At any rate, cloning is less common than you may think. Less than 5 percent of the classes in the standard library implement `clone`.

The program in Listing 6.4 clones an instance of the class `Employee` (Listing 6.5), then invokes two mutators. The `raiseSalary` method changes the value of the `salary` field, whereas the `setHireDay` method changes the state of the `hireDay` field. Neither mutation affects the original object because `clone` has been defined to make a deep copy.

NOTE:

All array types have a `clone` method that is public, not protected. You can use it to make a new array that contains copies of all elements. For example:

```
int[] luckyNumbers = { 2, 3, 5, 7, 11, 13 };
int[] cloned = luckyNumbers.clone();
cloned[5] = 12; // doesn't change luckyNumbers[5]
```

NOTE:

Chapter 2 of Volume II shows an alternate mechanism for cloning objects, using the object serialization feature of Java. That mechanism is easy to implement and safe, but not very efficient.

Listing 6.4 `clone/CloneTest.java`

```
package clone;

/**
 * This program demonstrates cloning.
 * @version 1.11 2018-03-16
 * @author Cay Horstmann
 */
public class CloneTest
{
   public static void main(String[] args) throws
CloneNotSupportedException
   {
      var original = new Employee("John Q. Public", 50000);
      original.setHireDay(2000, 1, 1);
      Employee copy = original.clone();
      copy.raiseSalary(10);
```

```
      copy.setHireDay(2002, 12, 31);
      System.out.println("original=" + original);
      System.out.println("copy=" + copy);
   }
}
```

Listing 6.5 `clone/Employee.java`

```
package clone;

import java.util.Date;
import java.util.GregorianCalendar;

public class Employee implements Cloneable
{
   private String name;
   private double salary;
   private Date hireDay;

   public Employee(String name, double salary)
   {
      this.name = name;
      this.salary = salary;
      hireDay = new Date();
   }

   public Employee clone() throws CloneNotSupportedException
   {
      // call Object.clone()
      Employee cloned = (Employee) super.clone();

      // clone mutable fields
      cloned.hireDay = (Date) hireDay.clone();

      return cloned;
   }

   /**
```

```
    * Set the hire day to a given date.
    * @param year the year of the hire day
    * @param month the month of the hire day
    * @param day the day of the hire day
    */
   public void setHireDay(int year, int month, int day)
   {
      Date newHireDay = new GregorianCalendar(year, month - 1, day).getTime();

      // example of instance field mutation
      hireDay.setTime(newHireDay.getTime());
   }

   public void raiseSalary(double byPercent)
   {
      double raise = salary * byPercent / 100;
      salary += raise;
   }

   public String toString()
   {
      return "Employee[name=" + name + ",salary=" + salary + ",hireDay=" + hireDay + "]";
   }
}
```

6.2 Lambda Expressions

In the following sections, you will learn how to use lambda expressions for defining blocks of code with a concise syntax, and how to write code that consumes lambda expressions.

6.2.1 Why Lambdas?

A lambda expression is a block of code that you can pass around so it can be executed later, once or multiple times. Before getting into the syntax (or even the curious name), let’s step back and observe where we have used such code blocks in Java.

In Section 6.1.7, “Interfaces and Callbacks,” on p. 326, you saw how to do work in timed intervals. Put the work into the `actionPerformed` method of an `ActionListener`:

```
class Worker implements ActionListener
{
   public void actionPerformed(ActionEvent event)
   {
       // do some work
   }
}
```

Then, when you want to repeatedly execute this code, you construct an instance of the `Worker` class. You then submit the instance to a `Timer` object.

The key point is that the `actionPerformed` method contains code that you want to execute later.

Or consider sorting with a custom comparator. If you want to sort strings by length instead of the default dictionary order, you can pass a `Comparator` object to the `sort` method:

```
class LengthComparator implements Comparator<String>
{
   public int compare(String first, String second)
   {
      return first.length() - second.length();
   }
}
. . .
Arrays.sort(strings, new LengthComparator());
```

The `compare` method isn’t called right away. Instead, the `sort` method keeps calling the `compare` method, rearranging the elements if they are out of order, until the array is sorted. You give the `sort` method a snippet of code needed to compare elements, and that code is integrated into the rest of the sorting logic, which you'd probably not care to reimplement.

Both examples have something in common. A block of code was passed to someone—a timer, or a `sort` method. That code block was called at some later time.

Up to now, giving someone a block of code hasn't been easy in Java. You couldn't just pass code blocks around. Java is an object-oriented language, so you had to construct an object belonging to a class that has a method with the desired code.

In other languages, it is possible to work with blocks of code directly. The Java designers have resisted adding this feature for a long time. After all, a great strength of Java is its simplicity and consistency. A language can become an unmaintainable mess if it includes every feature that yields marginally more concise code. However, in those other languages it isn't just easier to spawn a thread or to register a button click handler; large swaths of their APIs are simpler, more consistent, and more powerful. In Java, one could have written similar APIs taking objects of classes that implement a particular interface, but such APIs would be unpleasant to use.

For some time, the question was not whether to augment Java for functional programming, but how to do it. It took several years of experimentation before a design emerged that is a good fit for Java. In the next section, you will see how you can work with blocks of code in Java.

6.2.2 The Syntax of Lambda Expressions

Consider again the sorting example from the preceding section. We pass code that checks whether one string is shorter than another. We compute

```
first.length() - second.length()
```

What are `first` and `second`? They are both strings. Java is a strongly typed language, and we must specify that as well:

```
(String first, String second)
   -> first.length() - second.length()
```

You have just seen your first *lambda expression*. Such an expression is simply a block of code, together with the specification of any variables that must be passed to the code.

Why the name? Many years ago, before there were any computers, the logician Alonzo Church wanted to formalize what it means for a mathematical function to be effectively computable. (Curiously, there are functions that are known to exist, but nobody knows how to compute their values.) He used the Greek letter lambda (λ) to mark parameters. Had he known about the Java API, he would have written

```
λfirst.λsecond.first.length() - second.length()
```

NOTE:

Why the letter λ? Did Church run out of other letters of the alphabet? Actually, the venerable *Principia Mathematica* used the ^ accent to denote free variables, which inspired Church to use an uppercase lambda Λ for parameters. But in the end, he switched to the lowercase version. Ever since, an expression with parameter variables has been called a lambda expression.

What you have just seen is a simple form of lambda expressions in Java: parameters, the -> arrow, and an expression. If the code carries out a computation that doesn't fit in a single expression, write it exactly like you would have written a method: enclosed in {} and with explicit `return` statements. For example,

```
(String first, String second) ->
   {
      if (first.length() < second.length()) return -1;
      else if (first.length() > second.length()) return 1;
```

```
        else return 0;
     }
```

If a lambda expression has no parameters, you still supply empty parentheses, just as with a parameterless method:

```
() -> { for (int i = 100; i >= 0; i--) System.out.println(i); }
```

If the parameter types of a lambda expression can be inferred, you can omit them. For example,

```
Comparator<String> comp
  = (first, second) // same as (String first, String second)
  -> first.length() - second.length();
```

Here, the compiler can deduce that `first` and `second` must be strings because the lambda expression is assigned to a string comparator. (We will have a closer look at this assignment in the next section.)

If a method has a single parameter with inferred type, you can even omit the parentheses:

```
ActionListener listener = event ->
   System.out.println("The time is "
    + Instant.ofEpochMilli(event.getWhen()));
    // instead of (event) -> . . . or (ActionEvent event) -> .
. .
```

You never specify the result type of a lambda expression. It is always inferred from context. For example, the expression

```
(String first, String second) -> first.length() -
second.length()
```

can be used in a context where a result of type `int` is expected.

Finally, you can use `var` to denote an inferred type. This isn't common. The syntax was invented for attaching annotations (see Chapter 8 of Volume II):

```
(@NonNull var first, @NonNull var second) -> first.length() -
second.length()
```

NOTE:

It is illegal for a lambda expression to return a value in some branches but not in others. For example, `(int x) -> { if (x >= 0) return 1; }` is invalid.

The program in Listing 6.6 shows how to use lambda expressions for a comparator and an action listener.

Listing 6.6 `lambda/LambdaTest.java`

```
package lambda;

import java.util.*;
import javax.swing.*;
import javax.swing.Timer;

/**
 * This program demonstrates the use of lambda expressions.
 * @version 1.0 2015-05-12
 * @author Cay Horstmann
 */
public class LambdaTest
{
   public static void main(String[] args)
   {
      var planets = new String[] { "Mercury", "Venus", "Earth", "Mars",
         "Jupiter", "Saturn", "Uranus", "Neptune" };
```

```
      System.out.println(Arrays.toString(planets));
      System.out.println("Sorted in dictionary order:");
      Arrays.sort(planets);
      System.out.println(Arrays.toString(planets));
      System.out.println("Sorted by length:");
      Arrays.sort(planets, (first, second) -> first.length() - second.length());
      System.out.println(Arrays.toString(planets));

      var timer = new Timer(1000, event ->
         System.out.println("The time is " + new Date()));
      timer.start();

      // keep program running until user selects "OK"
      JOptionPane.showMessageDialog(null, "Quit program?");
      System.exit(0);
   }
}
```

6.2.3 Functional Interfaces

As we discussed, there are many existing interfaces in Java that encapsulate blocks of code, such as `ActionListener` or `Comparator`. Lambdas are compatible with these interfaces.

You can supply a lambda expression whenever an object of an interface with a single abstract method is expected. Such an interface is called a *functional interface*.

NOTE:

You may wonder why a functional interface must have a single *abstract* method. Aren't all methods in an interface abstract? Actually, it has always been possible for an interface to redeclare methods from the `Object` class such as `toString` or `clone`, and these declarations do not make the methods abstract. (Some interfaces in the Java API redeclare `Object` methods in order to attach javadoc comments. Check out the `Comparator` API for an example.) More importantly, as you saw in Section 6.1.5, “Default Methods,” on p. 323, interfaces can declare nonabstract methods.

To demonstrate the conversion to a functional interface, consider the `Arrays.sort` method. Its second parameter requires an instance of `Comparator`, an interface with a single method. Simply supply a lambda:

```
Arrays.sort(words,
  (first, second) -> first.length() - second.length());
```

Behind the scenes, the `Arrays.sort` method receives an object of some class that implements `Comparator<String>`. Invoking the `compare` method on that object executes the body of the lambda expression. The management of these objects and classes is completely implementation-dependent, and it can be much more efficient than using traditional inner classes. It is best to think of a lambda expression as a function, not an object, and to accept that it can be passed to a functional interface.

This conversion to interfaces is what makes lambda expressions so compelling. The syntax is short and simple. Here is another example:

```
var timer = new Timer(1000, event ->
   {
     System.out.println("At the tone, the time is "
       + Instant.ofEpochMilli(event.getWhen()));
     Toolkit.getDefaultToolkit().beep();
   });
```

That’s a lot easier to read than the alternative with a class that implements the `ActionListener` interface.

In fact, conversion to a functional interface is the *only* thing that you can do with a lambda expression in Java. In other programming languages that support function literals, you can declare function types such as `(String, String) -> int`, declare variables of those types, and use the variables to save function expressions. However, the Java designers decided to stick with the familiar concept of interfaces instead of adding function types to the language.

NOTE:

You can't even assign a lambda expression to a variable of type `Object`—`Object` is not a functional interface.

The Java API defines a number of very generic functional interfaces in the `java.util.function` package. One of the interfaces, `BiFunction<T, U, R>`, describes functions with parameter types `T` and `U` and return type `R`. You can save your string comparison lambda in a variable of that type:

```
BiFunction<String, String, Integer> comp
   = (first, second) -> first.length() - second.length();
```

However, that does not help you with sorting. There is no `Arrays.sort` method that wants a `BiFunction`. If you have used a functional programming language before, you may find this curious. But for Java programmers, it's pretty natural. An interface such as `Comparator` has a specific purpose, not just a method with given parameter and return types. When you want to do something with lambda expressions, you still want to keep the purpose of the expression in mind, and have a specific functional interface for it.

A particularly useful interface in the `java.util.function` package is `Predicate`:

```
public interface Predicate<T>
{
  boolean test(T t);
  // additional default and static methods
}
```

The `ArrayList` class has a `removeIf` method whose parameter is a `Predicate`. It is specifically designed to pass a lambda expression. For example, the following statement removes all `null` values from an array list:

```
list.removeIf(e -> e == null);
```

Another useful functional interface is `Supplier<T>`:

```
public interface Supplier<T>
{
  T get();
}
```

A supplier has no arguments and yields a value of type `T` when it is called. Suppliers are used for *lazy evaluation*. For example, consider the call

```
LocalDate hireDay = Objects.requireNonNullElse(day,
   new LocalDate.of(1970, 1, 1));
```

This is not optimal. We expect that `day` is rarely `null`, so we only want to construct the default `LocalDate` when necessary. By using the supplier, we can defer the computation:

```
LocalDate hireDay = Objects.requireNonNullElseGet(day,
   () -> new LocalDate.of(1970, 1, 1));
```

The `requireNonNullElseGet` method only calls the supplier when the value is needed.

6.2.4 Method References

Sometimes, a lambda expression involves a single method. For example, suppose you simply want to print the event object whenever a timer event occurs. Of course, you could call

```
var timer = new Timer(1000, event ->
System.out.println(event));
```

It would be nicer if you could just pass the `println` method to the `Timer` constructor. Here is how you do that:

```
var timer = new Timer(1000, System.out::println);
```

The expression `System.out::println` is a *method reference*. It directs the compiler to produce an instance of a functional interface, overriding the single abstract method of the interface to call the given method. In this example, an `ActionListener` is produced whose `actionPerformed(ActionEvent e)` method calls `System.out.println(e)`.

NOTE:

Like a lambda expression, a method reference is not an object. It gives rise to an object when assigned to a variable whose type is a functional interface.

NOTE:

There are ten overloaded `println` methods in the `PrintStream` class (of which `System.out` is an instance). The compiler needs to figure out which one to use, depending on context. In our example, the method reference `System.out::println` must be turned into an `ActionListener` instance with a method

```
void actionPerformed(ActionEvent e)
```

The `println(Object x)` method is selected from the ten overloaded `println` methods since `Object` is the best match for `ActionEvent`. When the `actionPerformed` method is called, the event object is printed.

Now suppose we assign the same method reference to a different functional interface:

```
Runnable task = System.out::println;
```

The `Runnable` functional interface has a single abstract method with no parameters

```
void run()
```

In this case, the `println()` method with no parameters is chosen. Calling `task.run()` prints a blank line to `System.out`.

As another example, suppose you want to sort strings regardless of letter case. You can pass this method expression:

```
Arrays.sort(strings, String::compareToIgnoreCase)
```

As you can see from these examples, the `::` operator separates the method name from the name of an object or class. There are three variants:

1. *object*`::`*instanceMethod*

2. *Class*`::`*instanceMethod*

3. *Class*`::`*staticMethod*

In the first variant, the method reference is equivalent to a lambda expression whose parameters are passed to the method. In the case of `System.out::println`, the object is `System.out`, and the method expression is equivalent to `x -> System.out.println(x)`.

In the second variant, the first parameter becomes the implicit parameter of the method. For example, `String::compareToIgnoreCase` is the same as `(x, y) -> x.compareToIgnoreCase(y)`.

In the third variant, all parameters are passed to the static method: `Math::pow` is equivalent to `(x, y) -> Math.pow(x, y)`.

Table 6.1 walks you through additional examples.

Note that a lambda expression can only be rewritten as a method reference if the body of the lambda expression calls a single method and doesn't do anything else. Consider the lambda expression

```
s -> s.length() == 0
```

There is a single method call. But there is also a comparison, so you can't use a method reference here.

NOTE:

When there are multiple overloaded methods with the same name, the compiler will try to find from the context which one you mean. For example, there are two versions of the `Math.max` method, one for integers and one for `double` values. Which one gets picked depends on the method parameters of the functional interface to which `Math::max` is converted. Just like lambda expressions, method references don't live in isolation. They are always turned into instances of functional interfaces.

NOTE:

Sometimes, the API contains methods that are specifically intended to be used as method references. For example, the `Objects` class has a method `isNull` to test whether an object reference is `null`. At first glance, this doesn't seem useful because the test `obj == null` is easier to read than `Objects.isNull(obj)`. But you can pass the method reference to any method with a `Predicate` parameter. For example, to remove all `null` references from a list, you can call

```
list.removeIf(Objects::isNull);
   // A bit easier to read than list.removeIf(e -> e == null);
```

Table 6.1 Method Reference Examples

Method Reference	Equivalent Lambda Expression	Notes
`separator::equals`	`x -> separator.equals(x)`	This is a method expression with an *object* and an instance method. The lambda parameter is passed as the explicit parameter of the method.
`String::trim`	`x -> x.strip()`	This is a method expression with a *class* and an instance method. The lambda parameter becomes the implicit parameter.
`String::concat`	`(x, y) -> x.concat(y)`	Again, we have an instance method, but this time, with an explicit parameter. As before, the *first* lambda parameter becomes the implicit parameter, and the remaining ones are passed to the method.
`Integer::valueOf`	`x -> Integer.valueOf(x)`	This is a method expression with a *static* method. The lambda parameter is passed to the static method.
`Integer::sum`	`(x, y) -> Integer.sum(x, y)`	This is another static method, but this time with two parameters. Both lambda parameters are passed to the static method. The `Integer.sum` method was specifically created to be used as a method reference. As a lambda, you could just write `(x, y) -> x + y`.
`String::new`	`x -> new String(x)`	This is a constructor reference—see Section 6.2.5. The lambda parameters are passed to the constructor.
`String[]::new`	`n -> new String[n]`	This is an array constructor reference—see Section 6.2.5. The lambda parameter is the array length.

NOTE:

There is a tiny difference between a method reference with an object and its equivalent lambda expression. Consider a method reference such as `separator::equals`. If `separator` is `null`, forming `separator::equals` immediately throws a `NullPointerException`. The lambda expression `x -> separator.equals(x)` only throws a `NullPointerException` if it is invoked.

You can capture the `this` parameter in a method reference. For example, `this::equals` is the same as `x -> this.equals(x)`. It is also valid to use `super`. The method expression

`super::`*instanceMethod*

uses `this` as the target and invokes the superclass version of the given method. Here is an artificial example that shows the mechanics:

```
class Greeter
{
   public void greet(ActionEvent event)
   {
      System.out.println("Hello, the time is "
         + Instant.ofEpochMilli(event.getWhen()));
   }
}
class RepeatedGreeter extends Greeter
{
   public void greet(ActionEvent event)
   {
      var timer = new Timer(1000, super::greet);
      timer.start();
   }
}
```

When the `RepeatedGreeter.greet` method starts, a `Timer` is constructed that executes the `super::greet` method on every timer tick.

6.2.5 Constructor References

Constructor references are just like method references, except that the name of the method is `new`. For example, `Person::new` is a reference to a `Person` constructor. Which constructor? It depends on the context. Suppose you have a list of strings. Then you can turn it into an array of `Person` objects, by calling the constructor on each of the strings, with the following invocation:

```
ArrayList<String> names = . . .;
Stream<Person> stream = names.stream().map(Person::new);
List<Person> people = stream.toList();
```

We will discuss the details of the `stream`, `map`, and `toList` methods in Chapter 1 of Volume II. For now, what's important is that the `map` method calls the `Person(String)` constructor for each list element. If there are multiple `Person` constructors, the compiler picks the one with a `String` parameter because it infers from the context that the constructor is called with a string.

You can form constructor references with array types. For example, `int[]::new` is a constructor reference with one parameter: the length of the array. It is equivalent to the lambda expression `n -> new int[n]`.

Array constructor references are useful to overcome a limitation of Java. As you will see in Chapter 8, it is not possible to construct an array of a generic type `T`. (The expression `new T[n]` is an error since it would be "erased" to `new Object[n]`). That is a problem for library authors. For example, suppose we want to have an array of `Person` objects. The `Stream` interface has a `toArray` method that returns an `Object` array:

```
Object[] people = stream.toArray();
```

But that is unsatisfactory. The user wants an array of references to `Person`, not references to `Object`. The stream library solves that problem with constructor references. Pass `Person[]::new` to the `toArray` method:

```
Person[] people = stream.toArray(Person[]::new);
```

The `toArray` method invokes this constructor to obtain an array of the correct type. Then it fills and returns the array.

6.2.6 Variable Scope

Often, you want to be able to access variables from an enclosing method or class in a lambda expression. Consider this example:

```
public static void repeatMessage(String text, int delay)
{
   ActionListener listener = event ->
      {
         System.out.println(text);
         Toolkit.getDefaultToolkit().beep();
      };
   new Timer(delay, listener).start();
}
```

Consider a call

```
repeatMessage("Hello", 1000); // prints Hello every 1,000
milliseconds
```

Now look at the variable `text` inside the lambda expression. Note that this variable is *not* defined in the lambda expression. Instead, it is a parameter variable of the `repeatMessage` method.

If you think about it, something nonobvious is going on here. The code of the lambda expression may run long after the call to `repeatMessage` has returned and the parameter variables are gone. How does the `text` variable stay around?

To understand what is happening, we need to refine our understanding of a lambda expression. A lambda expression has three ingredients:

1. A block of code
2. Parameters
3. Values for the *free* variables—that is, the variables that are not parameters and not defined inside the code

In our example, the lambda expression has one free variable, `text`. The data structure representing the lambda expression must store the values for the free variables—in our case, the string `"Hello"`. We say that such values have been *captured* by the lambda expression. (It's an implementation detail how that is done. For example, one can translate a lambda expression into an object with a single method, so that the values of the free variables are copied into instance variables of that object.)

NOTE:

The technical term for a block of code together with the values of the free variables is a *closure*. If someone gloats that their language has closures, rest assured that Java has them as well. In Java, lambda expressions are closures.

As you have seen, a lambda expression can capture the value of a variable in the enclosing scope. In Java, to ensure that the captured value is well-defined, there is an important restriction. In a lambda expression, you can only reference variables whose value doesn't change. For example, the following is illegal:

```
public static void countDown(int start, int delay)
{
   ActionListener listener = event ->
        {
          start--; // ERROR: Can't mutate captured variable
          System.out.println(start);
```

```
        };
    new Timer(delay, listener).start();
}
```

There is a reason for this restriction. Mutating variables in a lambda expression is not safe when multiple actions are executed concurrently. This won't happen for the kinds of actions that we have seen so far, but in general, it is a serious problem. See Chapter 12 for more information on this important issue.

It is also illegal to refer, in a lambda expression, to a variable that is mutated outside. For example, the following is illegal:

```
public static void repeat(String text, int count)
{
  for (int i = 1; i <= count; i++)
  {
       ActionListener listener = event ->
          {
             System.out.println(i + ": " + text);
                 // ERROR: Cannot refer to changing i
          };
  new Timer(1000, listener).start();
  }
}
```

The rule is that any captured variable in a lambda expression must be *effectively final*. An effectively final variable is a variable that is never assigned a new value after it has been initialized. In our case, `text` always refers to the same `String` object, and it is OK to capture it. However, the value of `i` is mutated, and therefore `i` cannot be captured.

The body of a lambda expression has *the same scope as a nested block*. The same rules for name conflicts and shadowing apply. It is illegal to declare a parameter or a local variable in the lambda that has the same name as a local variable.

```
Path first = Path.of("/usr/bin");
Comparator<String> comp
   = (first, second) -> first.length() - second.length();
   // ERROR: Variable first already defined
```

Inside a method, you can't have two local variables with the same name, and therefore, you can't introduce such variables in a lambda expression either.

When you use the `this` keyword in a lambda expression, you refer to the `this` parameter of the method that creates the lambda. For example, consider

```
public class Application
{
   public void init()
   {
      ActionListener listener = event ->
         {
           System.out.println(this.toString());
           . . .
         }
      . . .
   }
}
```

The expression `this.toString()` calls the `toString` method of the `Application` object, *not* the `ActionListener` instance. There is nothing special about the use of `this` in a lambda expression. The scope of the lambda expression is nested inside the `init` method, and `this` has the same meaning anywhere in that method.

6.2.7 Processing Lambda Expressions

Up to now, you have seen how to produce lambda expressions and pass them to a method that expects a functional interface. Now let us see how to write methods that can consume lambda expressions.

The point of using lambdas is *deferred execution*. After all, if you wanted to execute some code right now, you'd do that, without wrapping it inside a lambda. There are many reasons for executing code later, such as:

- Running the code in a separate thread
- Running the code multiple times
- Running the code at the right point in an algorithm (for example, the comparison operation in sorting)
- Running the code when something happens (a button was clicked, data has arrived, and so on)
- Running the code only when necessary

Let's look at a simple example. Suppose you want to repeat an action `n` times. The action and the count are passed to a `repeat` method:

```
repeat(10, () -> System.out.println("Hello, World!"));
```

To accept the lambda, we need to pick (or, in rare cases, provide) a functional interface. Table 6.2 lists the most important functional interfaces that are provided in the Java API. In this case, we can use the `Runnable` interface:

```
public static void repeat(int n, Runnable action)
{
  for (int i = 0; i < n; i++) action.run();
}
```

Table 6.2 Common Functional Interfaces

Functional Interface	Parameter Types	Return Type	Abstract Method Name	Description	Other Methods
`Runnable`	none	`void`	`run`	Runs an action without arguments or return value	
`Supplier<T>`	none	`T`	`get`	Supplies a value of type `T`	
`Consumer<T>`	`T`	`void`	`accept`	Consumes a value of type `T`	`andThen`
`BiConsumer<T, U>`	`T, U`	`void`	`accept`	Consumes values of types `T` and `U`	`andThen`
`Function<T, R>`	`T`	`R`	`apply`	A function with argument of type `T`	`compose`, `andThen`, `identity`
`BiFunction<T, U, R>`	`T, U`	`R`	`apply`	A function with arguments of types `T` and `U`	`andThen`
`UnaryOperator<T>`	`T`	`T`	`apply`	A unary operator on the type `T`	`compose`, `andThen`, `identity`
`BinaryOperator<T>`	`T, T`	`T`	`apply`	A binary operator on the type `T`	`andThen`, `maxBy`, `minBy`
`Predicate<T>`	`T`	`boolean`	`test`	A boolean-valued function	`and`, `or`, `negate`, `isEqual`, `not`
`BiPredicate<T, U>`	`T, U`	`boolean`	`test`	A boolean-valued function with two arguments	`and`, `or`, `negate`

Note that the body of the lambda expression is executed when `action.run()` is called.

Now let's make this example a bit more sophisticated. We want to tell the action in which iteration it occurs. For that, we need to pick a functional interface that has a method with an `int` parameter and a `void` return. The standard interface for processing `int` values is

```
public interface IntConsumer
{
  void accept(int value);
}
```

Here is the improved version of the `repeat` method:

```
public static void repeat(int n, IntConsumer action)
{
  for (int i = 0; i < n; i++) action.accept(i);
}
```

And here is how you call it:

```
repeat(10, i -> System.out.println("Countdown: " + (9 - i)));
```

Table 6.3 lists the 34 available specializations for primitive types `int`, `long`, and `double`. As you will see in Chapter 8, it is more efficient to use these specializations than the generic interfaces. For that reason, I used an `IntConsumer` instead of a `Consumer<Integer>` in the example of the preceding section.

Table 6.3 Functional Interfaces for Primitive Types p, q is `int`, `long`, `double`; P, Q is `Int`, `Long`, `Double`

Functional Interface	Parameter Types	Return Type	Abstract Method Name
BooleanSupplier	none	boolean	getAsBoolean
*P*Supplier	none	*p*	getAs*P*
*P*Consumer	*p*	void	accept
Obj*P*Consumer<T>	T, *p*	void	accept
*P*Function<T>	*p*	T	apply
*P*To*Q*Function	*p*	*q*	applyAs*Q*
To*P*Function<T>	T	*p*	applyAs*P*
To*P*BiFunction<T, U>	T, U	*p*	applyAs*P*
*P*UnaryOperator	*p*	*p*	applyAs*P*
*P*BinaryOperator	*p*, *p*	*p*	applyAs*P*
*P*Predicate	*p*	boolean	test

TIP:

It is a good idea to use an interface from Tables 6.2 or 6.3 whenever you can. For example, suppose you write a method to process files that match a certain criterion. There is a legacy interface java.io.FileFilter, but it is better to use the standard Predicate<File>. The only reason not to do so would be if you already have many useful methods producing FileFilter instances.

NOTE:

Most of the standard functional interfaces have nonabstract methods for producing or combining functions. For example, Predicate.isEqual(a) is the same as `a::equals`, but it also works if `a` is `null`. There are default methods `and`, `or`, `negate` for combining predicates. For example, `Predicate.isEqual(a). or(Predicate.isEqual(b))` is the same as `x -> a.equals(x) || b.equals(x)`.

NOTE:

If you design your own interface with a single abstract method, you can tag it with the `@FunctionalInterface` annotation. This has two advantages. The compiler gives an error message if you accidentally add another abstract method. And the javadoc page includes a statement that your interface is a functional interface.

It is not required to use the annotation. Any interface with a single abstract method is, by definition, a functional interface. But using the `@FunctionalInterface` annotation is a good idea.

NOTE:

Some programmers love chains of method calls, such as

```
XXX
String input = " 618970019642690137449562111 ";
boolean isPrime = input.strip().transform(BigInteger::new).isProbablePrime(20);
```

The `transform` method of the `String` class (added in Java 12) applies a `Function` to the string and yields the result. You could have equally well written

```
boolean prime = new BigInteger(input.strip()).isProbablePrime(20);
```

But then your eyes jump inside-out and left-to-right to find out what happens first and what happens next: Calling `strip`, then constructing the `BigInteger`, and finally testing if it is a probable prime.

I am not sure that the eyes-jumping-inside-out-and-left-to-right is a huge problem. But if you prefer the orderly left-to-right sequence of chained method calls, then `transform` is your friend.

Sadly, it only works for strings. Why isn't there a `transform(java.util.function. Function)` method in the `Object` class?

The Java API designers weren't fast enough. They had one chance to do this right—in Java 8, when the `java.util.function.Function` interface was added to the API. Up to that point, nobody could have added a `transform(java.util.function. Function)` method to their own classes. But in Java 12, it was too late. Someone somewhere could have defined `transform(java.util.function.Function)` in their class, with a different meaning. Admittedly, it is unlikely that this ever happened, but there is no way to know.

That is how Java works. It takes its commitments seriously, and won't renege on them for convenience.

6.2.8 More about Comparators

The `Comparator` interface has a number of convenient static methods for creating comparators. These methods are intended to be used with lambda expressions or method references.

The static `comparing` method takes a "key extractor" function that maps a type `T` to a comparable type (such as `String`). The function is applied to the objects to be compared, and the comparison is then made on the returned keys. For example, suppose you have an array of `Person` objects. Here is how you can sort them by name:

```
Arrays.sort(people, Comparator.comparing(Person::getName));
```

This is certainly much easier than implementing a `Comparator` by hand. Moreover, the code is clearer since it is obvious that we want to compare people by name.

You can chain comparators with the `thenComparing` method for breaking ties. For example,

```
Arrays.sort(people,
      Comparator.comparing(Person::getLastName)
      .thenComparing(Person::getFirstName));
```

If two people have the same last name, then the second comparator is used.

There are a few variations of these methods. You can specify a comparator to be used for the keys that the `comparing` and `thenComparing` methods extract. For example, here we sort people by the length of their names:

```
Arrays.sort(people, Comparator.comparing(Person::getName,
  (s, t) -> Integer.compare(s.length(), t.length())));
```

Moreover, both the `comparing` and `thenComparing` methods have variants that avoid boxing of `int`, `long`, or `double` values. An easier way of producing the preceding operation would be

```
Arrays.sort(people, Comparator.comparingInt(p ->
p.getName().length()));
```

If your key function can return `null`, you will like the `nullsFirst` and `nullsLast` adapters. These static methods take an existing comparator and modify it so that it doesn't throw an exception when encountering `null` values but ranks them as smaller or larger than regular values. For example, suppose `getMiddleName` returns a `null` when a person has no middle name. Then you can use `Comparator.comparing(Person::getMiddleName, Comparator.nullsFirst(. . .))`.

The nullsFirst method needs a comparator—in this case, one that compares two strings. The naturalOrder method makes a comparator for any class implementing Comparable. A Comparator.<String>naturalOrder() is what we need. Here is the complete call for sorting by potentially null middle names. I use a static import of java.util.Comparator.*, to make the expression more legible. Note that the type for naturalOrder is inferred.

```
Arrays.sort(people, comparing(Person::getMiddleName,
nullsFirst(naturalOrder())));
```

The static reverseOrder method gives the reverse of the natural order. To reverse any comparator, use the reversed instance method. For example, naturalOrder(). reversed() is the same as reverseOrder().

6.3 Inner Classes

An *inner class* is a class that is defined inside another class. Why would you want to do that? There are two reasons:

- Inner classes can be hidden from other classes in the same package.
- Inner class methods can access the data from the scope in which they are defined—including the data that would otherwise be private.

Inner classes used to be very important for concisely implementing callbacks, but nowadays lambda expressions do a much better job. Still, inner classes can be very useful for structuring your code. The following sections walk you through all the details.

C++ NOTE:

C++ has *nested classes*. A nested class is contained inside the scope of the enclosing class. Here is a typical example: A linked list class defines a class to hold the links, and a class to define an iterator position.

```
class LinkedList
{
public:
   class Iterator // a nested class
   {
   public:
      void insert(int x);
      int erase();
      . . .
   private:
      Link* current;
      LinkedList* owner;
   };
   . . .
private:
   Link* head;
   Link* tail;
};
```

Nested classes are similar to inner classes in Java. However, the Java inner classes have an additional feature that makes them richer and more useful than nested classes in C++. An object that comes from an inner class has an implicit reference to the outer class object that instantiated it. Through this pointer, it gains access to the total state of the outer object. For example, in Java, the `Iterator` class would not need an explicit pointer to the `LinkedList` into which it points.

In Java, `static` inner classes do not have this added pointer. They are the Java analog to nested classes in C++.

6.3.1 Use of an Inner Class to Access Object State

The syntax for inner classes is rather complex. For that reason, I present a simple but somewhat artificial example to demonstrate the use of inner classes. Let's refactor the `TimerTest` example and extract a `TalkingClock` class. A talking clock is constructed with two parameters: the interval between announcements and a flag to turn beeps on or off.

```
public class TalkingClock
{
  private int interval;
  private boolean beep;
  public TalkingClock(int interval, boolean beep) { . . . }
  public void start() { . . . }
  public class TimePrinter implements ActionListener
     // an inner class
  {
  . . .
  }
}
```

Note that the `TimePrinter` class is now located inside the `TalkingClock` class. This does *not* mean that every `TalkingClock` has a `TimePrinter` instance field. As you will see, the `TimePrinter` objects are constructed by methods of the `TalkingClock` class.

Here is the `TimePrinter` class in greater detail. Note that the `actionPerformed` method checks the `beep` flag before emitting a beep.

```
public class TimePrinter implements ActionListener
{
   public void actionPerformed(ActionEvent event)
   {
      System.out.println("At the tone, the time is "
         + Instant.ofEpochMilli(event.getWhen()));
      if (beep) Toolkit.getDefaultToolkit().beep();
   }
}
```

Something surprising is going on. The `TimePrinter` class has no instance field or variable named `beep`. Instead, `beep` refers to the field of the `TalkingClock` object that created this `TimePrinter`. As you can see, an inner class method gets to access both its own instance fields *and* those of the outer object creating it.

For this to work, an object of an inner class always gets an implicit reference to the object that created it (see Figure 6.3).

This reference is invisible in the definition of the inner class. However, to illuminate the concept, let us call the reference to the outer object *outer*. Then the `actionPerformed` method is equivalent to the following:

```
public void actionPerformed(ActionEvent event)
{
   System.out.println("At the tone, the time is "
      + Instant.ofEpochMilli(event.getWhen()));
   if (outer.beep) Toolkit.getDefaultToolkit().beep();
}
```

The outer class reference is set in the constructor. The compiler modifies all inner class constructors, adding a parameter for the outer class reference. The `TimePrinter` class defines no constructors; therefore, the compiler synthesizes a no-argument constructor, generating code like this:

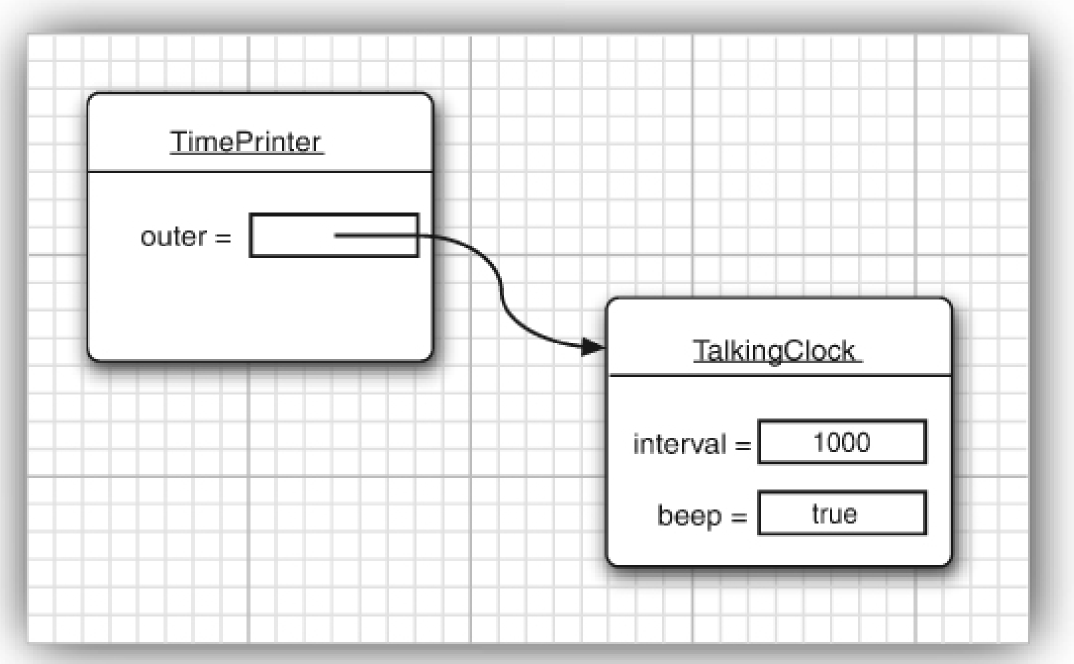


Figure 6.3 An inner class object has a reference to an outer class object.

```
public TimePrinter(TalkingClock clock) // automatically
generated code
{
   outer = clock;
}
```

Again, please note that *outer* is not a Java keyword. We just use it to illustrate the mechanism involved in an inner class.

When a `TimePrinter` object is constructed in the `start` method, the compiler passes the `this` reference to the current talking clock into the constructor:

```
var listener = new TimePrinter(this); // parameter
automatically added
```

Listing 6.7 shows the complete program that tests the inner class. Have another look at the access control. Had the `TimePrinter` class been a regular class, it would have needed to access the `beep` flag through a public method of the `TalkingClock` class. Using an inner class is an improvement. There is no need to provide accessors that are of interest only to one other class.

NOTE:

We could have declared the `TimePrinter` class as `private`. Then only `TalkingClock` methods would be able to construct `TimePrinter` objects. Only inner classes can be private. Regular classes always have either package or public access.

Listing 6.7 `innerClass/InnerClassTest.java`

```
package innerClass;

```

```
import java.awt.*;
import java.awt.event.*;
import java.time.*;

import javax.swing.*;

/**
 * This program demonstrates the use of inner classes.
 * @version 1.11 2017-12-14
 * @author Cay Horstmann
 */
public class InnerClassTest
{
   public static void main(String[] args)
   {
      var clock = new TalkingClock(1000, true);
      clock.start();

      // keep program running until the user selects "OK"
      JOptionPane.showMessageDialog(null, "Quit program?");
      System.exit(0);
   }
}

/**
 * A clock that prints the time in regular intervals.
 */
class TalkingClock
{
   private int interval;
   private boolean beep;

  /**
   * Constructs a talking clock
   * @param interval the interval between messages (in milliseconds)
   * @param beep true if the clock should beep
   */
  public TalkingClock(int interval, boolean beep)
```

```
    {
     this.interval = interval;
     this.beep = beep;
    }

   /**
    * Starts the clock.
    */
   public void start()
   {
      var listener = new TimePrinter();
      var timer = new Timer(interval, listener);
      timer.start();
   }

   public class TimePrinter implements ActionListener
   {
      public void actionPerformed(ActionEvent event)
      {
         System.out.println("At the tone, the time is "
            + Instant.ofEpochMilli(event.getWhen()));
         if (beep) Toolkit.getDefaultToolkit().beep();
      }
   }
}
```

6.3.2 Special Syntax Rules for Inner Classes

In the preceding section, we explained the outer class reference of an inner class by calling it *outer*. Actually, the proper syntax for the outer reference is a bit more complex. The expression

OuterClass`.this`

denotes the outer class reference. For example, you can write the `actionPerformed` method of the `TimePrinter` inner class as

```
public void actionPerformed(ActionEvent event)
{
  . . .
  if (TalkingClock.this.beep)
Toolkit.getDefaultToolkit().beep();
}
```

Conversely, you can write the inner object constructor more explicitly, using the syntax

outerObject`.new` *InnerClass*`(`*construction parameters*`)`

For example:

```
ActionListener listener = this.new TimePrinter();
```

Here, the outer class reference of the newly constructed `TimePrinter` object is set to the `this` reference of the method that creates the inner class object. This is the most common case. As always, the `this.` qualifier is redundant. However, it is also possible to set the outer class reference to another object by explicitly naming it. For example, since `TimePrinter` is a public inner class, you can construct a `TimePrinter` for any talking clock:

```
var jabberer = new TalkingClock(1000, true);
TalkingClock.TimePrinter listener = jabberer.new TimePrinter();
```

Note that you refer to an inner class as

OuterClass`.`*InnerClass*

when it occurs outside the scope of the outer class.

NOTE:

Any static fields declared in an inner class must be final and initialized with a compile-time constant. If the field was not a constant, it might not be unique.

An inner class cannot have `static` methods. The Java Language Specification gives no reason for this limitation. It would have been possible to allow static methods that only access static fields and methods from the enclosing class. Apparently, the language designers decided that the complexities outweighed the benefits.

6.3.3 Are Inner Classes Useful? Actually Necessary? Secure?

When inner classes were added to the Java language in Java 1.1, many programmers considered them a major new feature that was out of character with the Java philosophy of being simpler than C++. The inner class syntax is undeniably complex. (It gets more complex as we study anonymous inner classes later in this chapter.) It is not obvious how inner classes interact with other features of the language, such as access control and security.

Inner classes are translated into regular class files with `$` (dollar signs) separating the outer and inner class names. For example, the `TimePrinter` class inside the `TalkingClock` class is translated to a class file `TalkingClock$TimePrinter.class`. To see this at work, try the following experiment: run the `ReflectionTest` program of Chapter 5, and give it the class `TalkingClock$TimePrinter` to reflect upon. Alternatively, simply use the `javap` utility:

```
javap -private ClassName
```

NOTE:

If you use UNIX, remember to escape the `$` character when you supply the class name on the command line. That is, run the `ReflectionTest` or `javap` program as

```
java --classpath .:../v1ch05 reflection.ReflectionTest \
   innerClass.TalkingClock\$TimePrinter
```

or

```
javap -private innerClass.TalkingClock\$TimePrinter
```

You will get the following printout:

```
public class innerClass.TalkingClock$TimePrinter
     implements java.awt.event.ActionListener
{
  final innerClass.TalkingClock this$0;
  public
innerClass.TalkingClock$TimePrinter(innerClass.TalkingClock);
  public void actionPerformed(java.awt.event.ActionEvent);
}
```

You can plainly see that the compiler has generated an additional instance field, `this$0`, for the reference to the outer class. (The name `this$0` is synthesized by the compiler—you cannot refer to it in your code.) You can also see the `TalkingClock` parameter for the constructor.

If the compiler can automatically do this transformation, couldn't you simply program the same mechanism by hand? Let's try it. We would make `TimePrinter` a regular class, outside the `TalkingClock` class. When constructing a `TimePrinter` object, we pass it the `this` reference of the object that is creating it.

```
class TalkingClock
{
  . . .
  public void start()
  {
      var listener = new TimePrinter(this);
```

```
        var timer = new Timer(interval, listener);
        timer.start();
    }
  }
  class TimePrinter implements ActionListener
  {
    private TalkingClock outer;
    . . .
    public TimePrinter(TalkingClock clock)
    {
        outer = clock;
    }
  }
```

Now let us look at the `actionPerformed` method. It needs to access `outer.beep`.

```
  if (outer.beep) . . . // ERROR
```

Here we run into a problem. The inner class can access the private data of the outer class, but our external `TimePrinter` class cannot.

Thus, inner classes are genuinely more powerful than regular classes because they have more access privileges.

You may well wonder how inner classes manage to acquire those added access privileges. Before Java 11, inner classes were purely a phenomenon of the *compiler*, and the virtual machine did not have any special knowledge about them. In those days, spying on the `TalkingClock` class with the `ReflectionTest` pro-gram or with `javap` and the `-private` option showed:

```
  class TalkingClock
  {
    private int interval;
    private boolean beep;
    public TalkingClock(int, boolean);
    static boolean access$0(TalkingClock); // Prior to Java 11
```

```
    public void start();
}
```

Notice the static `access$0` method that the compiler added to the outer class. It returns the `beep` field of the object that is passed as a parameter. (The method name might be slightly different, such as `access$000`, depending on the compiler.)

That was a potential security risk, and it made life complicated for tools that analyze class files. As of Java 11, the virtual machine understands nesting relationships between classes, and the access methods are no longer generated.

6.3.4 Local Inner Classes

If you look carefully at the code of the `TalkingClock` example, you will find that you need the name of the type `TimePrinter` only once: when you create an object of that type in the `start` method.

In a situation like this, you can define the class *locally in a single method*.

```
public void start()
{
   class TimePrinter implements ActionListener
   {
      public void actionPerformed(ActionEvent event)
      {
         System.out.println("At the tone, the time is "
            + Instant.ofEpochMilli(event.getWhen()));
         if (beep) Toolkit.getDefaultToolkit().beep();
      }
   }
   var listener = new TimePrinter();
   var timer = new Timer(interval, listener);
   timer.start();
}
```

Local classes are never declared with an access specifier (that is, `public` or `private`). Their scope is always restricted to the block in which they are declared.

Local classes have one great advantage: They are completely hidden from the outside world—not even other code in the `TalkingClock` class can access them. No method except `start` has any knowledge of the `TimePrinter` class.

6.3.5 Accessing Variables from Outer Methods

Local classes have another advantage over other inner classes. Not only can they access the fields of their outer classes; they can even access local variables! However, those local variables must be *effectively* `final`. That means, they may never change once they have been assigned.

Here is a typical example. Let's move the `interval` and `beep` parameters from the `TalkingClock` constructor to the `start` method.

```
public void start(int interval, boolean beep)
{
   class TimePrinter implements ActionListener
   {
      public void actionPerformed(ActionEvent event)
      {
         System.out.println("At the tone, the time is "
            + Instant.ofEpochMilli(event.getWhen()));
         if (beep) Toolkit.getDefaultToolkit().beep();
      }
   }
   var listener = new TimePrinter();
   var timer = new Timer(interval, listener);
   timer.start();
}
```

Note that the `TalkingClock` class no longer needs to store a `beep` instance field. It simply refers to the `beep` parameter variable of the `start` method.

Maybe this should not be so surprising. The line

```
if (beep) . . .
```

is, after all, ultimately inside the `start` method, so why shouldn't it have access to the value of the `beep` variable?

To see why there is a subtle issue here, let's consider the flow of control more closely.

1. The `start` method is called.
2. The object variable `listener` is initialized by a call to the constructor of the inner class `TimePrinter`.
3. The `listener` reference is passed to the `Timer` constructor, the timer is started, and the `start` method exits. At this point, the `beep` parameter variable of the `start` method no longer exists.
4. A second later, the `actionPerformed` method executes `if (beep) . . .`

For the code in the `actionPerformed` method to work, the `TimePrinter` class must have copied the `beep` field as a local variable of the `start` method, before the `beep` parameter value went away. That is indeed exactly what happens. In our example, the compiler synthesizes the name `TalkingClock$1TimePrinter` for the local inner class. If you use the `ReflectionTest` program or the `javap` utility again to spy on the `TalkingClock$1TimePrinter` class, you will get the following output:

```
class TalkingClock$1TimePrinter
{
  TalkingClock$1TimePrinter();
  public void actionPerformed(java.awt.event.ActionEvent);
  final boolean val$beep;
  final TalkingClock this$0;
}
```

When an object is created, the current value of the `beep` variable is stored in the `val$beep` field. As of Java 11, this happens with "nest mate" access. Previously, the inner class constructor had an additional parameter to set the field. Either way, the inner class field persists even if the local variable goes out of scope.

6.3.6 Anonymous Inner Classes

When using local inner classes, you can often go a step further. If you want to make only a single object of this class, you don't even need to give the class a name. Such a class is called an *anonymous inner class*.

```
public void start(int interval, boolean beep)
{
   var listener = new ActionListener()
      {
         public void actionPerformed(ActionEvent event)
         {
            System.out.println("At the tone, the time is "
               + Instant.ofEpochMilli(event.getWhen()));
            if (beep) Toolkit.getDefaultToolkit().beep();
         }
      };
   var timer = new Timer(interval, listener);
   timer.start();
}
```

This syntax is very cryptic indeed. What it means is this: Create a new object of a class that implements the `ActionListener` interface, where the required method `actionPerformed` is the one defined inside the braces `{ }`.

In general, the syntax is

```
new SuperType(construction parameters)
   {
inner class methods and data
   }
```

Here, *SuperType* can be an interface, such as `ActionListener`; then, the inner class implements that interface. *SuperType* can also be a class; then, the inner class extends that class.

An anonymous inner class cannot have constructors because the name of a constructor must be the same as the name of a class, and the class has no name. Instead, the construction parameters are given to the *superclass* constructor. In particular, whenever an inner class implements an interface, it cannot have any construction parameters. Nevertheless, you must supply a set of parentheses as in

```
new InterfaceType()
  {
    methods and data
  }
```

You have to look carefully to see the difference between the construction of a new object of a class and the construction of an object of an anonymous inner class extending that class.

```
var queen = new Person("Mary");
  // a Person object
var count = new Person("Dracula") { . . . };
  // an object of an inner class extending Person
```

If the closing parenthesis of the construction parameter list is followed by an opening brace, then an anonymous inner class is being defined.

NOTE:

Even though an anonymous class cannot have constructors, you can provide an object initialization block:

```
var count = new Person("Dracula")
  {
     { initialization }
     . . .
  };
```

Listing 6.8 contains the complete source code for the talking clock program with an anonymous inner class. If you compare this program with Listing 6.7, you will see that in this case, the solution with the anonymous inner class is quite a bit shorter and, hopefully, with some practice, as easy to comprehend.

For many years, Java programmers routinely used anonymous inner classes for event listeners and other callbacks. Nowadays, you are better off using a lambda expression. For example, the `start` method from the beginning of this section can be written much more concisely with a lambda expression like this:

```
public void start(int interval, boolean beep)
{
  var timer = new Timer(interval, event -> {
System.out.println(
     "At the tone, the time is " +
Instant.ofEpochMilli(event.getWhen()));
     if (beep) Toolkit.getDefaultToolkit().beep(); });
  timer.start();
}
```

NOTE:

If you store an anonymous class instance in a variable defined with `var`, the variable knows about added methods or fields:

```
var bob = new Object() { String name = "Bob"; }
System.out.println(bob.name);
```

If you declare `bob` as having type `Object`, then `bob.name` does not compile.

The object constructed with `new Object() { String name = "Bob"; }` has type "`Object` with a `Sting name` field". This is a *non-denotable* type—a type that you cannot express with Java syntax. Nevertheless, the compiler understands the type, and it can set it as the type for the `bob` variable.

NOTE:

The following trick, called *double brace initialization*, takes advantage of the inner class syntax. Suppose you want to construct an array list and pass it to a method:

```
var friends = new ArrayList<String>();
friends.add("Harry");
friends.add("Tony");
invite(friends);
```

If you don't need the array list again, it would be nice to make it anonymous. But then how can you add the elements? Here is how:

```
invite(new ArrayList<String>() {{ add("Harry"); add("Tony");
}});
```

Note the double braces. The outer braces make an anonymous subclass of `ArrayList`. The inner braces are an object initialization block (see Chapter 4).

In practice, this trick is rarely useful. More likely than not, the `invite` method is willing to accept any `List<String>`, and you can simply pass `List.of("Harry", "Tony")`.

CAUTION:

It is often convenient to make an anonymous subclass that is almost, but not quite, like its superclass. But you need to be careful with the `equals` method. In Chapter 5, I recommended that your `equals` methods use a test

```
if (getClass() != other.getClass()) return false;
```

An anonymous subclass will fail this test.

TIP:

When you produce logging or debugging messages, you often want to include the name of the current class, such as

```
System.err.println("Something awful happened in " + getClass());
```

But that fails in a static method. After all, the call to `getClass` calls `this.getClass()`, and a static method has no `this`. Use the following expression instead:

```
new Object(){}.getClass().getEnclosingClass() // gets class of static method
```

Here, `new Object(){}` makes an anonymous object of an anonymous subclass of `Object`, and `getEnclosingClass` gets its enclosing class—that is, the class containing the static method.

Listing 6.8 `anonymousInnerClass/AnonymousInnerClassTest.java`

```java
package anonymousInnerClass;

import java.awt.*;
import java.awt.event.*;
import java.time.*;

import javax.swing.*;

/**
 * This program demonstrates anonymous inner classes.
 * @version 1.12 2017-12-14
 * @author Cay Horstmann
 */
public class AnonymousInnerClassTest
{
   public static void main(String[] args)
   {
      var clock = new TalkingClock();
      clock.start(1000, true);

      // keep program running until the user selects "OK"
      JOptionPane.showMessageDialog(null, "Quit program?");
      System.exit(0);
   }
}

/**
 * A clock that prints the time in regular intervals.
 */
class TalkingClock
{
 /**
  * Starts the clock.
  * @param interval the interval between messages (in milliseconds)
  * @param beep true if the clock should beep
  */
 public void start(int interval, boolean beep)
 {
```

```
   var listener = new ActionListener()
      {
         public void actionPerformed(ActionEvent event)
         {
            System.out.println("At the tone, the time is "
               + Instant.ofEpochMilli(event.getWhen()));
            if (beep) Toolkit.getDefaultToolkit().beep();
         }
      };
   var timer = new Timer(interval, listener);
   timer.start();
 }
}
```

6.3.7 Static Inner Classes

Occasionally, you may want to use an inner class simply to hide one class inside another—but you don't need the inner class to have a reference to the outer class object. You can suppress the generation of that reference by declaring the inner class `static`.

Here is a typical example of where you would want to do this. Consider the task of computing the minimum and maximum value in an array. Of course, you write one method to compute the minimum and another method to compute the maximum. When you call both methods, the array is traversed twice. It would be more efficient to traverse the array only once, computing both the minimum and the maximum simultaneously.

```
double min = Double.POSITIVE_INFINITY;
double max = Double.NEGATIVE_INFINITY;
for (double v : values)
{
  if (min > v) min = v;
  if (max < v) max = v;
}
```

However, the method must return two numbers. We can achieve that by defining a class `Pair` that holds two values:

```
class Pair
{
  private double first;
  private double second;
  public Pair(double f, double s)
  {
     first = f;
     second = s;
  }
  public double getFirst() { return first; }
  public double getSecond() {  return second; }
}
```

The `minmax` method can then return an object of type `Pair`.

```
class ArrayAlg
{
  public static Pair minmax(double[] values)
  {
    . . .
    return new Pair(min, max);
  }
}
```

The caller of the method uses the `getFirst` and `getSecond` methods to retrieve the answers:

```
Pair p = ArrayAlg.minmax(d);
System.out.println("min = " + p.getFirst());
System.out.println("max = " + p.getSecond());
```

Of course, the name `Pair` is an exceedingly common name, and in a large project, it is quite possible that some other programmer had the same bright idea—but made a `Pair` class that contains a pair of strings. We can solve this potential name clash by making `Pair` a public inner class inside `ArrayAlg`. Then the class will be known to the public as `ArrayAlg.Pair`:

```
ArrayAlg.Pair p = ArrayAlg.minmax(d);
```

However, unlike the inner classes used in previous examples, we do not want to have a reference to any other object inside a `Pair` object. That reference can be suppressed by declaring the inner class `static`:

```
class ArrayAlg
{
  public static class Pair
  {
    . . .
  }
  . . .
}
```

Of course, only inner classes can be declared static. A static inner class is exactly like any other inner class, except that an object of a static inner class does not have a reference to the outer class object that generated it. In our example, we must use a static inner class because the inner class object is constructed inside a static method:

```
public static Pair minmax(double[] d)
{
  . . .
  return new Pair(min, max);
}
```

Had the `Pair` class not been declared as `static`, the compiler would have complained that there was no implicit object of type `ArrayAlg` available to initialize the inner class object.

NOTE:

Use a static inner class whenever the inner class does not need to access an outer class object. Some programmers use the term *nested class* to describe static inner classes.

NOTE:

Unlike regular inner classes, static inner classes can have static fields and methods.

NOTE:

Classes that are declared inside an interface are automatically `static` and `public`.

NOTE:

Interfaces, records, and enumerations that are declared inside a class are automatically `static`.

Listing 6.9 contains the complete source code of the `ArrayAlg` class and the nested `Pair` class.

Listing 6.9 `staticInnerClass/StaticInnerClassTest.java`

```java
package staticInnerClass;

/**
 * This program demonstrates the use of static inner classes.
 * @version 1.02 2015-05-12
 * @author Cay Horstmann
 */
public class StaticInnerClassTest
{
   public static void main(String[] args)
   {
      var values = new double[20];
      for (int i = 0; i < values.length; i++)
         values[i] = 100 * Math.random();
      ArrayAlg.Pair p = ArrayAlg.minmax(values);
      System.out.println("min = " + p.getFirst());
      System.out.println("max = " + p.getSecond());
   }
}

class ArrayAlg
{
  /**
   * A pair of floating-point numbers
   */
  public static class Pair
  {
      private double first;
      private double second;

    /**
     * Constructs a pair from two floating-point numbers
     * @param f the first number
     * @param s the second number
     */
    public Pair(double f, double s)
    {
      first = f;
      second = s;
```

```
  }

  /**
   * Returns the first number of the pair
   * @return the first number
   */
  public double getFirst()
  {
   return first;
  }

  /**
   * Returns the second number of the pair
   * @return the second number
   */
  public double getSecond()
  {
   return second;
  }
}

/**
 * Computes both the minimum and the maximum of an array
 * @param values an array of floating-point numbers
 * @return a pair whose first element is the minimum and whose second element
 * is the maximum
 */
public static Pair minmax(double[] values)
{
   double min = Double.POSITIVE_INFINITY;
   double max = Double.NEGATIVE_INFINITY;
   for (double v : values)
   {
      if (min > v) min = v;
      if (max < v) max = v;
   }
   return new Pair(min, max);
```

```
   }
}
```

6.4 Service Loaders

Sometimes, you develop an application with a service architecture. There are platforms that encourage this approach, such as OSGi (`http://osgi.org`), which are used in development environments, application servers, and other complex applications. Such platforms go well beyond the scope of this book, but the JDK also offers a simple mechanism for loading services, described here. This mechanism is well supported by the Java Platform Module System—see Chapter 9 of Volume II.

Often, when providing a service, a program wants to give the service designer some freedom of how to implement the service's features. It can also be desirable to have multiple implementations to choose from. The `ServiceLoader` class makes it easy to load services that conform to a common interface.

Define an interface (or, if you prefer, a superclass) with the methods that each instance of the service should provide. For example, suppose your service provides encryption.

```
package serviceLoader;
public interface Cipher
{
    byte[] encrypt(byte[] source, byte[] key);
    byte[] decrypt(byte[] source, byte[] key);
    int strength();
}
```

The service provider supplies one or more classes that implement this service, for example

```
package serviceLoader.impl;
public class CaesarCipher implements Cipher
{
```

```
    public byte[] encrypt(byte[] source, byte[] key)
    {
      var result = new byte[source.length];
      for (int i = 0; i < source.length; i++)
         result[i] = (byte)(source[i] + key[0]);
      return result;
    }
    public byte[] decrypt(byte[] source, byte[] key)
    {
      return encrypt(source, new byte[] { (byte) -key[0] });
    }
    public int strength() { return 1; }
}
```

The implementing classes can be in any package, not necessarily the same package as the service interface. Each of them must have a no-argument constructor.

Now add the names of the classes to a UTF-8 encoded text file in a file in the `META-INF/services` directory whose name matches the fully qualified interface name. In our example, the file `META-INF/services/serviceLoader.Cipher` would contain the line

```
serviceLoader.impl.CaesarCipher
```

In this example, we provide a single implementing class. You could also provide multiple classes and later pick among them.

With this preparation done, the program initializes a service loader as follows:

```
public static ServiceLoader<Cipher> cipherLoader =
ServiceLoader.load(Cipher.class);
```

This should be done just once in the program.

The `iterator` method of the service loader returns an iterator through all provided implementations of the service. (See Chapter 9 for more information about iterators.) It is easiest to use an enhanced `for` loop to traverse them. In the loop, pick an appropriate object to carry out the service.

```
public static Cipher getCipher(int minStrength)
{
  for (Cipher cipher : cipherLoader) // implicitly calls
cipherLoader.iterator()
  {
     if (cipher.strength() >= minStrength) return cipher;
  }
  return null;
}
```

Alternatively, you can use streams (see Chapter 1 of Volume II) to locate the desired service. The `stream` method yields a stream of `ServiceLoader.Provider` instances. That interface has methods `type` and `get` for getting the provider class and the provider instance. If you select a provider by type, then you just call `type` and no service instances are unnecessarily instantiated.

```
public static Optional<Cipher> getCipher2(int minStrength)
{
  return cipherLoader.stream()
     .filter(descr -> descr.type() ==
serviceLoader.impl.CaesarCipher.class)
     .findFirst()
     .map(ServiceLoader.Provider::get);
}
```

Finally, if you are willing to take any service instance, simply call `findFirst`:

```
Optional<Cipher> cipher = cipherLoader.findFirst();
```

The `Optional` class is explained in Chapter 1 of Volume II.

java.util.ServiceLoader<S> 1.6

- `static <S> ServiceLoader<S> load(Class<S> service)`

  creates a service loader for loading the classes that implement the given service interface.

- `Iterator<S> iterator()`

  yields an iterator that lazily loads the service classes. That is, a class is loaded whenever the iterator advances.

- `Stream<ServiceLoader.Provider<S>> stream()` 9

  returns a stream of provider descriptors, so that a provider of a desired class can be loaded lazily.

- `Optional<S> findFirst()` 9

  finds the first available service provider, if any.

java.util.ServiceLoader.Provider<S> 9

- `Class<? extends S> type()`

  gets the type of this provider.

- `S get()`

  gets an instance of this provider.

6.5 Proxies

In the final section of this chapter, we discuss *proxies*. You can use a proxy to create, at runtime, new classes that implement a given set of interfaces. Proxies are only necessary when you don't yet know at compile time which interfaces you need to implement. This is not a common situation for application programmers, so feel free to skip this section if you are not interested in advanced wizardry. However, for certain systems programming applications, the flexibility that proxies offer can be very important.

6.5.1 When to Use Proxies

Suppose you want to construct an object of a class that implements one or more interfaces whose exact nature you may not know at compile time. This is a difficult problem. To construct an actual class, you can simply use the `newInstance` method or use reflection to find a constructor. But you can't instantiate an interface. You need to define a new class in a running program.

To overcome this problem, some programs generate code, place it into a file, invoke the compiler, and then load the resulting class file. Naturally, this is slow, and it also requires deployment of the compiler together with the program. The *proxy* mechanism is a better solution. The proxy class can create brand-new classes at runtime. Such a proxy class implements the interfaces that you specify. In particular, the proxy class has the following methods:

- All methods required by the specified interfaces; and
- All methods defined in the `Object` class (`toString`, `equals`, and so on).

However, you cannot define new code for these methods at runtime. Instead, you must supply an *invocation handler*. An invocation handler is an object of any class that implements the `InvocationHandler` interface. That interface has a single method:

```
Object invoke(Object proxy, Method method, Object[] args)
```

Whenever a method is called on the proxy object, the `invoke` method of the invocation handler gets called, with the `Method` object and parameters of the original call. The invocation handler must then figure out how to handle the call.

6.5.2 Creating Proxy Objects

To create a proxy object, use the `newProxyInstance` method of the `Proxy` class. The method has three parameters:

- A *class loader*. As part of the Java security model, different class loaders can be used for platform and application classes, classes that are downloaded from the Internet, and so on. We will discuss class loaders in Chapter 9 of Volume II. In this example, we specify the "system class loader" that loads platform and application classes.
- An array of `Class` objects, one for each interface to be implemented.
- An invocation handler.

There are two remaining questions. How do we define the handler? And what can we do with the resulting proxy object? The answers depend, of course, on the problem that we want to solve with the proxy mechanism. Proxies can be used for many purposes, such as

- Routing method calls to remote servers
- Associating user interface events with actions in a running program
- Tracing method calls for debugging purposes

In our example program, we use proxies and invocation handlers to trace method calls. We define a `TraceHandler` wrapper class that stores a wrapped object. Its `invoke` method simply prints the name and parameters of the method to be called and then calls the method with the wrapped object as the implicit parameter.

```
class TraceHandler implements InvocationHandler
{
    private Object target;
    public TraceHandler(Object t)
    {
      target = t;
    }
    public Object invoke(Object proxy, Method m, Object[] args)
          throws Throwable
    {
```

```
        // print method name and parameters
        . . .
        // invoke actual method
        return m.invoke(target, args);
      }
   }
```

Here is how you construct a proxy object that causes the tracing behavior whenever one of its methods is called:

```
Object value = . . .;
// construct wrapper
var handler = new TraceHandler(value);
// construct proxy for one or more interfaces
var interfaces = new Class[] { Comparable.class};
Object proxy = Proxy.newProxyInstance(
  ClassLoader.getSystemClassLoader(),
  new Class[] { Comparable.class } , handler);
```

Now, whenever a method from one of the interfaces is called on `proxy`, the method name and parameters are printed out and the method is then invoked on `value`.

In the program shown in Listing 6.10, we use proxy objects to trace a binary search. We fill an array with proxies to the integers `1 . . . 1000`. Then we invoke the `binarySearch` method of the `Arrays` class to search for a random integer in the array. Finally, we print the matching element.

```
var elements = new Object[1000];
// fill elements with proxies for the integers 1 . . . 1000
for (int i = 0; i < elements.length; i++)
{
    Integer value = i + 1;
    elements[i] = Proxy.newProxyInstance(. . .); // proxy for
value;
}
// construct a random integer
Integer key = (int) (Math.random() * elements.length) + 1;
```

```
// search for the key
int result = Arrays.binarySearch(elements, key);
// print match if found
if (result >= 0) System.out.println(elements[result]);
```

The `Integer` class implements the `Comparable` interface. The proxy objects belong to a class that is defined at runtime. (It has a name such as `$Proxy0`.) That class also implements the `Comparable` interface. However, its `compareTo` method calls the `invoke` method of the proxy object's handler.

NOTE:

As you saw earlier in this chapter, the `Integer` class actually implements `Comparable<Integer>`. However, at runtime, all generic types are erased and the proxy is constructed with the class object for the raw `Comparable` class.

The `binarySearch` method makes calls like this:

```
if (elements[i].compareTo(key) < 0) . . .
```

Since we filled the array with proxy objects, the `compareTo` calls the `invoke` method of the `TraceHandler` class. That method prints the method name and parameters and then invokes `compareTo` on the wrapped `Integer` object.

Finally, at the end of the sample program, we call

```
System.out.println(elements[result]);
```

The `println` method calls `toString` on the proxy object, and that call is also redirected to the invocation handler.

Here is the complete trace of a program run:

```
500.compareTo(288)
250.compareTo(288)
375.compareTo(288)
312.compareTo(288)
281.compareTo(288)
296.compareTo(288)
288.compareTo(288)
288.toString()
```

You can see how the binary search algorithm homes in on the key by cutting the search interval in half in every step. Note that the `toString` method is proxied even though it does not belong to the `Comparable` interface—as you will see in the next section, certain `Object` methods are always proxied.

Listing 6.10 `proxy/ProxyTest.java`

```
package proxy;

import java.lang.reflect.*;
import java.util.*;

/**
 * This program demonstrates the use of proxies.
 * @version 1.02 2021-06-16
 * @author Cay Horstmann
 */
public class ProxyTest
{
   public static void main(String[] args)
   {
      var elements = new Object[1000];

      // fill elements with proxies for the integers 1 . . . 1000
      for (int i = 0; i < elements.length; i++)
      {
         Integer value = i + 1;
         var handler = new TraceHandler(value);
```

```
            Object proxy = Proxy.newProxyInstance(
               ClassLoader.getSystemClassLoader(),
               new Class[] { Comparable.class }, handler);
            elements[i] = proxy;
         }

         // construct a random integer
         Integer key = (int) (Math.random() * elements.length) + 1;

         // search for the key
         int result = Arrays.binarySearch(elements, key);

         // print match if found
         if (result >= 0) System.out.println(elements[result]);
      }
   }

   /**
    * An invocation handler that prints out the method name and parameters, then
    * invokes the original method
    */
   class TraceHandler implements InvocationHandler
   {
      private Object target;

      /**
       * Constructs a TraceHandler
       * @param t the implicit parameter of the method call
       */
      public TraceHandler(Object t)
      {
        target = t;
      }

    public Object invoke(Object proxy, Method m, Object[] args) throws Throwable
    {
```

```
      // print implicit argument
      System.out.print(target);
      // print method name
      System.out.print("." + m.getName() + "(");
      // print explicit arguments
      if (args != null)
      {
         for (int i = 0; i < args.length; i++)
         {
            System.out.print(args[i]);
            if (i < args.length - 1) System.out.print(", ");
         }
      }
      System.out.println(")");

      // invoke actual method
      return m.invoke(target, args);
   }
}
```

6.5.3 Properties of Proxy Classes

Now that you have seen proxy classes in action, let's go over some of their properties. Remember that proxy classes are created on the fly in a running program. However, once they are created, they are regular classes, just like any other classes in the virtual machine.

All proxy classes extend the class `Proxy`. A proxy class has only one instance field—the invocation handler, which is defined in the `Proxy` superclass. Any additional data required to carry out the proxy objects' tasks must be stored in the invocation handler. For example, when we proxied `Comparable` objects in the program shown in Listing 6.10, the `TraceHandler` wrapped the actual objects.

All proxy classes override the `toString`, `equals`, and `hashCode` methods of the `Object` class. Like all proxy methods, these methods simply call `invoke` on the invocation handler. The other methods of the `Object` class (such as `clone` and `getClass`) are not redefined.

The names of proxy classes are not defined. The `Proxy` class in Oracle's virtual machine generates class names that begin with the string `$Proxy`.

There is only one proxy class for a particular class loader and ordered set of interfaces. That is, if you call the `newProxyInstance` method twice with the same class loader and interface array, you get two objects of the same class. You can also obtain that class with the `getProxyClass` method:

```
Class proxyClass = Proxy.getProxyClass(null, interfaces);
```

A proxy class is always `public` and `final`. If all interfaces that the proxy class implements are `public`, the proxy class does not belong to any particular package. Otherwise, all non-`public` interfaces must belong to the same package, and the proxy class will also belong to that package.

You can test whether a particular `Class` object represents a proxy class by calling the `isProxyClass` method of the `Proxy` class.

NOTE:

Calling a default method of a proxy triggers the invocation handler. To actually invoke the method, use the static `invokeDefault` method of the `InvocationHandler` interface. For example, here is an invocation handler that calls the default methods and passes the abstract methods to another target.

```
InvocationHandler handler = (proxy, method, args) ->
  {
      if (method.isDefault())
           return InvocationHandler.invokeDefault(proxy, method,
args)
      else
          return method.invoke(target, args);
  }
```

java.lang.reflect.InvocationHandler 1.3

- `Object invoke(Object proxy, Method method, Object[] args)`

  define this method to contain the action that you want carried out whenever a method was invoked on the proxy object.

- `static Object invokeDefault(Object proxy, Method method, Object... args)` 16

  Invokes a default method of the proxy instance with the given arguments, bypassing the invocation handler.

java.lang.reflect.Proxy 1.3

- `static Class<?> getProxyClass(ClassLoader loader, Class<?>... interfaces)`

  returns the proxy class that implements the given interfaces.

- `static Object newProxyInstance(ClassLoader loader, Class<?>[] interfaces, InvocationHandler handler)`

  constructs a new instance of the proxy class that implements the given interfaces. All methods call the `invoke` method of the given handler object.

- `static boolean isProxyClass(Class<?> cl)`

  returns `true` if `cl` is a proxy class.

This ends the final chapter on the object-oriented features of the Java programming language. Interfaces, lambda expressions, and inner classes are concepts that you will encounter frequently, whereas cloning, service loaders, and proxies are advanced techniques that are of interest mainly to library designers and tool builders, not application programmers. You are now ready to learn how to deal with exceptional situations in your programs in Chapter 7.

Chapter 7. Exceptions, Assertion, and Logging

In this chapter

In a perfect world, users would never enter data in the wrong form, files they choose to open would always exist, and code would never have bugs. So far, I've mostly presented code as if we all lived in this kind of perfect world. It is now time to turn to the mechanisms the Java programming language has for dealing with the real world of bad data and buggy code.

Encountering errors is unpleasant. If a user loses all the work he or she did during a program session because of a programming mistake or some external circumstance, that user may forever turn away from your program. At the very least, you must:

• Notify the user of an error;

• Save all work; and

• Allow users to gracefully exit the program.

For exceptional situations, such as bad input data with the potential to bomb the program, Java uses a form of error trapping called, naturally enough, *exception handling*. Exception handling in Java is similar to that in C++ or Delphi. The first part of this chapter covers Java's exceptions.

During testing, you need to run lots of checks to make sure your program does the right thing. But those checks can be time-consuming and unnecessary after testing has completed. You could just remove the checks and stick them back in when additional testing is required—but that is tedious. The second part of this chapter shows you how to use the assertion facility for selectively activating checks.

When your program does the wrong thing, you can't always communicate with the user or terminate. Instead, you may want to record the problem for later analysis. The third part of this chapter discusses the standard Java logging framework.

7.1 Dealing with Errors

Suppose an error occurs while a Java program is running. The error might be caused by a file containing wrong information, a flaky network connection, or (I hate to mention it) use of an invalid array index or an object reference that hasn't yet been assigned to an object. Users expect that programs will act sensibly when errors happen. If an operation cannot be completed because of an error, the program ought to either

- Return to a safe state and enable the user to execute other commands; or
- Allow the user to save all work and terminate the program gracefully.

This may not be easy to do, because the code that detects (or even causes) the error condition is usually far removed from the code that can roll back the data to a safe state or save the user's work and exit cheerfully. The mission of exception handling is to transfer control from where the error occurred to an error handler that can deal with the situation. To handle exceptional situations in your program, you must take into account the errors and problems that may occur. What sorts of problems do you need to consider?

- *User input errors*. In addition to the inevitable typos, some users like to blaze their own trail instead of following directions. Suppose, for example, that a user asks to connect to a URL that is syntactically wrong. Your code should check the syntax, but suppose it does not. Then the network layer will complain.

- *Device errors*. Hardware does not always do what you want it to. The printer may be turned off. A web page may be temporarily unavailable.

Devices will often fail in the middle of a task. For example, a printer may run out of paper during printing.

- *Physical limitations*. Disks can fill up; you can run out of available memory.
- *Code errors*. A method may not perform correctly. For example, it could deliver wrong answers or use other methods incorrectly. Computing an invalid array index, trying to find a nonexistent entry in a hash table, or trying to pop an empty stack are all examples of a code error.

The traditional reaction to an error in a method is to return a special error code that the calling method analyzes. For example, methods that read information back from files often return a `-1` end-of-file value marker rather than a standard character. This can be an efficient method for dealing with many exceptional conditions. Another common return value to denote an error condition is the `null` reference.

Unfortunately, it is not always possible to return an error code. There may be no obvious way of distinguishing valid and invalid data. A method returning an integer cannot simply return `-1` to denote the error; the value `-1` might be a perfectly valid result.

Instead, as I mentioned back in Chapter 5, Java allows every method an alternative exit path if it is unable to complete its task in the normal way. In this situation, the method does not return a value. Instead, it *throws* an object that encapsulates the error information. Note that the method exits immediately; it does not return its normal (or any) value. Moreover, execution does not resume at the code that called the method; instead, the exception-handling mechanism begins its search for an *exception handler* that can deal with this particular error condition.

Exceptions have their own syntax and are part of a special inheritance hierarchy. I'll take up the syntax first and then give a few hints on how to use this language feature effectively.

7.1.1 The Classification of Exceptions

In the Java programming language, an exception object is always an instance of a class derived from `Throwable`. As you will soon see, you can create your own exception classes if those built into Java do not suit your needs.

Figure 7.1 is a simplified diagram of the exception hierarchy in Java.

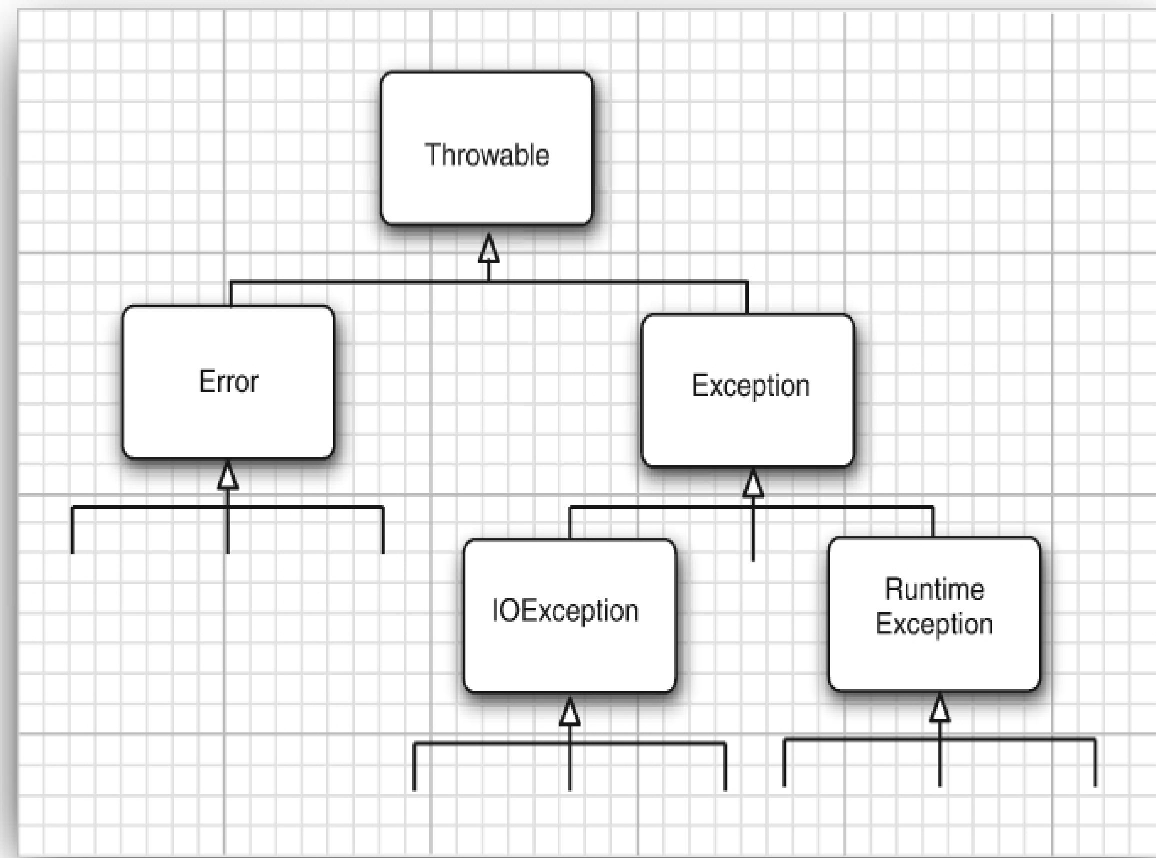


Figure 7.1 Exception hierarchy in Java

Notice that all exceptions descend from `Throwable`, but the hierarchy immediately splits into two branches: `Error` and `Exception`.

The `Error` hierarchy describes internal errors and resource exhaustion situations inside the Java runtime system. You should not throw an object of this type. There is little you can do if such an internal error occurs, beyond notifying the user and trying to terminate the program gracefully. These situations are quite rare.

When doing Java programming, focus on the `Exception` hierarchy. The `Exception` hierarchy also splits into two branches: exceptions that derive from `RuntimeException` and those that do not. The general rule is this: A `RuntimeException` happens because you made a programming error. Any other exception occurs because a bad thing, such as an I/O error, happened to your otherwise good program.

Exceptions that inherit from `RuntimeException` include such problems as

- A bad cast
- An out-of-bounds array access
- A null pointer access

Exceptions that do not inherit from `RuntimeException` include

- Trying to read past the end of a file
- Trying to open a file that doesn't exist
- Trying to find a `Class` object for a string that does not denote an existing class

The rule "If it is a `RuntimeException`, it was your fault" works pretty well. You could have avoided that `ArrayIndexOutOfBoundsException` by testing the array index against the array bounds. The `NullPointerException` would not have happened had you checked whether the variable was `null` before using it.

How about a file that doesn't exist? Can't you first check whether the file exists, and then open it? Well, the file might be deleted right after you checked for its existence. Thus, the notion of "existence" depends on the environment, not just on your code.

The Java Language Specification calls any exception that derives from the class `Error` or the class `RuntimeException` an *unchecked* exception. All other exceptions are called *checked* exceptions. This is useful terminology that I also adopt in this book. The compiler checks that you provide exception handlers for all checked exceptions.

NOTE:

The name `RuntimeException` is somewhat confusing. Of course, all of the errors we are discussing occur at runtime. The name originated in prehistoric times, when the "runtime" of Oak, the predecessor of Java, generated out-of-bounds exceptions and null pointer exceptions. Presumably I/O exceptions were produced by some other component.

C++ NOTE:

If you are familiar with the (much more limited) exception hierarchy of the standard C++ library, you may be really confused at this point. C++ has two fundamental exception classes, `runtime_error` and `logic_error`. The `logic_error` class is the equivalent of Java's `RuntimeException` and also denotes logical errors in the program. The `runtime_error` class is the base class for exceptions caused by unpredictable problems. It is equivalent to those exceptions in Java that are *not* of type `RuntimeException`.

7.1.2 Declaring Checked Exceptions

A Java method can throw an exception if it encounters a situation it cannot handle. The idea is simple: A method will not only tell the Java compiler what values it can return, *it is also going to tell the compiler what can go wrong*. For example, code that attempts to read from a file knows that the file might not exist or that it might be empty. The code that tries to process the information in a file therefore will need to notify the compiler that it can throw some sort of `IOException`.

The place in which you advertise that your method can throw an exception is the header of the method; the header changes to reflect the checked exceptions the method can throw. For example, here is the declaration of one of the constructors of the `FileInputStream` class from the standard library. (See Chapter 1 of Volume II for more on input and output.)

```
public FileInputStream(String name) throws
FileNotFoundException
```

The declaration says that this constructor produces a `FileInputStream` object from a `String` parameter but that it *also* can go wrong in a special way—by throwing a `FileNotFoundException`. If this sad state should come to pass, the constructor call will not initialize a new `FileInputStream` object but instead will throw an object of the `FileNotFoundException` class. If it does, the runtime system will begin to search for an exception handler that knows how to deal with `FileNotFoundException` objects.

When you write your own methods, you don't have to advertise every possible throwable object that your method might actually throw. To understand when (and what) you have to advertise in the `throws` clause of the methods you write, keep in mind that an exception is thrown in any of the following four situations:

- You call a method that throws a checked exception—for example, the `FileInputStream` constructor.
- You detect an error and throw a checked exception with the `throw` statement (the `throw` statement is covered in the next section).
- You make a programming error, such as `a[-1] = 0` that gives rise to an unchecked exception (in this case, an `ArrayIndexOutOfBoundsException`).
- An internal error occurs in the virtual machine or runtime library.

If either of the first two scenarios occurs, you must tell the programmers who will use your method about the possibility of an exception. Why? Any method that throws an exception is a potential death trap. If no handler catches the exception, the current thread of execution terminates.

As with Java methods that are part of the supplied classes, you declare that your method may throw an exception with an *exception specification* in the method header.

```
class MyAnimation
{
   . . .
   public Image loadImage(String s) throws IOException
   {
      . . .
   }
}
```

If a method might throw more than one checked exception type, you must list all exception classes in the header. Separate them by commas, as in the following example:

```
class MyAnimation
{
   . . .
   public Image loadImage(String s) throws
FileNotFoundException, EOFException
   {
      . . .
   }
}
```

However, you do not need to advertise internal Java errors—that is, exceptions inheriting from `Error`. Any code could potentially throw those exceptions, and they are entirely beyond your control.

Similarly, you should not advertise unchecked exceptions inheriting from

```
RuntimeException.
class MyAnimation
{
   . . .
   void drawImage(int i) throws ArrayIndexOutOfBoundsException
// bad style
   {
      . . .
```

```
    }
}
```

These runtime errors are completely under your control. If you are so concerned about array index errors, you should spend your time fixing them instead of advertising the possibility that they can happen.

In summary, a method must declare all the *checked* exceptions that it might throw. Unchecked exceptions are either beyond your control (`Error`) or result from conditions that you should not have allowed in the first place (`RuntimeException`). If your method fails to faithfully declare all checked exceptions, the compiler will issue an error message.

Of course, as you have already seen in quite a few examples, instead of declaring the exception, you can also catch it. Then the exception won't be thrown out of the method, and no `throws` specification is necessary. You will see later in this chapter how to decide whether to catch an exception or to enable someone else to catch it.

CAUTION:

If you override a method from a superclass, the checked exceptions that the subclass method declares cannot be more general than those of the superclass method. (It is OK to throw more specific exceptions, or not to throw any exceptions in the subclass method.) In particular, if the superclass method throws no checked exception at all, neither can the subclass. For example, if you override `JComponent.paintComponent`, your `paintComponent` method must not throw any checked exceptions, because the superclass method doesn't throw any.

When a method in a class declares that it throws an exception that is an instance of a particular class, it may throw an exception of that class or of any of its subclasses. For example, the `FileInputStream` constructor could have declared that it throws an `IOException`. In that case, you would not have known what kind of `IOException` it is; it could be a plain `IOException` or an object of one of the various subclasses, such as `FileNotFoundException`.

C++ NOTE:

The `throws` specifier is the same as the `throw` specifier in C++, with one important difference. In C++, `throw` specifiers are enforced at runtime, not at compile time. That is, the C++ compiler pays no attention to exception specifications. But if an exception is thrown in a function that is not part of the `throw` list, the `unexpected` function is called, and, by default, the program terminates.

Also, in C++, a function may throw any exception if no `throw` specification is given. In Java, a method without a `throws` specifier may not throw any checked exceptions at all.

7.1.3 How to Throw an Exception

Now, suppose something terrible has happened in your code. You have a method, `readData`, that is reading in a file whose header promised

```
Content-length: 1024
```

but you got an end of file after 733 characters. You may decide this situation is so abnormal that you want to throw an exception.

You need to decide what exception type to throw. Some kind of `IOException` would be a good choice. Perusing the Java API documentation, you find an `EOFException` with the description “Signals that an EOF has been reached unexpectedly during input.” Perfect. Here is how you throw it:

```
throw new EOFException();
```

or, if you prefer,

```
var e = new EOFException();
throw e;
```

Here is how it all fits together:

```
String readData(Scanner in) throws EOFException
{
   . . .
   while (. . .)
   {
      if (!in.hasNext()) // EOF encountered
      {
         if (n < len)
            throw new EOFException();
      }
      . . .
   }
   return s;
}
```

The `EOFException` has a second constructor that takes a string argument. You can put this to good use by describing the exceptional condition more carefully.

```
String gripe = "Content-length: " + len + ", Received: " + n;
throw new EOFException(gripe);
```

As you can see, throwing an exception is easy if one of the existing exception classes works for you. In this case:

1. Find an appropriate exception class.
2. Make an object of that class.
3. Throw it.

Once a method throws an exception, it does not return to its caller. This means you do not have to worry about cooking up a default return value or an error code.

C++ NOTE:

Throwing an exception is the same in C++ and in Java, with one small difference. In Java, you can throw only objects of subclasses of `Throwable`. In C++, you can throw values of any type.

7.1.4 Creating Exception Classes

Your code may run into a problem which is not adequately described by any of the standard exception classes. In this case, it is easy enough to create your own exception class. Just derive it from `Exception`, or from a child class of

`Exception` such as `IOException`. It is customary to give both a default constructor and a constructor that contains a detailed message. (The `toString` method of the `Throwable` superclass returns a string containing that detailed message, which is handy for debugging.)

```
class FileFormatException extends IOException
{
   public FileFormatException() {}
   public FileFormatException(String gripe)
   {
      super(gripe);
   }
}
```

Now you are ready to throw your very own exception type.

```
String readData(Scanner in) throws FileFormatException
{
   . . .
   while (. . .)
   {
      if (ch == -1) // EOF encountered
      {
         if (n < len)
            throw new FileFormatException();
      }
      . . .
   }
   return s;
}
```

java.lang.Throwable 1.0

- `Throwable()`

  constructs a new `Throwable` object with no detailed message.

- `Throwable(String message)`

  constructs a new `Throwable` object with the specified detailed message. By convention, all derived exception classes support both a default constructor and a constructor with a detailed message.

- `String getMessage()`

  gets the detailed message of the `Throwable` object.

7.2 Catching Exceptions

You now know how to throw an exception. It is pretty easy: You throw it and you forget it. Of course, some code has to catch the exception. Catching exceptions requires more planning. That's what the next sections will cover.

7.2.1 Catching an Exception

If an exception occurs that is not caught anywhere, the program will terminate and print a message to the console, giving the type of the exception and a stack trace. However, GUI programs may catch exceptions, print stack trace messages, and then go back to the user interface processing loop. (When you are debugging a GUI program, it is a good idea to keep the console on the screen and not minimized.)

To catch an exception, set up a `try/catch` block. The simplest form of the `try`

block is as follows:

```
try
{
    code
  more code
  more code
}
catch (ExceptionType e)
{
    handler for this type
}
```

If any code inside the `try` block throws an exception of the class specified in the `catch` clause, then

1. The program skips the remainder of the code in the `try` block.
2. The program executes the handler code inside the `catch` clause.

If none of the code inside the `try` block throws an exception, then the program skips the `catch` clause.

If any of the code in a method throws an exception of a type other than the one named in the `catch` clause, this method exits immediately. (Hopefully, one of its callers has already provided a `catch` clause for that type.)

To show this at work, here's some fairly typical code for reading in data:

```
public void read(String filename)
{
   try
   {
      var in = new FileInputStream(filename);
      int b;
      while ((b = in.read()) != -1)
      {
         process input
      }
   }
   catch (IOException exception)
   {
      exception.printStackTrace();
   }
}
```

Notice that most of the code in the `try` clause is straightforward: It reads and processes bytes until it encounters the end of the file. As you can see by looking at the Java API, there is the possibility that the `read` method will throw an `IOException`. In that case, we skip out of the entire `while` loop, enter the `catch` clause, and generate a stack trace. For a toy program, that seems like a reasonable way to deal with this exception. What other choice do you have?

Often, the best choice is to do nothing at all and simply pass the exception on to the caller. If an error occurs in the `read` method, let the caller of the `read` method worry about it! If we take that approach, then we have to advertise the fact that the method may throw an `IOException`.

```
public void read(String filename) throws IOException
{
   var in = new FileInputStream(filename);
   int b;
   while ((b = in.read()) != -1)
   {
```

```
        process input
      }
   }
```

Remember, the compiler strictly enforces the `throws` specifiers. If you call a method that throws a checked exception, you must either handle it or pass it on.

Which of the two is better? As a general rule, you should catch those exceptions that you know how to handle and propagate those that you do not know how to handle.

When you propagate an exception, you must add a `throws` specifier to alert the caller that an exception may be thrown.

Look at the Java API documentation to see what methods throw which exceptions. Then decide whether you should handle them or add them to the `throws` list. There is nothing embarrassing about the latter choice. It is better to direct an exception to a competent handler than to squelch it.

Please keep in mind that, as mentioned earlier, there is one exception to this rule. If you are writing a method that overrides a superclass method which throws no exceptions (such as `paintComponent` in `JComponent`), then you *must* catch each checked exception in your method's code. You are not allowed to add more `throws` specifiers to a subclass method than are present in the superclass method.

C++ NOTE:

Catching exceptions is almost the same in Java and in C++. Strictly speaking, the analog of

```
catch (Exception e) // Java
```

is

```
catch (Exception& e) // C++
```

There is no analog to the C++ `catch (. . .)`. This is not needed in Java because all exceptions derive from a common superclass.

7.2.2 Catching Multiple Exceptions

You can catch multiple exception types in a `try` block and handle each type differently. Use a separate `catch` clause for each type, as in the following example:

```
try
{
   code that might throw exceptions
}
catch (FileNotFoundException e)
{
   emergency action for missing files
}
catch (UnknownHostException e)
{
   emergency action for unknown hosts
}
catch (IOException e)
{
   emergency action for all other I/O problems
}
```

The exception object may contain information about the nature of the exception. To find out more about the object, try

```
e.getMessage()
```

to get the detailed error message (if there is one), or

```
e.getClass().getName()
```

to get the actual type of the exception object.

As of Java 7, you can catch multiple exception types in the same `catch` clause. For example, suppose that the action for missing files and unknown hosts is the same. Then you can combine the `catch` clauses:

```
try
{
   code that might throw exceptions
}
   catch (FileNotFoundException | UnknownHostException e)
{
   emergency action for missing files and unknown hosts
}
   catch (IOException e)
{
   emergency action for all other I/O problems
}
```

This feature is only needed when catching exception types that are not subclasses of one another.

NOTE:

When you catch multiple exceptions, the exception variable is implicitly `final`. For example, you cannot assign a different value to `e` in the body of the clause

```
catch (FileNotFoundException | UnknownHostException e) { . . . }
```

NOTE:

Catching multiple exceptions doesn't just make your code look simpler but also more efficient. The generated bytecodes contain a single block for the shared `catch` clause.

7.2.3 Rethrowing and Chaining Exceptions

You can throw an exception in a `catch` clause. Typically, you do this when you want to change the exception type. If you build a subsystem that other programmers use, it makes a lot of sense to use an exception type that indicates a failure of the subsystem. An example of such an exception type is the `ServletException`. The code that executes a servlet may not want to know in minute detail what went wrong, but it definitely wants to know that the servlet was at fault.

Here is how you can catch an exception and rethrow it:

```
try
{
   access the database
}
catch (SQLException e)
{
   throw new ServletException("database error: " +
e.getMessage());
}
```

Here, the `ServletException` is constructed with the message text of the exception.

However, it is a better idea to set the original exception as the "cause" of the new exception:

```
try
{
   access the database
}
catch (SQLException original)
{
   var e = new ServletException("database error");
   e.initCause(original);
   throw e;
}
```

When the exception is caught, the original exception can be retrieved:

```
Throwable original = caughtException.getCause();
```

This wrapping technique is highly recommended. It allows you to throw high-level exceptions in subsystems without losing the details of the original failure.

TIP:

The wrapping technique is also useful if a checked exception occurs in a method that is not allowed to throw a checked exception. You can catch the checked exception and wrap it into a runtime exception.

Sometimes, you just want to log an exception and rethrow it without any change:

```
try
{
   access the database
}
catch (Exception e)
{
```

```
        logger.log(level, message, e);
        throw e;
    }
```

Before Java 7, there was a problem with this approach. Suppose the code is inside a method

```
public void updateRecord() throws SQLException
```

The Java compiler looked at the `throw` statement inside the `catch` block, then at the type of `e`, and complained that this method might throw any `Exception`, not just a `SQLException`. This has now been improved. The compiler now tracks the fact that `e` originates from the `try` block. Provided that the only checked exceptions in that block are `SQLException` instances, and provided that `e` is not changed in the `catch` block, it is valid to declare the enclosing method as `throws SQLException`.

7.2.4 The `finally` Clause

When your code throws an exception, it stops processing the remaining code in your method and exits the method. This is a problem if the method has acquired some local resource, which only this method knows about, and that resource must be cleaned up. One solution is to catch all exceptions, carry out the cleanup, and rethrow the exceptions. But this solution is tedious because you need to clean up the resource allocation in two places—in the normal code and in the exception code. The `finally` clause can solve this problem.

NOTE:

Since Java 7, there is a more elegant solution, the `try`-with-resources statement that you will see in the following section. We discuss the `finally` mechanism in detail because it is the conceptual foundation. But in practice, you will probably use `try`-with-resources statements more often than `finally` clauses.

The code in the `finally` clause executes whether or not an exception was caught. In the following example, the program will close the input stream *under all circumstances*:

```
var in = new FileInputStream(. . .);
try
{
   // 1
   code that might throw exceptions
   // 2
}
catch (IOException e){
   // 3
   show error message
   // 4
}
finally
{
   // 5
   in.close();
}
// 6
```

Let us look at the three possible situations in which the program will execute the `finally` clause.

1. The code throws no exceptions. In this case, the program first executes all the code in the `try` block. Then, it executes the code in the `finally` clause. Afterwards, execution continues with the first statement after the `finally` clause. In other words, execution passes through points 1, 2, 5, and 6. 2. The code throws an exception that is caught in a `catch` clause—in our case, an `IOException`. For this, the program executes all code in the `try` block, up to the point at which the exception was thrown. The remaining code in the `try` block is skipped. The program then executes the code in the matching `catch` clause, and then the code in the `finally` clause.

If the `catch` clause does not throw an exception, the program executes the first line after the `finally` clause. In this scenario, execution passes through points 1, 3, 4, 5, and 6.

If the `catch` clause throws an exception, then the exception is thrown back to the caller of this method, and execution passes through points 1, 3, and 5 only.

3. The code throws an exception that is not caught in any `catch` clause. Here, the program executes all code in the `try` block until the exception is thrown. The remaining code in the `try` block is skipped. Then, the code in the `finally` clause is executed, and the exception is thrown back to the caller of this method. Execution passes through points 1 and 5 only.

You can use the `finally` clause without a `catch` clause. For example, consider the following `try` statement:

```
InputStream in = . . .;
try
{
   code that might throw exceptions
}
finally
{
   in.close();
}
```

The `in.close()` statement in the `finally` clause is executed whether or not an exception is encountered in the `try` block. Of course, if an exception is encountered, it is rethrown and must be caught in another `catch` clause.

```
InputStream in = . . .;
try
{
   try
   {
      code that might throw exceptions
   }
```

```
      finally
      {
         in.close();
      }
   }
   catch (IOException e)
   {
      show error message
   }
```

The inner `try` block has a single responsibility: to make sure that the input stream is closed. The outer `try` block has a single responsibility: to ensure that errors are reported. Not only is this solution clearer, it is also more functional: Errors in the `finally` clause are reported.

CAUTION:

A `finally` clause can yield unexpected results when it contains `return` statements. Suppose you exit the middle of a `try` block with a `return` statement. Before the method returns, the `finally` block is executed. If the `finally` block also contains a `return` statement, then it masks the original return value. Consider this example:

```
public static int parseInt(String s)
{
   try
   {
      return Integer.parseInt(s);
   }
   finally
   {
      return 0; // ERROR
   }
}
```

It looks as if in the call `parseInt("42")`, the body of the `try` block returns the integer 42. However, the `finally` clause is executed before the method actually returns and causes the method to return 0, ignoring the original return value.

And it gets worse. Consider the call `parseInt("zero")`. The `Integer.parseInt` method throws a `NumberFormatException`. Then the `finally` clause is executed, and the `return` statement swallows the exception!

The body of the finally clause is intended for cleaning up resources. Don't put statements that change the control flow (`return`, `throw`, `break`, `continue`) inside a `finally` clause.

7.2.5 The `try`-with-Resources Statement

As of Java 7, there is a useful shortcut to the code pattern

```
open a resource
try
{
    work with the resource
}
finally
{
    close the resource
}
```

provided the resource belongs to a class that implements the `AutoCloseable` interface. That interface has a single method

```
void close() throws Exception
```

NOTE:

There is also a `Closeable` interface. It is a subinterface of `AutoCloseable`, also with a single `close` method. However, that method is declared to throw an `IOException`.

In its simplest variant, the `try`-with-resources statement has the form

```
try (Resource res = . . .)
{
   work with res
}
```

When the `try` block exits, then `res.close()` is called automatically. Here is a typical example—reading all words of a file:

```
try (var in = new Scanner(Path.of("in.txt"),
StandardCharsets.UTF_8))
{
   while (in.hasNext())
      System.out.println(in.next());
}
```

When the block exits normally, or when there was an exception, the `in.close()` method is called, exactly as if you had used a `finally` block.

You can specify multiple resources. For example,

```
try (var in = new Scanner(Path.of("in.txt"),
StandardCharsets.UTF_8);
      var out = new PrintWriter("out.txt",
StandardCharsets.UTF_8))
{
   while (in.hasNext())
```

```
        out.println(in.next().toUpperCase());
}
```

No matter how the block exits, both `in` and `out` are closed. If you programmed this by hand, you would have needed two nested `try`/`finally` statements.

As of Java 9, you can provide previously declared effectively final variables in the `try` header:

```
public static void printAll(String[] lines, PrintWriter out)
{
   try (out)
   { // effectively final variable
      for (String line : lines)
         out.println(line);
   } // out.close() called here
}
```

A difficulty arises when the `try` block throws an exception and the `close` method also throws an exception. The `try`-with-resources statement handles this situation quite elegantly. The original exception is rethrown, and any exceptions thrown by `close` methods are considered “suppressed.” They are automatically caught and added to the original exception with the `addSuppressed` method. If you are interested in them, call the `getSuppressed` method which yields an array of the suppressed expressions from `close` methods.

You don’t want to program this by hand. Use the `try`-with-resources statement whenever you need to close a resource.

NOTE:

A `try`-with-resources statement can itself have `catch` clauses and even a `finally` clause. These are executed after closing the resources.

7.2.6 Analyzing Stack Trace Elements

A *stack trace* is a listing of all pending method calls at a particular point in the execution of a program. You have almost certainly seen stack trace listings—they are displayed whenever a Java program terminates with an uncaught exception.

You can access the text description of a stack trace by calling the `printStackTrace`

method of the `Throwable` class.

```
var t = new Throwable();
var out = new StringWriter(); t.printStackTrace(new
PrintWriter(out));
String description = out.toString();
```

A more flexible approach is the `StackWalker` class that yields a stream of `StackWalker.StackFrame` instances, each describing one stack frame. You can iterate over the stack frames with this call:

```
StackWalker walker = StackWalker.getInstance();
walker.forEach(frame -> analyze frame)
```

If you want to process the `Stream<StackWalker.StackFrame>` lazily, call

```
walker.walk(stream -> process stream)
```

Stream processing is described in detail in Chapter 1 of Volume II.

The `StackWalker.StackFrame` class has methods to obtain the file name and line number, as well as the class object and method name, of the executing line of code. The `toString` method yields a formatted string containing all of this information.

NOTE:

Prior to Java 9, the `Throwable.getStackTrace` method yielded a `StackTraceElement[]` array with similar information as the stream of `StackWalker. StackFrame` instances. However, that call is less efficient since it captures the entire stack even though the caller may only need a few frames, and it only provides access to the class names, but not the class objects, of the pending methods.

Listing 7.1 prints the stack trace of a recursive factorial function. For example, if you compute `factorial(3)`, the printout is

```
factorial(3):
stackTrace.StackTraceTest.factorial(StackTraceTest.java:20)
stackTrace.StackTraceTest.main(StackTraceTest.java:36)factorial
(2):
stackTrace.StackTraceTest.factorial(StackTraceTest.java:20)
stackTrace.StackTraceTest.factorial(StackTraceTest.java:26)
stackTrace.StackTraceTest.main(StackTraceTest.java:36)
factorial(1):
stackTrace.StackTraceTest.factorial(StackTraceTest.java:20)
stackTrace.StackTraceTest.factorial(StackTraceTest.java:26)
stackTrace.StackTraceTest.factorial(StackTraceTest.java:26)
stackTrace.StackTraceTest.main(StackTraceTest.java:36)
return 1
return 2
return 6
```

Listing 7.1 `stackTrace/StackTraceTest.java`

```
package stackTrace;

import java.util.*;

/**
 * A program that displays a trace feature of a recursive
```

```
method call.
  * @version 1.10 2017-12-14
  * @author Cay Horstmann
  */
public class StackTraceTest
{
   /**
    * Computes the factorial of a number
    * @param n a non-negative integer
    * @return n! = 1 * 2 * . . . * n
    */
  public static int factorial(int n)
  {
     System.out.println("factorial(" + n + "):");
     var walker = StackWalker.getInstance();
     walker.forEach(System.out::println);
     int r;
     if (n <= 1) r = 1;
     else r = n * factorial(n - 1);
     System.out.println("return " + r);
     return r;
  }

  public static void main(String[] args)
  {
     try (var in = new Scanner(System.in))
  {       System.out.print("Enter n: ");
     int n = in.nextInt();
     factorial(n);
  }
 }
}
```

java.lang.Throwable 1.0

- `Throwable(Throwable cause)` 1.4

- `Throwable(String message, Throwable cause)` 1.4

  constructs a `Throwable` with a given cause.

- `Throwable initCause(Throwable cause)` 1.4

  sets the cause for this object or throws an exception if this object already has a cause. Returns `this`.

- `Throwable getCause()` 1.4

  gets the exception object that was set as the cause for this object, or `null` if no cause was set.

- `StackTraceElement[] getStackTrace()` 1.4

  gets the trace of the call stack at the time this object was constructed.

- `void addSuppressed(Throwable t)` 7 adds a "suppressed" exception to this exception. This happens in a `try`-with-resources statement where `t` is an exception thrown by a `close` method.

- `Throwable[] getSuppressed()` 7 gets all "suppressed" exceptions of this exception. Typically, these are exceptions thrown by a `close` method in a `try`-with-resources statement.

java.lang.Exception 1.0

- `Exception(Throwable cause)` 1.4

- `Exception(String message, Throwable cause)`

  constructs an `Exception` with a given cause.

java.lang.RuntimeException 1.0

- `RuntimeException(Throwable cause)` 1.4

- `RuntimeException(String message, Throwable cause)` 1.4

constructs a `RuntimeException` with a given cause.

`java.lang.StackWalker` 9

- `static StackWalker getInstance()`
- `static StackWalker getInstance(StackWalker.Option option)`
- `static StackWalker getInstance(Set<StackWalker.Option> options)`

  gets a `StackWalker` instance. The options include `RETAIN_CLASS_REFERENCE`, `SHOW_HIDDEN_FRAMES`, and `SHOW_REFLECT_FRAMES` from the `StackWalker.Option` enumeration.

- `forEach(Consumer<? super StackWalker.StackFrame> action)`

  carries out the given action on each stack frame, starting with the most recently called method.

- `walk(Function<? super Stream<StackWalker.StackFrame>,? extends T> function)`

  applies the given function to the stream of stack frames and returns the result of the function.

`java.lang.StackWalker.StackFrame` 9

- `String getFileName()`

  gets the name of the source file containing the execution point of this element, or `null` if the information is not available.

- `int getLineNumber()`

  gets the line number of the source file containing the execution point of this element, or `-1` if the information is not available.

- `String getClassName()`

gets the fully qualified name of the class whose method contains the execution point of this element.

- `String getDeclaringClass()`

  gets the `Class` object of the method containing the execution point of this element. An exception is thrown if the stack walker was not constructed with the `RETAIN_CLASS_REFERENCE` option.

- `String getMethodName()`

  gets the name of the method containing the execution point of this element. The name of a constructor is `<init>`. The name of a static initializer is `<clinit>`. You can't distinguish between overloaded methods with the same name.

- `boolean isNativeMethod()`

  returns `true` if the execution point of this element is inside a native method.

- `String toString()`

  returns a formatted string containing the class and method name and the file name and line number, if available.

java.lang.StackTraceElement 1.4

- `String getFileName()`

  gets the name of the source file containing the execution point of this element, or `null` if the information is not available.

- `int getLineNumber()`

  gets the line number of the source file containing the execution point of this element, or `-1` if the information is not available.

- `String getClassName()`

  gets the fully qualified name of the class containing the execution point of this element.

- `String getMethodName()`

  gets the name of the method containing the execution point of this element. The name of a constructor is `<init>`. The name of a static initializer is `<clinit>`. You can't distinguish between overloaded methods with the same name.

- `boolean isNativeMethod()`

  returns `true` if the execution point of this element is inside a native method.

- `String toString()`

  returns a formatted string containing the class and method name and the file name and line number, if available.

7.3 Tips for Using Exceptions

There is a certain amount of controversy about the proper use of exceptions. Some programmers believe that all checked exceptions are a nuisance, others can't seem to throw enough of them. I think that exceptions (even checked exceptions) have their place, so I offer you these tips for their proper use.

1. *Exception handling is not supposed to replace a simple test.*

   As an example of this, here's code that tries 10,000,000 times to pop an empty stack. It first does this by finding out whether the stack is empty.

```
if (!s.empty()) s.pop();
```

Next, we force it to pop the stack no matter what and catch the `EmptyStackException` that tells us we should not have done that.

```
try
{
   s.pop();
}catch (EmptyStackException e)
```

```
{
}
```

On my test machine, the version that calls `isEmpty` ran in 646 milliseconds. The version that catches the `EmptyStackException` ran in 21,739 milliseconds.

As you can see, it took far longer to catch an exception than to perform a simple test. The moral is: Use exceptions for exceptional circumstances only.

2. *Do not micromanage exceptions*.

   Some programmers wrap every statement in a separate `try` block.

```
PrintStream out;
Stack s;
for (i = 0; i < 100; i++)
{
   try
   {
      n = s.pop();
   }
   catch (EmptyStackException e)
   {
      // stack was empty
   }
   try
   {
      out.writeInt(n);
   }
   catch (IOException e)
   {
      // problem writing to file
   }
}
```

This approach blows up your code dramatically. Think about the task that you want the code to accomplish. Here, we want to pop 100 numbers off a stack and save them to a file. (Never mind why—it is just a toy example.) There is nothing we can do if a problem rears its ugly head. If the stack is empty, it will not become occupied. If the file contains an error, the error will not magically go away. It therefore makes sense to wrap the *entire task* in a `try` block. If any one operation fails, you can then abandon the task.

```
try
{
   for (i = 0; i < 100; i++)   {
      n = s.pop();
      out.writeInt(n);
   }
}
catch (IOException e)
{
   // problem writing to file
}
catch (EmptyStackException e)
{
   // stack was empty
}
```

This code looks much cleaner. It fulfills one of the promises of exception handling: to *separate* normal processing from error handling.

3. *Make good use of the exception hierarchy.*

   Don't just throw a `RuntimeException`. Find an appropriate subclass or create your own.

   Don't just catch `Throwable`. It makes your code hard to read and maintain.

   Respect the difference between checked and unchecked exceptions. Checked exceptions are inherently burdensome—don't throw them for logic errors. (For example, the reflection library gets this wrong. Callers often need to catch exceptions that they know can never happen.)

   Do not hesitate to turn an exception into another exception that is more appropriate. For example, when you parse an integer in a file, catch the `NumberFormatException` and turn it into a subclass of `IOException` or `MySubsystemException`.

4. *Do not squelch exceptions.*

In Java, there is a tremendous temptation to shut up exceptions. If you're writing a method that calls a method that might throw an exception once a century, the compiler whines because you have not declared the exception in the `throws` list of your method. You do not want to put it in the

`throws` list because then the compiler will whine about all the methods that call your method. So you just shut it up:

```
public Image loadImage(String s)
{
   try
   {
      code that threatens to throw checked exceptions
   }
   catch (Exception e)      {} // so there
}
```

Now your code will compile without a hitch. It will run fine, except when an exception occurs. Then, the exception will be silently ignored. If you believe that exceptions are at all important, you should make some effort to handle them right.

5. *When you detect an error, "tough love" works better than indulgence.*

   Some programmers worry about throwing exceptions when they detect errors. Maybe it would be better to return a dummy value rather than throw an exception when a method is called with invalid parameters? For example, should `Stack.pop` return `null`, or throw an exception when a stack is empty? I think it is better to throw a `EmptyStackException` at the point of failure than to have a `NullPointerException` occur at later time.

6. *Propagating exceptions is not a sign of shame.*

   Some programmers feel compelled to catch all exceptions that are thrown. If they call a method that throws an exception, such as the `FileInputStream` constructor or the `readLine` method, they instinctively catch the exception that may be generated. In many situations, it is actually better to *propagate* the exception instead of catching it:

```
public void readStuff(String filename) throws IOException //
not a sign of shame!
{
   var in = new FileInputStream(filename,
StandardCharsets.UTF_8);
   . . .
}
```

Higher-level methods are often better equipped to inform the user of errors or to abandon unsuccessful commands.

7. *Use standard methods for reporting null-pointer and out-of-bounds exceptions.*

   The `Objects` class has methods

```
requireNonNull
checkIndex
checkFromToIndex
checkFromIndexSize
```

for these common checks. Use them for parameter validation:

```
public void putData(int position, Object newValue)
{
   Objects.checkIndex(position, data.length);
   Objects.requireNonNull(newValue);
   . . .
}
```

   If the method is called with an invalid index or a null argument, an exception is thrown, using the familiar message that the Java library uses.

8. *Don’t show stack traces to end users.*

   If your program encounters an unexpected exception, it may seem a good idea to display the stack trace so the users can report it, making it easier for you to pinpoint the issue. However, stack traces can contain implementation details that you do not want to reveal to potential attackers, such as the versions of libraries that you are using.

Log the stack trace so that you can retrieve it, but only display a summary message to your users.

NOTE:

Rules 5 and 6 can be summarized as “throw early, catch late.”

7.4 Using Assertions

Assertions are a commonly used idiom of defensive programming. In the following sections, you will learn how to use them effectively.

7.4.1 The Assertion Concept

Suppose you are convinced that a particular property is fulfilled, and you rely on that property in your code. For example, you may be computing

```
double y = Math.sqrt(x);
```

You are certain that `x` is not negative. Perhaps it is the result of another computation that can’t have a negative result, or it is a parameter of a method that requires its callers to supply only positive inputs. Still, you want to double-check rather than allow confusing “not a number” floating-point values creep into your computation. You could, of course, throw an exception:

```
if (x < 0) throw new IllegalArgumentException("x < 0");
```

But this code stays in the program, even after testing is complete. If you have lots of checks of this kind, the program may run quite a bit slower than it should.

The assertion mechanism allows you to put in checks during testing and to have them automatically removed in the production code.

The Java language has a keyword `assert`. There are two forms:

```
assert condition;
```

and

```
assert condition : expression;
```

Both statements evaluate the condition and throw an `AssertionError` if it is `false`. In the second statement, the expression is passed to the constructor of the `AssertionError` object and turned into a message string.

NOTE:

The sole purpose of the *expression* part is to produce a message string. The `AssertionError` object does not store the actual expression value, so you can't query it later. As the JDK documentation states, doing so "would encourage programmers to attempt to recover from assertion failure, which defeats the purpose of the facility."

To assert that `x` is non-negative, you can simply use the statement

```
assert x >= 0;
```

Or you can pass the actual value of `x` into the `AssertionError` object, so that it gets displayed later.

```
assert x >= 0 : x;
```

C++ NOTE:

The `assert` macro of the C language turns the assertion condition into a string that is printed if the assertion fails. For example, if `assert(x >= 0)` fails, it prints that `"x >= 0"` is the failing condition. In Java, the condition is not automatically part of the error report. If you want to see it, you have to pass it as a string into the `AssertionError` object: `assert x >= 0 : "x >= 0"`.

7.4.2 Assertion Enabling and Disabling

By default, assertions are disabled. Enable them by running the program with the `-enableassertions` or `-ea` option:

```
java -enableassertions MyApp
```

Note that you do not have to recompile your program to enable or disable assertions. Enabling or disabling assertions is a function of the *class loader*. When assertions are disabled, the class loader strips out the assertion code so that it won't slow execution.

You can even turn on assertions in specific classes or in entire packages. For example:


```
java -ea:MyClass -ea:com.mycompany.mylib MyApp
```

This command turns on assertions for the class `MyClass` and all classes in the `com.mycompany.mylib` package *and its subpackages*. The option `-ea...` turns on assertions in all classes of the unnamed package.

You can also disable assertions in certain classes and packages with the `-disableassertions` or `-da` option:

```
java -ea:... -da:MyClass MyApp
```

Some classes are not loaded by a class loader but directly by the virtual machine. You can use these switches to selectively enable or disable assertions in those classes.

However, the `-ea` and `-da` switches that enable or disable all assertions do not apply to the "system classes" without class loaders. Use the `-enablesystemassertions/-esa` switch to enable assertions in system classes.

It is also possible to programmatically control the assertion status of class loaders. See the API notes at the end of this section.

NOTE:

The source code for the Java library has over four hundred assertions that are commented out. Some programmers comment out assertions after testing because otherwise they take up space in the class files. If you are concerned about that, you can conditionally include them as follows:

```
public static final boolean asserts = true; // Recompile with
false for production
...
if (asserts) assert x >= 0;
```

7.4.3 Using Assertions for Parameter Checking

The Java language gives you three mechanisms to deal with system failures:

- Throwing an exception
- Logging
- Using assertions

When should you choose assertions? Keep these points in mind:

- Assertion failures are intended to be fatal, unrecoverable errors.
- Assertion checks are turned on only during development and testing. (This is sometimes jokingly described as "wearing a life jacket when you are close to shore, and throwing it overboard once you are in the middle of the ocean.")

Therefore, you would not use assertions for signaling recoverable conditions to another part of the program or for communicating problems to the program user. Assertions should only be used to locate internal program errors during testing.

Let's look at a common scenario—the checking of method parameters. Should you use assertions to check for illegal index values or `null` references? To answer that question, you have to look at the documentation of the method. Suppose you implement a sorting method.

```
/**
   Sorts the specified range of the specified array in
ascending numerical order.
   The range to be sorted extends from fromIndex, inclusive, to
toIndex, exclusive.
   @param a the array to be sorted.
   @param fromIndex the index of the first element (inclusive)
to be sorted.
   @param toIndex the index of the last element (exclusive) to
be sorted.
   @throws IllegalArgumentException if fromIndex > toIndex
   @throws ArrayIndexOutOfBoundsException if fromIndex < 0 or
toIndex > a.length
*/
static void sort(int[] a, int fromIndex, int toIndex)
```

The documentation states that the method throws an exception if the index values are incorrect. That behavior is part of the contract that the method makes with its callers. If you implement the method, you have to respect that contract and throw the indicated exceptions. It would not be appropriate to use assertions instead.

Should you assert that `a` is not `null`? That is not appropriate either. The method documentation is silent on the behavior of the method when `a` is `null`. The callers have the right to assume that the method will return successfully in that case and not throw an assertion error.

However, suppose the method contract had been slightly different:

```
@param a the array to be sorted (must not be null).
```

Now the callers of the method have been put on notice that it is illegal to call the method with a `null` array. Then the method may start with the assertion

```
assert a != null;
```

Computer scientists call this kind of contract a *precondition*. The original method had no preconditions on its parameters—it promised a well-defined behavior in all cases. The revised method has a single precondition: that `a` is not `null`. If the caller fails to fulfill the precondition, then all bets are off and the method can do anything it wants. In fact, with the assertion in place, the method has a rather unpredictable behavior when it is called illegally. It sometimes throws an assertion error, and sometimes a null pointer exception, depending on how its class loader is configured.

7.4.4 Using Assertions for Documenting Assumptions

Often, programmers use comments to document their underlying assumptions. Consider this example from http://docs.oracle.com/javase/8/docs/technotes/guides/language/assert.html:

```
if (i % 3 == 0)
   . . .
else if (i % 3 == 1)
```

```
   . . .
else // (i % 3 == 2)
   . . .
```

In this case, it makes a lot of sense to use an assertion instead.

```
if (i % 3 == 0)
   . . .
else if (i % 3 == 1)
   . . .
else
{
   assert i % 3 == 2;
   . . .
}
```

Of course, it would make even more sense to think through the issue thoroughly. What are the possible values of `i % 3`? If `i` is positive, the remainders must be `0`, `1`, or `2`. If `i` is negative, then the remainders can be `-1` or `-2`. Thus, the real assumption is that `i` is not negative. A better assertion would be

```
assert i >= 0;
```

before the `if` statement.

At any rate, this example shows a good use of assertions as a self-check for the programmer. As you can see, assertions are a tactical tool for testing and debugging. In contrast, logging is a strategic tool for the entire lifecycle of a program. We will examine logging in the next section.

java.lang.ClassLoader 1.0

- `void setDefaultAssertionStatus(boolean b)` 1.4

enables or disables assertions for all classes loaded by this class loader that don't have an explicit class or package assertion status.

- `void setClassAssertionStatus(String className, boolean b)` **1.4**

  enables or disables assertions for the given class and its inner classes.

- `void setPackageAssertionStatus(String packageName, boolean b)` **1.4**

  enables or disables assertions for all classes in the given package and its subpackages.

- `void clearAssertionStatus()` **1.4**

  removes all explicit class and package assertion status settings and disables assertions for all classes loaded by this class loader.

7.5 Logging

Every Java programmer is familiar with the process of inserting calls to `System.out.println` into troublesome code to gain insight into program behavior. Of course, once you have figured out the cause of trouble, you remove the print statements, only to put them back in when the next problem surfaces. The logging API is designed to overcome this problem. Here are the principal advantages of the API:

- It is easy to suppress all log records or just those below a certain level, and just as easy to turn them back on.
- Suppressed logs are very cheap, so there is only a minimal penalty for leaving the logging code in your application.
- Log records can be directed to different handlers—for displaying in the console, writing to a file, and so on.
- Both loggers and handlers can filter records. Filters can discard boring log entries, using any criteria supplied by the filter implementor.
- Log records can be formatted in different ways—for example, in plain text or XML.

- Applications can use multiple loggers, with hierarchical names such as `com.mycompany.myapp`, similar to package names.
- The logging configuration is controlled by a configuration file.

NOTE:

Many applications use other logging frameworks, such as Log4J 2 (`https://logging.apache.org/log4j/2.x`) and Logback (`https://logback.qos.ch`), that offer higher performance than the standard Java logging framework. These frameworks have slightly different APIs. Logging façades such as SLF4J (`https://www.slf4j.org`) and Commons Logging (`https://commons.apache.org/proper/commons-logging`) provide a unified API so that you can replace the logging framework without rewriting your application. To make matters more confusing, Log4J 2 can also be a façade to components that use SLF4J. In this book, I cover the standard Java logging framework. It is good enough for many purposes, and learning its API will prepare you for understanding the alternatives.

NOTE:

As of Java 9, the Java platform has a separate lightweight logging system that does not depend on the `java.logging` module (which contains the standard Java logging framework). This system is intended only for use in the Java API. If the `java.logging` module is present, log messages are automatically forwarded to it. Third-party log frameworks can provide adapters to receive platform logging messages. I do not cover platform logging since it is not meant to be used by application programmers.

7.5.1 Basic Logging

For simple logging, use the global logger and call its `info` method:

```
Logger.getGlobal().info("File->Open menu item selected");
```

By default, the record is printed like this:

```
May 10, 2013 10:12:15 PM LoggingImageViewer fileOpen
INFO: File->Open menu item selected
```

But if you call

```
Logger.getGlobal().setLevel(Level.OFF);
```

at an appropriate place (such as the beginning of `main`), all logging is suppressed.

7.5.2 Advanced Logging

Now that you have seen "logging for dummies," let's go on to industrial-strength logging. In a professional application, you wouldn't want to log all records to a single global logger. Instead, you can define your own loggers.

Call the `getLogger` method to create or retrieve a logger:

```
private static final Logger myLogger =
Logger.getLogger("com.mycompany.myapp");
```

TIP:

A logger that is not referenced by any variable can be garbage-collected. To prevent this, save a reference to the logger with a static variable, as in the example above.

Similar to package names, logger names are hierarchical. In fact, they are *more* hierarchical than packages. There is no semantic relationship between a package and its parent, but logger parents and children share certain properties. For example, if you set the log level on the logger `"com.mycompany"`, then the child loggers inherit that level.

There are seven logging levels:

- `SEVERE`
- `WARNING`
- `INFO`
- `CONFIG`
- `FINE`
- `FINER`
- `FINEST`

By default, the top three levels are actually logged. You can set a different level—for example,

```
logger.setLevel(Level.FINE);
```

Now `FINE` and all levels above it are logged.

You can also use `Level.ALL` to turn on logging for all levels or `Level.OFF` to turn all logging off.

There are logging methods for all levels, such as

```
logger.warning(message);
logger.fine(message);
```

and so on. Alternatively, you can use the `log` method and supply the level, such as

```
logger.log(Level.FINE, message);
```

TIP:

The default logging configuration logs all records with the level of `INFO` or higher. Therefore, you should use the levels `CONFIG`, `FINE`, `FINER`, and `FINEST` for debugging messages that are useful for diagnostics but meaningless to the user.

CAUTION:

If you set the logging level to a value finer than `INFO`, you also need to change the log handler configuration. The default log handler suppresses messages below `INFO`. See the next section for details.

The default log record shows the name of the class and method that contain the logging call, as inferred from the call stack. However, if the virtual machine optimizes execution, accurate call information may not be available. You can use the `logp` method to give the precise location of the calling class and method. The method signature is

```
void logp(Level l, String className, String methodName, String
message)
```

There are convenience methods for tracing execution flow:

```
void entering(String className, String methodName)
void entering(String className, String methodName, Object
param)
void entering(String className, String methodName, Object[]
params)
void exiting(String className, String methodName)
void exiting(String className, String methodName, Object
result)
```

For example:

```
int read(String file, String pattern)
{
   logger.entering("com.mycompany.mylib.Reader", "read",
      new Object[] { file, pattern });
   . . .
   logger.exiting("com.mycompany.mylib.Reader", "read", count);
   return count;
}
```

These calls generate log records of level `FINER` that start with the strings `ENTRY` and `RETURN`.

NOTE:

At some point in the future, the logging methods with an `Object[]` parameter will be rewritten to support variable parameter lists ("varargs"). Then, you will be able to make calls such as `logger.entering("com.mycompany.mylib.Reader", "read", file, pattern)`.

A common use for logging is to log unexpected exceptions. Two convenience methods include a description of the exception in the log record.

```
void throwing(String className, String methodName, Throwable t)
void log(Level l, String message, Throwable t)
```

Typical uses are

```
if (. . .)
{
   var e = new IOException(". . .");
```

```
        logger.throwing("com.mycompany.mylib.Reader", "read", e);
        throw e;
    }
```

and

```
    try
    {
        . . .
    }
    catch (IOException e)
    {
        Logger.getLogger("com.mycompany.myapp").log(Level.WARNING,
    "Reading image", e);
    }
```

The `throwing` call logs a record with level `FINER` and a message that starts with `THROW`.

7.5.3 Changing the Log Manager Configuration

You can change various properties of the logging system by editing a configuration file. The default configuration file is located at *jdk*`/conf/logging.properties` (or at *jre*`/lib/logging.properties` prior to Java 9).

```
conf/logging.properties
```

(or at *jre*`/lib/logging.properties` prior to Java 9).

To use another file, set the `java.util.logging.config.file` property to the file location by starting your application with

```
java -Djava.util.logging.config.file=configFile MainClass
```

To change the default logging level, edit the configuration file and modify the line

```
.level=INFO
```

You can specify the logging levels for your own loggers by adding lines such as

```
com.mycompany.myapp.level=FINE
```

That is, append the `.level` suffix to the logger name.

As you will see later in this section, the loggers don't actually send the messages to the console—that is the job of the handlers. Handlers also have levels. To see `FINE` messages on the console, you also need to set

```
java.util.logging.ConsoleHandler.level=FINE
```

CAUTION:

The settings in the log manager configuration are *not* system properties. Starting a program with `-Dcom.mycompany.myapp.level=FINE` does not have any effect on the logger.

The log manager is initialized during VM startup, before `main` executes. If you want to customize the logging properties but didn't start your application with the `-Djava.util.logging.config.file` command-line option, call `System.setProperty( "java.util.logging.config.file", file)` in your program. But then you must also call `LogManager.getLogManager().readConfiguration()` to reinitialize the log manager.

As of Java 9, you can instead update the logging configuration by calling

```
LogManager.getLogManager().updateConfiguration(mapper);
```

A new configuration is read from the location specified by the java.util.logging.config.file system property. Then the mapper is applied to resolve the values for all keys in the old or new configuration. The mapper is a Function<String,BiFunction<String,String,String>>. It maps keys in the existing configuration to replacement functions. Each replacement function receives the old and new values associated with the key (or null if there is no associated value), and produces a replacement, or null if the key should be dropped in the update.

That sounds rather complex, so let's walk through a couple of examples. A useful mapping scheme would be to merge the old and new configurations, preferring the new value when a key is present in both the old and new configurations. Then the mapper is

```
key -> ((oldValue, newValue) -> newValue == null ? oldValue :
newValue)
```

Or perhaps you want to only update the keys that start with com.mycompany and leave the others unchanged:

```
key -> key.startsWith("com.mycompany")
   ? ((oldValue, newValue) -> newValue)
   : ((oldValue, newValue) -> oldValue)
```

It is also possible to change logging levels in a running program by using the jconsole program. See www.oracle.com/technetwork/articles/java/jconsole-1564139.html#LoggingControl for information.

NOTE:

The logging properties file is processed by the java.util.logging.LogManager class. It is possible to specify a different log manager by setting the java.util. logging.manager system property to the name of a subclass. Alternatively, you can keep the standard log manager and still bypass the initialization from the logging properties file. Set the `java.util.logging.config.class` system property to the name of a class that sets log manager properties in some other way. See the API documentation for the `LogManager` class for more information.

7.5.4 Localization

You may want to localize logging messages so that they are readable for international users. Internationalization of applications is the topic of Chapter 7 of Volume II. Briefly, here are the points to keep in mind when localizing logging messages.

Localized applications contain locale-specific information in *resource bundles*. A resource bundle consists of a set of mappings for various locales (such as United States or Germany). For example, a resource bundle may map the string `"readingFile"` into strings `"Reading file"` in English or `"Achtung! Datei wird eingelesen"` in German.

A program may contain multiple resource bundles—for example, one for menus and another for log messages. Each resource bundle has a name (such as `"com.mycompany.logmessages"`). To add mappings to a resource bundle, supply a file for each locale. English message mappings are in a file `com/mycompany/logmessages_en.properties`, and German message mappings are in a file `com/mycompany/logmessages_de.properties`. (The `en` and `de` are the language codes.) You place the files together with the class files of your application, so that the `ResourceBundle` class will automatically locate them. These files are plain text files, consisting of entries such as

```
readingFile=Achtung! Datei wird eingelesen
renamingFile=Datei wird umbenannt
. . .
```

When requesting a logger, you can specify a resource bundle:

```
Logger logger = Logger.getLogger(loggerName,
"com.mycompany.logmessages");
```

Then specify the resource bundle key, not the actual message string, for the log message:

```
logger.info("readingFile");
```

You often need to include arguments into localized messages. A message may contain placeholders: `{0}`, `{1}`, and so on. For example, to include the file name with a log message, use the placeholder like this:

```
Reading file {0}.
Achtung! Datei {0} wird eingelesen.
```

Then, to pass values into the placeholders, call one of the following methods:

```
logger.log(Level.INFO, "readingFile", fileName);
logger.log(Level.INFO, "renamingFile", new Object[] { oldName,
newName });
```

Alternatively, as of Java 9, you can specify the resource bundle object (and not the name) in the `logrb` method:

```
logger.logrb(Level.INFO, bundle, "renamingFile", oldName,
newName);
```

NOTE:

This is the only logging method that uses variable arguments for the message parameters.

7.5.5 Handlers

By default, loggers send records to a `ConsoleHandler` that prints them to the `System.err` stream. Specifically, the logger sends the record to the parent handler, and the ultimate ancestor (with name `""`) has a `ConsoleHandler`.

Like loggers, handlers have a logging level. For a record to be logged, its logging level must be above the threshold of *both* the logger and the handler. The log manager configuration file sets the logging level of the default console handler as

```
java.util.logging.ConsoleHandler.level=INFO
```

To log records with level `FINE`, change both the default logger level and the handler level in the configuration. Alternatively, you can bypass the configuration file altogether and install your own handler.

```
Logger logger = Logger.getLogger("com.mycompany.myapp");
logger.setLevel(Level.FINE);
logger.setUseParentHandlers(false);
var handler = new ConsoleHandler();
handler.setLevel(Level.FINE);
logger.addHandler(handler);
```

By default, a logger sends records both to its own handlers and to the handlers of the parent. Our logger is a child of the primordial logger (with name `""`) that sends all records with level `INFO` and above to the console. We don't want to see those records twice, however, so we set the `useParentHandlers` property to `false`.

To send log records elsewhere, add another handler. The logging API provides two useful handlers for this purpose: a `FileHandler` and a `SocketHandler`. The `SocketHandler` sends records to a specified host and port. Of greater interest is the `FileHandler` that collects records in a file.

You can simply send records to a default file handler, like this:

```
var handler = new FileHandler();
logger.addHandler(handler);
```

The records are sent to a file `java`*n*`.log` in the user's home directory, where *n* is a number to make the file unique. If a system has no concept of the user's home directory (for example, in Windows 95/98/ME), then the file is stored in a default location such as `C:\Windows`. By default, the records are formatted in XML. A typical log record has the form

```
<record>
  <date>2002-02-04T07:45:15</date>
  <millis>1012837515710</millis>
  <sequence>1</sequence>
  <logger>com.mycompany.myapp</logger>
  <level>INFO</level>
  <class>com.mycompany.mylib.Reader</class>
  <method>read</method>
  <thread>10</thread>
  <message>Reading file corejava.gif</message>
</record>
```

You can modify the default behavior of the file handler by setting various parameters in the log manager configuration (see Table 7.1) or by using another constructor (see the API notes at the end of this section).

You probably don't want to use the default log file name. Therefore, you should use another pattern, such as `%h/myapp.log`. (See Table 7.2 for an explanation of the pattern variables.)

If multiple applications (or multiple copies of the same application) use the same log file, you should turn the `append` flag on. Alternatively, use `%u` in the file name pattern so that each application creates a unique copy of the log.

It is also a good idea to turn file rotation on. Log files are kept in a rotation sequence, such as `myapp.log.0`, `myapp.log.1`, `myapp.log.2`, and so on. Whenever a file exceeds the size limit, the oldest log is deleted, the other files are renamed, and a new file with generation number `0` is created.

Table 7.1 File Handler Configuration Parameters

Configuration Property	Description	Default
java.util.logging.FileHandler.level	The handler level	Level.ALL
java.util.logging.FileHandler.append	Controls whether the handler should append to an existing file, or open a new file for each program run	false
java.util.logging.FileHandler.limit	The approximate maximum number of bytes to write to a file before opening another (0 = no limit)	0 (no limit) in the FileHandler class, 50000 in the default log manager configuration
java.util.logging.FileHandler.pattern	The pattern for the log file name. See Table 7.2 for pattern variables.	%h/java%u.log
java.util.logging.FileHandler.count	The number of logs in a rotation sequence	1 (no rotation)
java.util.logging.FileHandler.filter	The filter class to use	No filtering
java.util.logging.FileHandler.encoding	The character encoding to use	The platform encoding
java.util.logging.FileHandler.formatter	The record formatter	java.util.logging.XMLFormatter

Table 7.2 Log File Pattern Variables

Variable	Description
%h	The value of the user.home system property
%t	The system temporary directory
%u	A unique number to resolve conflicts
%g	The generation number for rotated logs (a .%g suffix is used if rotation is specified and the pattern doesn't contain %g)
%%	The % character

TIP:

Some programmers use logging as an aid for the technical support staff. If a program misbehaves in the field, the user can send back the log files for inspection. In that case, you should turn the `append` flag on, use rotating logs, or both.

You can also define your own handlers by extending the `Handler` or the `StreamHandler` class. We define such a handler in the example program at the end of this section. That handler displays the records in a window (see Figure 7.2).

Figure 7.2 A log handler that displays records in a window

The handler extends the `StreamHandler` class and installs a stream whose `write`

methods display the stream output in a text area.

```
class WindowHandler extends StreamHandler
{
   public WindowHandler()
   {
      . . .
      var output = new JTextArea();
      setOutputStream(new
         OutputStream()
         {
            public void write(int b) {} // not called
            public void write(byte[] b, int off, int len)
            {
               output.append(new String(b, off, len));
            }
         });
   }   . . .
}
```

There is just one problem with this approach—the handler buffers the records and only writes them to the stream when the buffer is full. Therefore, we override the `publish` method to flush the buffer after each record:

```
class WindowHandler extends StreamHandler
{
   . . .
   public void publish(LogRecord record)
   {
      super.publish(record);
      flush();
   }
}
```

If you want to write more exotic stream handlers, extend the `Handler` class and define the `publish`, `flush`, and `close` methods.

7.5.6 Filters

By default, records are filtered according to their logging levels. Each logger and handler can have an optional filter to perform additional filtering. To define a filter, implement the `Filter` interface and define the method

```
boolean isLoggable(LogRecord record)
```

Analyze the log record, using any criteria that you desire, and return `true` for those records that should be included in the log. For example, a particular filter may only be interested in the messages generated by the `entering` and `exiting` methods. The filter should then call `record.getMessage()` and check whether it starts with `ENTRY` or `RETURN`.

To install a filter into a logger or handler, simply call the `setFilter` method. Note that you can have at most one filter at a time.

7.5.7 Formatters

The `ConsoleHandler` and `FileHandler` classes emit the log records in text and XML formats. However, you can define your own formats as well. You need to extend the `Formatter` class and override the method

```
String format(LogRecord record)
```

Format the information in the record in any way you like and return the resulting string. In your `format` method, you may want to call the method

```
String formatMessage(LogRecord record)
```

That method formats the message part of the record, substituting parameters and applying localization.

Many file formats (such as XML) require a head and tail parts that surround the formatted records. To achieve this, override the methods

```
String getHead(Handler h)
String getTail(Handler h)
```

Finally, call the `setFormatter` method to install the formatter into the handler.

7.5.8 A Logging Recipe

With so many options for logging, it is easy to lose track of the fundamentals. The following recipe summarizes the most common operations.

1. For a simple application, choose a single logger. It is a good idea to give the logger the same name as your main application package, such as `com.mycompany.myprog`. You can always get the logger by calling

   ```
   Logger logger = Logger.getLogger("com.mycompany.myprog");
   ```

   For convenience, you may want to add static fields

```
private static final Logger logger =
Logger.getLogger("com.mycompany.myprog");
```

to classes with a lot of logging activity.

2. The default logging configuration logs all messages of level `INFO` or higher to the console. Users can override the default configuration, but as you have seen, the process is a bit involved. Therefore, it is a good idea to install a more reasonable default in your application.

   The following code ensures that all messages are logged to an application-specific file. Place the code into the `main` method of your application.

```
if (System.getProperty("java.util.logging.config.class") ==
null
      && System.getProperty("java.util.logging.config.file") ==
null)
{
   try
   {
      Logger.getLogger("").setLevel(Level.ALL);
      final int LOG_ROTATION_COUNT = 10;
      var handler = new FileHandler("%h/myapp.log", 0,
LOG_ROTATION_COUNT);
      Logger.getLogger("").addHandler(handler);
   }
   catch (IOException e)
   {
      logger.log(Level.SEVERE, "Can't create log file handler",
e);
   }
}
```

3. Now you are ready to log to your heart’s content. Keep in mind that all messages with level `INFO`, `WARNING`, and `SEVERE` show up on the console. Therefore, reserve these levels for messages that are meaningful to the users of your program. The level `FINE` is a good choice for logging messages that are intended for programmers.

Whenever you are tempted to call `System.out.println`, emit a log message instead:

```
logger.fine("File open dialog canceled");
```

It is also a good idea to log unexpected exceptions. For example:

```
try
{
   . . .
}
catch (SomeException e)
{
   logger.log(Level.FINE, "explanation", e);
}
```

Listing 7.2 puts this recipe to use with an added twist: Logging messages are also displayed in a log window.

Listing 7.2 `logging/LoggingImageViewer.java`

```
package logging;

import java.awt.*;
import java.awt.event.*;
import java.io.*;
import java.util.logging.*;
import javax.swing.*;

/**
 * A modification of the image viewer program that logs various events.
 * @version 1.03 2015-08-20
 * @author Cay Horstmann
 */
public class LoggingImageViewer
{
   public static void main(String[] args)
```

```
   {
      if (System.getProperty("java.util.logging.config.class") == null
      && System.getProperty("java.util.logging.config.file") == null)
      {
         try
         {
            Logger.getLogger("com.horstmann.corejava").setLevel(Level.ALL);
            final int LOG_ROTATION_COUNT = 10;
            var handler = new FileHandler("%h/LoggingImageViewer.log", 0, LOG_ROTATION_COUNT);
            Logger.getLogger("com.horstmann.corejava").addHandler(handler);
      }
      catch (IOException e)
         {
            Logger.getLogger("com.horstmann.corejava").log(Level.SEVERE,
               "Can't create log file handler", e);
         }
   }

   EventQueue.invokeLater(() ->
         {
            var windowHandler = new WindowHandler();
            windowHandler.setLevel(Level.ALL);
            Logger.getLogger("com.horstmann.corejava").addHandler(windowHandler);

            var frame = new ImageViewerFrame();
            frame.setTitle("LoggingImageViewer");
            frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

            Logger.getLogger("com.horstmann.corejava").fine("Showing frame");
            frame.setVisible(true);
```

```
         });
   }
}

/**
 * The frame that shows the image.
 */
class ImageViewerFrame extends JFrame
{
   private static final int DEFAULT_WIDTH = 300;
   private static final int DEFAULT_HEIGHT = 400;

   private JLabel label;
   private static Logger logger = Logger.getLogger("com.horstmann.corejava");

   public ImageViewerFrame()
   {
      logger.entering("ImageViewerFrame", "<init>");
      setSize(DEFAULT_WIDTH, DEFAULT_HEIGHT);

      // set up menu bar
      var menuBar = new JMenuBar();
      setJMenuBar(menuBar);

      var menu = new JMenu("File");
      menuBar.add(menu);

      var openItem = new JMenuItem("Open");
      menu.add(openItem);
      openItem.addActionListener(new FileOpenListener());

      var exitItem = new JMenuItem("Exit");
      menu.add(exitItem);
      exitItem.addActionListener(new ActionListener()
         {
            public void actionPerformed(ActionEvent event)
            {
               logger.fine("Exiting.");
```

```
              System.exit(0);
           }
        });

     // use a label to display the images
     label = new JLabel();
     add(label);
     logger.exiting("ImageViewerFrame", "<init>");
}

private class FileOpenListener implements ActionListener
{
   public void actionPerformed(ActionEvent event)
   {
      logger.entering("ImageViewerFrame.FileOpenListener",
"actionPerformed", event);

      // set up file chooser
      var chooser = new JFileChooser();
      chooser.setCurrentDirectory(new File("."));

      // accept all files ending with .gif
      chooser.setFileFilter(new
javax.swing.filechooser.FileFilter()
         {
            public boolean accept(File f)
            {
               return
f.getName().toLowerCase().endsWith(".gif") || f.isDirectory();
            }

            public String getDescription()
            {
               return "GIF Images";
            }
         });

     // show file chooser dialog
     int r =
```

```
chooser.showOpenDialog(ImageViewerFrame.this);

         // if image file accepted, set it as icon of the label
         if (r == JFileChooser.APPROVE_OPTION)
         {
            String name = chooser.getSelectedFile().getPath();
            logger.log(Level.FINE, "Reading file {0}", name);
            label.setIcon(new ImageIcon(name));
         }
         else logger.fine("File open dialog canceled.");
         logger.exiting("ImageViewerFrame.FileOpenListener", "actionPerformed");
      }
   }
}

/**
 * A handler for displaying log records in a window.
 */
class WindowHandler extends StreamHandler
{
   private JFrame frame;

   public WindowHandler()
   {
      frame = new JFrame();
      var output = new JTextArea();
      output.setEditable(false);
      frame.setSize(200, 200);
      frame.add(new JScrollPane(output));
      frame.setFocusableWindowState(false);
      frame.setVisible(true);
      setOutputStream(new OutputStream()
         {
            public void write(int b)
            {
            } // not called
```

```

            public void write(byte[] b, int off, int len)
            {
               output.append(new String(b, off, len));
            }
         });
   }

   public void publish(LogRecord record)
   {
      if (!frame.isVisible()) return;
      super.publish(record);
      flush();
   }
}
```

`java.util.logging.Logger` 1.4

- `Logger getLogger(String loggerName)`
- `Logger getLogger(String loggerName, String bundleName)`

  gets the logger with the given name. If the logger doesn't exist, it is created. Localized messages are located in the resource bundle whose name is `bundleName`.

- `void severe(String message)`
- `void warning(String message)`
- `void info(String message)`
- `void config(String message)`
- `void fine(String message)`
- `void finer(String message)`
- `void finest(String message)`

  logs a record with the level indicated by the method name and the given message.

- `void entering(String className, String methodName)`
- `void entering(String className, String methodName, Object param)`
- `void entering(String className, String methodName, Object[] param)`
- `void exiting(String className, String methodName)`
- `void exiting(String className, String methodName, Object result)`

  logs a record that describes entering or exiting a method with the given parameter(s) or return value.

- `void throwing(String className, String methodName, Throwable t)`

  logs a record that describes throwing of the given exception object.

- `void log(Level level, String message)`
- `void log(Level level, String message, Object obj)`
- `void log(Level level, String message, Object[] objs)`
- `void log(Level level, String message, Throwable t)`

  logs a record with the given level and message, optionally including objects or a throwable. To include objects, the message must contain formatting placeholders (`{0}`, `{1}`, and so on).

- `void logp(Level level, String className, String methodName, String message)`
- `void logp(Level level, String className, String methodName, String message, Object obj)`
- `void logp(Level level, String className, String methodName, String message, Object[] objs)`
- `void logp(Level level, String className, String methodName, String message, Throwable t)`

  logs a record with the given level, precise caller information, and message, optionally including objects or a throwable.

- `void logrb(Level level, String className, String methodName, ResourceBundle bundle, String message, Object... params)` 9
- `void logrb(Level level, String className, String methodName, ResourceBundle bundle, String message, Throwable thrown)` 9

  logs a record with the given level, precise caller information, resource bundle, and message, followed by objects or a throwable.

- `Level getLevel()`
- `void setLevel(Level l)`

  gets and sets the level of this logger.

- `Logger getParent()`
- `void setParent(Logger l)`

  gets and sets the parent logger of this logger.

- `Handler[] getHandlers()`

  gets all handlers of this logger.

- `void addHandler(Handler h)`
- `void removeHandler(Handler h)`

  adds or removes a handler for this logger.

- `boolean getUseParentHandlers()`
- `void setUseParentHandlers(boolean b)`

  gets and sets the “use parent handler” property. If this property is `true`, the logger forwards all logged records to the handlers of its parent.

- `Filter getFilter()`
- `void setFilter(Filter f)`

  gets and sets the filter of this logger.

java.util.logging.Handler 1.4

- `abstract void publish(LogRecord record)`

  sends the record to the intended destination.
- `abstract void flush()`

  flushes any buffered data.
- `abstract void close()`

  flushes any buffered data and releases all associated resources.
- `Filter getFilter()`
- `void setFilter(Filter f)`

  gets and sets the filter of this handler.
- `Formatter getFormatter()`
- `void setFormatter(Formatter f)`

  gets and sets the formatter of this handler.
- `Level getLevel()`
- `void setLevel(Level l)`

  gets and sets the level of this handler.

`java.util.logging.ConsoleHandler` 1.4

- `ConsoleHandler()`

  constructs a new console handler.

`java.util.logging.FileHandler` 1.4

- `FileHandler(String pattern)`
- `FileHandler(String pattern, boolean append)`

• `FileHandler(String pattern, int limit, int count)`

• `FileHandler(String pattern, int limit, int count, boolean append)`

• `FileHandler(String pattern, long limit, int count, boolean append)` 9

constructs a file handler. See Table 7.2 for the pattern format. `limit` is the approximate maximum number of bytes before a new log file is opened. `count` is the number of files in a rotation sequence. If `append` is `true`, records should be appended to an existing log file.

java.util.logging.LogRecord 1.4

• `Level getLevel()`

gets the logging level of this record.

• `String getLoggerName()`

gets the name of the logger that is logging this record.

• `ResourceBundle getResourceBundle()`

• `String getResourceBundleName()`

gets the resource bundle, or its name, to be used for localizing the message, or `null` if none is provided.

• `String getMessage()`

gets the “raw” message before localization or formatting.

• `Object[] getParameters()`

gets the parameter objects, or `null` if none is provided.

• `Throwable getThrown()`

gets the thrown object, or `null` if none is provided.

• `String getSourceClassName()`

• `String getSourceMethodName()`

gets the location of the code that logged this record. This information may be supplied by the logging code or automatically inferred from the runtime stack. It might be inaccurate if the logging code supplied the wrong value or if the running code was optimized so that the exact location cannot be inferred.

- `long getMillis()`

  gets the creation time, in milliseconds since 1970.

- `Instant getInstant()` 9

  gets the creation time as a `java.time.Instant` (see Chapter 6 of Volume II).

- `long getSequenceNumber()`

  gets the unique sequence number of this record.

- `long getLongThreadID()` 16

  gets the unique ID for the thread in which this record was created. These IDs are assigned by the `LogRecord` class and have no relationship to other thread IDs. (The `getThreadID` method returns `int` IDs. It is now deprecated because a long-running program might generate more than `Integer.MAX_VALUE` log records.)

`java.util.logging.LogManager` 1.4

- `static LogManager getLogManager()`

  gets the global `LogManager` instance.

- `void readConfiguration()`
- `void readConfiguration(InputStream in)`

  reads the logging configuration from the file specified by the system property `java.util.logging.config.file`, or the given input stream.

- `void updateConfiguration(InputStream in, Function<String,BiFunction<String,String,String>> mapper)` 9

- `void updateConfiguration(Function<String,BiFunction<String,String, String>> mapper)` 9

  merges the logging configuration with the file specified by the system property `java.util.logging.config.file` or the given input stream. See Section 7.5.3, “Changing the Log Manager Configuration,” on p. 424 for a description of the `mapper` parameter.

`java.util.logging.Filter` 1.4

- `boolean isLoggable(LogRecord record)`

  returns `true` if the given log record should be logged.

`java.util.logging.Formatter` 1.4

- `abstract String format(LogRecord record)`

  returns the string that results from formatting the given log record.

- `String getHead(Handler h)`
- `String getTail(Handler h)`

  returns the strings that should appear at the head and tail of the document containing the log records. The `Formatter` superclass defines these methods to return the empty string; override them if necessary.

- `String formatMessage(LogRecord record)`

  returns the localized and formatted message part of the log record.

7.6 Debugging Tips

Suppose you wrote your program and made it bulletproof by catching and properly handling all exceptions. Then you run it, and it does not work right. Now what? (If you never have this problem, you can skip the remainder of this chapter.)

Of course, it is best if you have a convenient and powerful debugger. Debuggers are available as a part of professional development environments such as Eclipse, IntelliJ, and NetBeans. In this section, I offer a number of tips that may be worth trying before you launch the debugger.

1. You can print or log the value of any variable with code like this:

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

   or

   ```
   Logger.getGlobal().info("x=" + x);
   ```

   If `x` is a number, it is converted to its string equivalent. If `x` is an object, Java calls its `toString` method. To get the state of the implicit parameter object, print the state of the `this` object.

   ```
   Logger.getGlobal().info("this=" + this);
   ```

   Most of the classes in the Java library are very conscientious about overriding the `toString` method to give you useful information about the class. This is a real boon for debugging. You should make the same effort in your classes.
2. One seemingly little-known but very useful trick is putting a separate `main` method in each class. Inside it, you can put a unit test stub that lets you test the class in isolation.

   ```
   public class MyClass
   {
   methods and fields
       . . .
       public static void main(String[] args)
       {
           test code
   ```

```
    }
}
```

Make a few objects, call all methods, and check that each of them does the right thing. You can leave all these `main` methods in place and launch the Java virtual machine separately on each of the files to run the tests. When you run an applet, none of these `main` methods are ever called. When you run an application, the Java virtual machine calls only the `main` method of the startup class.

3. If you liked the preceding tip, you should check out JUnit from `http://junit.org`. JUnit is a very popular unit testing framework that makes it easy to organize suites of test cases. Run the tests whenever you make changes to a class, and add another test case whenever you find a bug.

4. A *logging proxy* is an object of a subclass that intercepts method calls, logs them, and then calls the superclass. For example, if you have trouble with the `nextDouble` method of the `Random` class, you can create a proxy object as an instance of an anonymous subclass:

```
var generator = new Random()
   {
      public double nextDouble()
      {
         double result = super.nextDouble();
         Logger.getGlobal().info("nextDouble: " + result);
         return result;
      }
   };
```

   Whenever the `nextDouble` method is called, a log message is generated.

   To find out who called the method, generate a stack trace.

5. You can get a stack trace from any exception object with the `printStackTrace` method in the `Throwable` class. The following code catches any exception, prints the exception object and the stack trace, and rethrows the exception so it can find its intended handler.

```
try
{
```

```
    . . .
}
catch (Throwable t)
{
   t.printStackTrace();
   throw t;
}
```

You don’t even need to catch an exception to generate a stack trace. Simply insert the statement

```
Thread.dumpStack();
```

anywhere into your code to get a stack trace.

6. Normally, the stack trace is displayed on `System.err`. If you want to log or display the stack trace, here is how you can capture it into a string:

```
var out = new StringWriter();
new Throwable().printStackTrace(new PrintWriter(out));
String description = out.toString();
```

7. It is often handy to trap program errors in a file. However, errors are sent to `System.err`, not `System.out`. Therefore, you cannot simply trap them by running

```
java MyProgram > errors.txt
```

Instead, capture the error stream as

```
java MyProgram 2> errors.txt
```

To capture both `System.err` and `System.out` in the same file, use

```
java MyProgram 1> errors.txt 2>&1
```

This works in `bash` and the Windows shell.

8. Having the stack traces of uncaught exceptions show up in `System.err` is not ideal. These messages are confusing to end users if they happen to see them, and they are not available for diagnostic purposes when you need them. A better approach is to log them to a file. You can change the

handler for uncaught exceptions with the static `Thread.setDefaultUncaughtExceptionHandler` method:

```
Thread.setDefaultUncaughtExceptionHandler(
   new Thread.UncaughtExceptionHandler()
   {
      public void uncaughtException(Thread t, Throwable e)
      {
         save information in log file
      };
   });
```

9. To watch class loading, launch the Java virtual machine with the `-verbose` flag. You will get a printout such as the following:

```
[0.012s][info][class,load] opened: /opt/jdk-11.0.1/lib/modules
[0.034s][info][class,load] java.lang.Object source:
jrt:/java.base
[0.035s][info][class,load] java.io.Serializable source:
jrt:/java.base
[0.035s][info][class,load] java.lang.Comparable source:
jrt:/java.base
[0.035s][info][class,load] java.lang.CharSequence source:
jrt:/java.base
[0.035s][info][class,load] java.lang.String source:
jrt:/java.base
[0.036s][info][class,load] java.lang.reflect.AnnotatedElement
source: jrt:/java.base
[0.036s][info][class,load] java.lang.reflect.GenericDeclaration
source: jrt:/java.base
[0.036s][info][class,load] java.lang.reflect.Type source:
jrt:/java.base
[0.036s][info][class,load] java.lang.Class source:
jrt:/java.base
[0.036s][info][class,load] java.lang.Cloneable source:
jrt:/java.base
[0.037s][info][class,load] java.lang.ClassLoader source:
jrt:/java.base
[0.037s][info][class,load] java.lang.System source:
jrt:/java.base
```

```
[0.037s][info][class,load] java.lang.Throwable source:
jrt:/java.base
[0.037s][info][class,load] java.lang.Error source:
jrt:/java.base
[0.037s][info][class,load] java.lang.ThreadDeath source:
jrt:/java.base
[0.037s][info][class,load] java.lang.Exception source:
jrt:/java.base[0.037s][info][class,load]
java.lang.RuntimeException source: jrt:/java.base
[0.038s][info][class,load] java.lang.SecurityManager source:
jrt:/java.base . . .
```

This can occasionally be helpful to diagnose class path problems.

10. The `-Xlint` option tells the compiler to spot common code problems. For example, if you compile with the command

```
javac -Xlint sourceFiles
```

the compiler will report missing `break` statements in `switch` statements. (The term "lint" originally described a tool for locating potential problems in C programs, but is now generically applied to any tools that flag constructs that are questionable but not illegal.)

You will get messages such as

```
warning: [fallthrough] possible fall-through into case
```

The string in square brackets identifies the warning category. You can enable and disable each category. Since most of them are quite useful, it seems best to leave them all in place and disable only those that you don't care about, like this:

```
javac -Xlint:all,-fallthrough,-serial sourceFiles
```

You get a list of all warnings from the command

```
javac --help -X
```

11. The Java VM has support for *monitoring and management* of Java applications, allowing the installation of agents in the virtual machine that track memory consumption, thread usage, class loading, and so on. This feature is particularly important for large and long-running Java programs, such as application servers. As a demonstration of these capabilities, the JDK ships with a graphical tool called `jconsole` that displays statistics about the performance of a virtual machine (see Figure 7.3). Start your program, then start `jconsole` and pick your program from the list of running Java programs.

    The console gives you a wealth of information about your running program. See `www.oracle.com/technetwork/articles/java/jconsole-1564139.html` for more information.

12. Java Mission Control is a professional-level profiling and diagnostics tool, available at `https://adoptopenjdk.net/jmc.html`. Like `jconsole`, Java Mission Control can attach to a running virtual machine. It can also analyze the output from Java Flight Recorder, a tool that collects diagnostic and profiling data from a running Java application. See `https://github.com/thegreystone/jmc-tutorial` for a comprehensive tutorial.

Figure 7.3 The `jconsole` program

This chapter introduced you to exception handling and logging. You also saw useful hints for testing and debugging. The next two chapters cover generic programming and its most important application: the Java collections framework.

Chapter 8. Generic Programming

In this chapter

Generic classes and methods have type parameters. This allows them to describe precisely what should happen when they are instantiated with specific types. Prior to generic classes, programmers had to use the `Object` for writing code that works with multiple types. This was both cumbersome and unsafe.

With the introduction of generics, Java has an expressive type system that allows designers to describe in detail how types of variables and methods should vary. In straightforward situations, you will find it simple to implement generic code. In more advanced cases, it can get quite complex—for implemetors. The goal is to provide classes and methods that other programmers can use without surprises.

The introduction of generics in Java 5 constitutes the most significant change in the Java programming language since its initial release. A major design goal was to be backwards compatible with earlier releases. As a result, Java generics have some uncomfortable limitations. You will learn about the benefits and challenges of generic programming in this chapter.

8.1 Why Generic Programming?

Generic programming means writing code that can be reused for objects of many different types. For example, you don't want to program separate classes to collect `String` and `File` objects. And you don't have to—the single class `ArrayList` collects objects of any class. This is one example of generic programming.

Actually, Java had an `ArrayList` class before it had generic classes. Let us investigate how the mechanism for generic programming has evolved, and what that means for users and implementors.

8.1.1 The Advantage of Type Parameters

Before generic classes were added to Java, generic programming was achieved with *inheritance*. The `ArrayList` class simply maintained an array of `Object` references:

```
public class ArrayList // before generic classes
{
   private Object[] elementData;
   . . .
   public Object get(int i) { . . . }
   public void add(Object o) { . . . }
}
```

This approach has two problems. A cast is necessary whenever you retrieve a value:

```
ArrayList files = new ArrayList(); . . .
String filename = (String) files.get(0);
```

Moreover, there is no error checking. You can add values of any class:

```
files.add(new File(". . ."));
```

This call compiles and runs without error. Elsewhere, casting the result of `get` to a `String` will cause an error.

Generics offer a better solution: *type parameters*. The `ArrayList` class now has a type parameter that indicates the element type:

```
var files = new ArrayList<String>();
```

This makes your code easier to read. You can tell right away that this particular array list contains `String` objects.

NOTE:

If you declare a variable with an explicit type instead of `var`, you can omit the type parameter in the constructor by using the “diamond” syntax:

```
ArrayList<String> files = new ArrayList<>();
```

The omitted type is inferred from the type of the variable.

Java 9 expands the use of the diamond syntax to situations where it was previously not accepted. For example, you can now use diamonds with anonymous subclasses:

```
ArrayList<String> passwords = new ArrayList<>() // diamond OK
in Java 9
   {
                    public   String   get(int   n)   {   return
super.get(n).replaceAll(".", "*"); }
   };
```

The compiler can make good use of the type information too. No cast is required for calling `get`. The compiler knows that the return type is `String`, not `Object`:

```
String filename = files.get(0);
```

The compiler also knows that the `add` method of an `ArrayList<String>` has a parameter of type `String`. That is a lot safer than having an `Object` parameter. Now the compiler can check that you don't insert objects of the wrong type. For example, the statement

```
files.add(new File(". . .")); // can only add String objects to
an ArrayList<String>
```

will not compile. A compiler error is much better than a class cast exception at runtime.

This is the appeal of type parameters: They make your programs easier to read and safer.

8.1.2 Who Wants to Be a Generic Programmer?

It is easy to use a generic class such as `ArrayList`. Most Java programmers will simply use types such as `ArrayList<String>` as if they had been built into the language, just like `String[]` arrays. (Of course, array lists are better than arrays because they can expand automatically.)

However, it is not so easy to implement a generic class. The programmers who use your code will want to plug in all sorts of classes for your type parameters. They will expect everything to work without onerous restrictions and confusing error messages. Your job as a generic programmer, therefore, is to anticipate all the potential future uses of your class.

How hard can this get? Here is a typical issue that the designers of the standard class library had to grapple with. The `ArrayList` class has a method `addAll` to add all elements of another collection. A programmer may want to add all elements from an `ArrayList<Manager>` to an `ArrayList<Employee>`. But, of course, doing it the other way round should not be legal. How do you allow one call and disallow the other? The Java language designers invented an ingenious new concept, the *wildcard type*, to solve this problem. Wildcard types are rather abstract, but they allow a library builder to make methods as flexible as possible.

Generic programming falls into three skill levels. At a basic level, you just use generic classes—typically, collections such as `ArrayList`—without thinking how and why they work. Most application programmers will want to stay at that level until something goes wrong. You may, however, encounter a confusing error message when mixing different generic classes, or when interfacing with legacy code that knows nothing about type parameters; at that point, you'll need to learn enough about Java generics to solve problems systematically rather than through random tinkering. Finally, of course, you may want to implement your own generic classes and methods.

Application programmers probably won't write lots of generic code. The JDK developers have already done the heavy lifting and supplied type parameters for all the collection classes. As a rule of thumb, only code that traditionally involved lots of casts from very general types (such as `Object` or the `Comparable` interface) will benefit from using type parameters.

In this chapter, I will show you everything you need to know to implement your own generic code. However, I expect that most readers will use this knowledge primarily for help with troubleshooting and to satisfy their curiosity about the inner workings of the parameterized collection classes.

8.2 Defining a Simple Generic Class

A *generic class* is a class with one or more type variables. In this chapter, a simple `Pair` class is used as an example. This class allows us to focus on generics without being distracted by data storage details. Here is the code for the generic `Pair` class:

```
public class Pair<T>
{
   private T first;
   private T second;

   public Pair() { first = null; second = null; }
```

```
   public Pair(T first, T second) { this.first = first;
this.second = second; }

   public T getFirst() { return first; }
   public T getSecond() { return second; }

   public void setFirst(T newValue) { first = newValue; }
   public void setSecond(T newValue) { second = newValue; }
}
```

The `Pair` class introduces a type variable `T`, enclosed in angle brackets `< >`, after the class name. A generic class can have more than one type variable. For example, we could have defined the `Pair` class with separate types for the first and second field:

```
public class Pair<T, U> { . . . }
```

The type variables are used throughout the class definition to specify method return types and the types of fields and local variables. For example:

```
private T first; // uses the type variable
```

NOTE:

It is common practice to use uppercase letters for type variables, and to keep them short. The Java library uses the variable `E` for the element type of a collection, `K` and `V` for key and value types of a table, and `T` (and the neighboring letters `U` and `S`, if necessary) for "any type at all."

You *instantiate* the generic type by substituting types for the type variables, such as

```
Pair<String>
```

You can think of the result as an ordinary class with constructors

```
Pair<String>()
Pair<String>(String, String)
```

and methods

```
String getFirst()
String getSecond()void setFirst(String)
void setSecond(String)
```

In other words, the generic class acts as a factory for ordinary classes.

The program in Listing 8.1 puts the `Pair` class to work. The static `minmax` method traverses an array and simultaneously computes the minimum and maximum values. It uses a `Pair` object to return both results. Recall that the `compareTo` method compares two strings, returning `0` if the strings are identical, a negative integer if the first string comes before the second in dictionary order, and a positive integer otherwise.

C++ NOTE:

Superficially, generic classes in Java are similar to template classes in C++. The only obvious difference is that Java has no special `template` keyword. However, as you will see throughout this chapter, there are substantial differences between these two mechanisms.

Listing 8.1 `pair1/PairTest1.java`

```
package pair1;

/**
 * @version 1.01 2012-01-26
 * @author Cay Horstmann
```

```
 */
public class PairTest1
{
   public static void main(String[] args)
   {
      String[] words = { "Mary", "had", "a", "little", "lamb" };
      Pair<String> mm = ArrayAlg.minmax(words);
      System.out.println("min = " + mm.getFirst());
      System.out.println("max = " + mm.getSecond());
   }
}

class ArrayAlg
{
   /**
    * Gets the minimum and maximum of an array of strings.
    * @param a an array of strings
    * @return a pair with the min and max values, or null if a is null or empty
    */
   public static Pair<String> minmax(String[] a)
   {
      if (a == null || a.length == 0) return null;
      String min = a[0];
      String max = a[0];
      for (int i = 1; i < a.length; i++)
      {
         if (min.compareTo(a[i]) > 0) min = a[i];
         if (max.compareTo(a[i]) < 0) max = a[i];
      }
      return new Pair<>(min, max);
   }
}
```

8.3 Generic Methods

In the preceding section, you have seen how to define a generic class. You can also define a single method with type parameters.

```
class ArrayAlg
{
   public static <T> T getMiddle(T... a)
   {
      return a[a.length / 2];
   }
}
```

This method is defined inside an ordinary class, not inside a generic class. However, it is a generic method, as you can see from the angle brackets and the type variable. Note that the type variables are inserted after the modifiers (`public static`, in our case) and before the return type.

You can define generic methods both inside ordinary classes and inside generic classes.

When you call a generic method, you can place the actual types, enclosed in angle brackets, before the method name:

```
String middle = ArrayAlg.<String>getMiddle("John", "Q.",
"Public");
```

In this case (and indeed in most cases), you can omit the `<String>` type parameter from the method call. The compiler has enough information to infer the method that you want. It matches the type of the arguments against the generic type `T...` and deduces that `T` must be `String`. That is, you can simply call

```
String middle = ArrayAlg.getMiddle("John", "Q.", "Public");
```

In almost all cases, type inference for generic methods works smoothly. Occasionally, the compiler gets it wrong, and you'll need to decipher an error report. Consider this example:

```
double middle = ArrayAlg.getMiddle(3.14, 1729, 0);
```

The error message complains, in cryptic terms that vary from one compiler version to another, that there are two ways of interpreting this code, both equally valid. In a nutshell, the compiler autoboxed the parameters into a Double and two Integer objects, and then it tried to find a common supertype of these classes. It actually found two: Number and the Comparable interface, which is itself a generic type. In this case, the remedy is to write all parameters as double values.

TIP:

Peter von der Ahé recommends this trick if you want to see which type the compiler infers for a generic method call: Purposefully introduce an error and study the resulting error message. For example, consider the call ArrayAlg.getMiddle("Hello", 0, null). Assign the result to a JButton, which can't possibly be right. You will get an error report:

```
found:
java.lang.Object&java.io.Serializable&java.lang.Comparable<?
extends
java.lang.Object&java.io.Serializable&java.lang.Comparable<?>>
```

In plain English, you can assign the result to Object, Serializable, or Comparable.

C++ NOTE:

In C++, you place the type parameters after the method name. That can lead to nasty parsing ambiguities. For example, g(f<a,b>(c)) can mean "call g with the result of f<a,b>(c)", or "call g with the two boolean values f<a and b>(c)".

8.4 Bounds for Type Variables

Sometimes, a class or a method needs to place restrictions on type variables. Here is a typical example. We want to compute the smallest element of an array:

```
class ArrayAlg
{
   public static <T> T min(T[] a) // almost correct
   {
      if (a == null || a.length == 0) return null;
      T smallest = a[0];
      for (int i = 1; i < a.length; i++)
         if (smallest.compareTo(a[i]) > 0) smallest = a[i];
      return smallest;
   }
}
```

But there is a problem. Look inside the code of the `min` method. The variable `smallest` has type `T`, which means it could be an object of an arbitrary class. How do we know that the class to which `T` belongs has a `compareTo` method? The solution is to restrict `T` to a class that implements the `Comparable` interface—a standard interface with a single method, `compareTo`. You can achieve this by giving a *bound* for the type variable `T`:

```
public static <T extends Comparable> T min(T[] a) . . .
```

Actually, the `Comparable` interface is itself a generic type. For now, ignore that complexity and the warnings that the compiler generates. Section 8.8, "Wild-card Types," on p. 475 discusses how to properly use type parameters with the `Comparable` interface.

Now, the generic `min` method can only be called with arrays of classes that implement the `Comparable` interface, such as `String`, `LocalDate`, and so on. Calling `min` with a `Rectangle` array is a compile-time error because the `Rectangle` class does not implement `Comparable`.

C++ NOTE:

In C++, you cannot restrict the types of template parameters. If a programmer instantiates a template with an inappropriate type, an (often obscure) error message is reported inside the template code.

You may wonder why I use the extends keyword rather than the implements keyword in this situation—after all, Comparable is an interface. The notation

```
<T extends BoundingType>
```

expresses that T should be a *subtype* of the bounding type. Both T and the bounding type can be either a class or an interface. The extends keyword was chosen because it is a reasonable approximation of the subtype concept, and the Java designers did not want to add a new keyword (such as sub) to the language.

A type variable or wildcard can have multiple bounds. For example:

```
T extends Comparable & Serializable
```

The bounding types are separated by ampersands (&) because commas are used to separate type variables.

As with Java inheritance, you can have as many interface supertypes as you like, but at most one of the bounds can be a class. If you have a class as a bound, it must be the first one in the bounds list.

In the next sample program (Listing 8.2), we rewrite the minmax method to be generic. The method computes the minimum and maximum of a generic array, returning a Pair<T>.

Listing 8.2 pair2/PairTest2.java

```
package pair2;

import java.time.*;

/**
 * @version 1.02 2015-06-21
 * @author Cay Horstmann
 */
public class PairTest2
{
   public static void main(String[] args)
   {
      LocalDate[] birthdays =
         {
            LocalDate.of(1906, 12, 9), // G. Hopper
            LocalDate.of(1815, 12, 10), // A. Lovelace
            LocalDate.of(1903, 12, 3), // J. von Neumann
            LocalDate.of(1910, 6, 22), // K. Zuse
         };
      Pair<LocalDate> mm = ArrayAlg.minmax(birthdays);
      System.out.println("min = " + mm.getFirst());
      System.out.println("max = " + mm.getSecond());
   }
}

class ArrayAlg
{
   /**
      Gets the minimum and maximum of an array of objects of type T.
      @param a an array of objects of type T
      @return a pair with the min and max values, or null if a is null or empty
   */
   public static <T extends Comparable> Pair<T> minmax(T[] a)
   {
      if (a == null || a.length == 0) return null;
      T min = a[0];
      T max = a[0];
```

```
      for (int i = 1; i < a.length; i++)
      {
         if (min.compareTo(a[i]) > 0) min = a[i];
         if (max.compareTo(a[i]) < 0) max = a[i];
      }
      return new Pair<>(min, max);
   }
}
```

8.5 Generic Code and the Virtual Machine

The virtual machine does not have objects of generic types—all objects belong to ordinary classes. An earlier version of the generics implementation was even able to compile a program that used generics into class files that executed on 1.0 virtual machines! In the following sections, you will see how the compiler “erases” type parameters, and what implication that process has for Java programmers.

8.5.1 Type Erasure

Whenever you define a generic type, a corresponding *raw* type is automatically provided. The name of the raw type is simply the name of the generic type, with the type parameters removed. The type variables are *erased* and replaced by their bounding types (or `Object` for variables without bounds).

For example, the raw type for `Pair<T>` looks like this:

```
public class Pair
{
   private Object first;
   private Object second;

   public Pair(Object first, Object second)
   {
      this.first = first;
      this.second = second;
```

```
   }

   public Object getFirst() { return first; }
   public Object getSecond() { return second; }

   public void setFirst(Object newValue) { first = newValue; }
   public void setSecond(Object newValue) { second = newValue;
}
}
```

Since `T` is an unbounded type variable, it is simply replaced by `Object`.

The result is an ordinary class, just as you might have implemented it before generics were added to Java.

Your programs may contain different kinds of `Pair`, such as `Pair<String>` or `Pair<LocalDate>`, but erasure turns them all into raw `Pair` types.

C++ NOTE:

In this regard, Java generics are very different from C++ templates. C++ produces different types for each template instantiation—a phenomenon called “template code bloat.” Java does not suffer from this problem.

The raw type replaces type variables with the first bound, or `Object` if no bounds are given. For example, the type variable in the class `Pair<T>` has no explicit bounds, hence the raw type replaces `T` with `Object`. Suppose we declare a slightly different type:

```
public class Interval<T extends Comparable & Serializable>
implements Serializable
{
   private T lower;
   private T upper;
   . . .
```

```
   public Interval(T first, T second)
   {
      if (first.compareTo(second) <= 0) { lower = first; upper
= second; }
      else { lower = second; upper = first; }
   }
}
```

The raw type `Interval` looks like this:

```
public class Interval implements Serializable
{
   private Comparable lower;
   private Comparable upper;
   . . .
   public Interval(Comparable first, Comparable second) { . . .
}
}
```

NOTE:

You may wonder what happens if you switch the bounds: `class Interval<T extends Serializable & Comparable>`. In that case, the raw type replaces `T` with `Serializable`, and the compiler inserts casts to `Comparable` when necessary. For efficiency, you should therefore put tagging interfaces (that is, interfaces without methods) at the end of the bounds list.

8.5.2 Translating Generic Expressions

When you program a call to a generic method, the compiler inserts casts when the return type has been erased. For example, consider the sequence of statements

```
Pair<Employee> buddies = . . .;
Employee buddy = buddies.getFirst();
```

The erasure of `getFirst` has return type `Object`. The compiler automatically inserts the cast to `Employee`. That is, the compiler translates the method call into two virtual machine instructions:

- A call to the raw method `Pair.getFirst`
- A cast of the returned `Object` to the type `Employee`

Casts are also inserted when you access a generic field. Suppose the `first` and `second` fields of the `Pair` class were public. (Not a good programming style, perhaps, but it is legal Java.) Then the expression

```
Employee buddy = buddies.first;
```

also has a cast inserted in the resulting bytecodes.

8.5.3 Translating Generic Methods

Type erasure also happens for generic methods. Programmers usually think of a generic method such as

```
public static <T extends Comparable> T min(T[] a)
```

as a whole family of methods, but after erasure, only a single method is left:

```
public static Comparable min(Comparable[] a)
```

Note that the type parameter `T` has been erased, leaving only its bounding type `Comparable`.

Erasure of methods brings up a couple of complexities. Consider this example:

```
class DateInterval extends Pair<LocalDate>
{
   public void setSecond(LocalDate second)
   {
      if (second.compareTo(getFirst()) >= 0)
      super.setSecond(second);
   }
   . . .
}
```

A date interval is a pair of `LocalDate` objects, and we'll want to override the methods to ensure that the second value is never smaller than the first. This class is erased to

```
class DateInterval extends Pair // after erasure
{
   public void setSecond(LocalDate second) { . . . }
   . . .
}
```

Perhaps surprisingly, there is another `setSecond` method, inherited from `Pair`, namely

```
public void setSecond(Object second)
```

This is clearly a different method because it has a parameter of a different type—`Object` instead of `LocalDate`. But it *shouldn't* be different. Consider this sequence of statements:

```
var interval = new DateInterval(. . .);
Pair<LocalDate> pair = interval; // OK--assignment to
superclass
pair.setSecond(aDate);
```

Our expectation is that the call to `setSecond` is polymorphic and that the appropriate method is called. Since `pair` refers to a `DateInterval` object, that should be `DateInterval.setSecond`. The problem is that the type erasure interferes with polymorphism. To fix this problem, the compiler generates a *bridge method* in the `DateInterval` class:

```
public void setSecond(Object second) { setSecond((LocalDate)
second); }
```

To see why this works, let us carefully follow the execution of the statement

```
pair.setSecond(aDate)
```

The variable `pair` has declared type `Pair<LocalDate>`, and that type only has a single method called `setSecond`, namely `setSecond(Object)`. The virtual machine calls that method on the object to which `pair` refers. That object is of type `DateInterval`. Therefore, the method `DateInterval.setSecond(Object)` is called. That method is the synthesized bridge method. It calls `DateInterval.setSecond(LocalDate)`, which is what we want.

Bridge methods can get even stranger. Suppose the `DateInterval` class also overrides the `getSecond` method:

```
class DateInterval extends Pair<LocalDate>
{
   public LocalDate getSecond() { return (LocalDate)
super.getSecond(); }
   . . .
}
```

In the `DateInterval` class, there are two `getSecond` methods:

```
LocalDate getSecond() // defined in DateInterval
Object getSecond() // overrides the method defined in Pair to
call the first method
```

You could not write Java code like that; it would be illegal to have two methods with the same parameter types—here, with no parameters. However, in the virtual machine, the parameter types *and the return type* specify a method. Therefore, the compiler can produce bytecodes for two methods that differ only in their return type, and the virtual machine will handle this situation correctly.

NOTE:

Bridge methods are not limited to generic types. You already saw in Chapter 5 that it is legal for a method to specify a more restrictive return type when overriding another method. For example:

```
public class Employee implements Cloneable
{
   public Employee clone() throws CloneNotSupportedException {
. . . }
}
```

The `Object.clone` and `Employee.clone` methods are said to have *covariant return types*.

Actually, the `Employee` class has *two* clone methods:

```
Employee clone() // defined above
Object clone() // synthesized bridge method, overrides
Object.clone
```

The synthesized bridge method calls the newly defined method.

In summary, you need to remember these facts about translation of Java generics:

- There are no generics in the virtual machine, only ordinary classes and methods.
- All type parameters are replaced by their bounds.
- Bridge methods are synthesized to preserve polymorphism.
- Casts are inserted as necessary to preserve type safety.

8.5.4 Calling Legacy Code

When Java generics were designed, a major goal was to allow interoperability between generics and legacy code. Let us look at a concrete example of such legacy. The Swing user interface toolkit provides a `JSlider` class whose "ticks" can be customized with labels that contain text or images. The labels are set with the call

```
void setLabelTable(Dictionary table)
```

The `Dictionary` class maps integers to labels. Before Java 5, that class was implemented as a map of `Object` instances. Java 5 made `Dictionary` into a generic class, but `JSlider` was never updated. At this point, `Dictionary` without type parameters is a raw type. This is where compatibility comes in.

When you populate the dictionary, you can use the generic type.

```
Dictionary<Integer, Component> labelTable = new Hashtable<>();
labelTable.put(0, new JLabel(new ImageIcon("nine.gif")));
labelTable.put(20, new JLabel(new ImageIcon("ten.gif")));
. . .
```

When you pass the `Dictionary<Integer, Component>` object to `setLabelTable`, the compiler issues a warning.

```
slider.setLabelTable(labelTable); // warning
```

After all, the compiler has no assurance about what the `setLabelTable` might do to the `Dictionary` object. That method might replace all the keys with strings. That breaks the guarantee that the keys have type `Integer`, and future operations may cause bad cast exceptions.

You should ponder it and ask what the `JSlider` is actually going to do with this `Dictionary` object. In our case, it is pretty clear that the `JSlider` only reads the information, so you can ignore the warning.

Now consider the opposite case, in which you get an object of a raw type from a legacy class. You can assign it to a variable whose type uses generics, but of course you will get a warning. For example:

```
Dictionary<Integer, Components> labelTable =
slider.getLabelTable(); // warning
```

That's OK—review the warning and make sure that the label table really contains `Integer` and `Component` objects. Of course, there never is an absolute guarantee. A malicious coder might have installed a different `Dictionary` in the slider. But again, the situation is no worse than it was before generics. In the worst case, your program will throw an exception.

After you are done pondering the warning, you can use an *annotation* to make it disappear. You can annotate a local variable:

```
@SuppressWarnings("unchecked")
Dictionary<Integer, Components> labelTable =
slider.getLabelTable(); // no warning
```

Or you can annotate an entire method, like this:

```
@SuppressWarnings("unchecked")
public void configureSlider() { . . . }
```

This annotation turns off checking for all code inside the method.

8.6 Restrictions and Limitations

In the following sections, I discuss a number of restrictions that you need to consider when working with Java generics. Most of these restrictions are a consequence of type erasure.

8.6.1 Type Parameters Cannot Be Instantiated with Primitive Types

You cannot substitute a primitive type for a type parameter. Thus, there is no `Pair<double>`, only `Pair<Double>`. The reason is, of course, type erasure. After erasure, the `Pair` class has fields of type `Object`, and you can't use them to store `double` values.

This is an annoyance, to be sure, but it is consistent with the separate status of primitive types in the Java language. It is not a fatal flaw—there are only eight primitive types, and you can always handle them with separate classes and methods when wrapper types are not an acceptable substitute.

8.6.2 Runtime Type Inquiry Only Works with Raw Types

Objects in the virtual machine always have a specific nongeneric type. Therefore, all type inquiries yield only the raw type. For example,

```
if (a instanceof Pair<String>) // ERROR
```

could only test whether `a` is a `Pair` of any type. The same is true for the test

```
if (a instanceof Pair<T>) // ERROR
```

or the cast

```
Pair<String> p = (Pair<String>) a; // warning--can only test
that a is a Pair
```

To remind you of the risk, you will get a compiler error (with `instanceof`) or warning (with casts) when you try to inquire whether an object belongs to a generic type.

In the same spirit, the `getClass` method always returns the raw type. For example:

```
Pair<String> stringPair = . . .;
Pair<Employee> employeePair = . . .;
if (stringPair.getClass() == employeePair.getClass()) // they
are equal
```

The comparison yields `true` because both calls to `getClass` return `Pair.class`.

8.6.3 You Cannot Create Arrays of Parameterized Types

You cannot instantiate arrays of parameterized types, such as

```
var table = new Pair<String>[10]; // ERROR
```

What's wrong with that? After erasure, the type of `table` is `Pair[]`. You can convert it to `Object[]`:

```
Object[] objarray = table;
```

An array remembers its component type and throws an `ArrayStoreException` if you try to store an element of the wrong type:

```
objarray[0] = "Hello"; // ERROR--component type is Pair
```

But erasure renders this mechanism ineffective for generic types. The assignment

```
objarray[0] = new Pair<Employee>();
```

would pass the array store check but still result in a type error. For this reason, arrays of parameterized types are outlawed.

Note that only the creation of these arrays is outlawed. You can declare a variable of type `Pair<String>[]`. But you can't initialize it with a `new Pair<String>[10]`.

NOTE:

You can declare arrays of wildcard types and then cast them:

```
var table = (Pair<String>[]) new Pair<?>[10];
```

The result is not safe. If you store a `Pair<Employee>` in `table[0]` and then call a `String` method on `table[0].getFirst()`, you get a `ClassCastException`.

TIP:

If you need to collect parameterized type objects, simply use an `ArrayList`: `ArrayList<Pair<String>>` is safe and effective.

8.6.4 Varargs Warnings

In the preceding section, you saw that Java doesn't support arrays of generic types. In this section, I discuss a related issue: passing instances of a generic type to a method with a variable number of arguments.

Consider this simple method with variable arguments:

```
public static <T> void addAll(Collection<T> coll, T... ts)
{
   for (T t : ts) coll.add(t);
}
```

Recall that the parameter `ts` is actually an array that holds all supplied arguments.

Now consider this call:

```
Collection<Pair<String>> table = . . .;
Pair<String> pair1 = . . .; Pair<String> pair2 = . . .;
addAll(table, pair1, pair2);
```

In order to call this method, the Java virtual machine must make an array of `Pair<String>`, which is against the rules. However, the rules have been relaxed for this situation, and you only get a warning, not an error.

You can suppress the warning in one of two ways. You can add the annotation `@SuppressWarnings("unchecked")` to the method containing the call to `addAll`. Or, as of Java 7, you can annotate the `addAll` method itself with `@SafeVarargs`:

```
@SafeVarargs
public static <T> void addAll(Collection<T> coll, T... ts)
```

This method can now be called with generic types. You can use this annotation for any methods that merely read the elements of the parameter array, which is bound to be the most common use case.

The `@SafeVarargs` can only be used with constructors and methods that are `static`, `final`, or (as of Java 9) `private`. Any other method could be overridden, making the annotation meaningless.

NOTE:

You can use the `@SafeVarargs` annotation to defeat the restriction against generic array creation, using this method:

```
@SafeVarargs static <E> E[] array(E... array) { return array; }
```

Now you can call

```
Pair<String>[] table = array(pair1, pair2);
```

This seems convenient, but there is a hidden danger. The code

```
Object[] objarray = table;
objarray[0] = new Pair<Employee>();
```

will run without an `ArrayStoreException` (because the array store only checks the erased type), and you'll get an exception elsewhere when you work with `table[0]`.

8.6.5 You Cannot Instantiate Type Variables

You cannot use type variables in an expression such as `new T(. . .)`. For example, the following `Pair<T>` constructor is illegal:

```
public Pair() { first = new T(); second = new T(); } // ERROR
```

Type erasure would change `T` to `Object`, and surely you don't want to call `new Object()`.

The best workaround, available since Java 8, is to make the caller provide a constructor expression. For example:

```
Pair<String> p = Pair.makePair(String::new);
```

The `makePair` method receives a `Supplier<T>`, the functional interface for a function with no arguments and a result of type `T`:

```
public static <T> Pair<T> makePair(Supplier<T> constr)
{
```

```
      return new Pair<>(constr.get(), constr.get());
   }
```

A more traditional workaround is to construct generic objects through reflection, by calling the `Constructor.newInstance` method.

Unfortunately, the details are a bit complex. You cannot call

```
   first = T.class.getConstructor().newInstance(); // ERROR
```

The expression `T.class` is not legal because it would erase to `Object.class`. Instead, you must design the API so that you are handed a `Class` object, like this:

```
   public static <T> Pair<T> makePair(Class<T> cl)
   {
      try
      {
         return new Pair<>(cl.getConstructor().newInstance(),
            cl.getConstructor().newInstance());
      }
      catch (Exception e) { return null; }
   }
```

This method could be called as follows:

```
   Pair<String> p = Pair.makePair(String.class);
```

Note that the `Class` class is itself generic. For example, `String.class` is an instance (indeed, the sole instance) of `Class<String>`. Therefore, the `makePair` method can infer the type of the pair that it is making.

8.6.6 You Cannot Construct a Generic Array

Just as you cannot instantiate a single generic instance, you cannot instantiate an array. The reasons are different—an array is, after all, filled with `null` values, which would seem safe to construct. But an array also carries a type, which is used to monitor array stores in the virtual machine. That type is erased. For example, consider

```
public static <T extends Comparable> T[] minmax(T... a)
{
   T[] mm = new T[2]; // ERROR
   . . .
}
```

Type erasure would cause this method to always construct an array `Comparable[2]`.

If the array is only used as a private instance field of a class, you can declare the element type of the array to be the erased type and use casts. For example, the `ArrayList` class could be implemented as follows:

```
public class ArrayList<E>
{
   private Object[] elements;
   . . .
   @SuppressWarnings("unchecked") public E get(int n) { return
(E) elements[n]; }
   public void set(int n, E e) { elements[n] = e; } // no cast
needed
}
```

The actual implementation is not quite as clean:

```
public class ArrayList<E>
{
   private E[] elements;
   . . .
   public ArrayList() { elements = (E[]) new Object[10]; }
}
```

Here, the cast `E[]` is an outright lie, but type erasure makes it undetectable.

This technique does not work for our `minmax` method since we are returning a `T[]` array, and a runtime error results if we lie about its type. Suppose we implement

```
public static <T extends Comparable> T[] minmax(T... a)
{
   var result = new Comparable[2]; // array of erased type
   . . .
   return (T[]) result; // compiles with warning
}
```

The call

```
String[] names = ArrayAlg.minmax("Tom", "Dick", "Harry");
```

compiles without any warning. A `ClassCastException` occurs when the `Comparable[]` reference is cast to `String[]` after the method returns.

In this situation, it is best to ask the user to provide an array constructor expression:

```
String[] names = ArrayAlg.minmax(String[]::new, "Tom", "Dick",
"Harry");
```

The constructor expression `String[]::new` denotes a function that, given the desired length, constructs a `String` array of that length.

The method uses that parameter to produce an array of the correct type:

```
public static <T extends Comparable> T[]
minmax(IntFunction<T[]> constr, T... a)
{
   T[] result = constr.apply(2);
   . . .
}
```

A more old-fashioned approach is to use reflection and call `Array.newInstance`:

```
public static <T extends Comparable> T[] minmax(T... a)
{
   var result = (T[])
Array.newInstance(a.getClass().getComponentType(), 2);
   . . .
}
```

The `toArray` method of the `ArrayList` class is not so lucky. It needs to produce a `T[]` array, but it doesn't have the component type. Therefore, there are two variants:

```
Object[] toArray()
T[] toArray(T[] result)
```

The second method receives an array parameter. If the array is large enough, it is used. Otherwise, a new array of sufficient size is created, using the component type of `result`.

8.6.7 Type Variables Are Not Valid in Static Contexts of Generic Classes

You cannot reference type variables in static fields or methods. For example, the following clever idea won't work:

```
public class Singleton<T>
{
   private static T singleInstance; // ERROR

   public static T getSingleInstance() // ERROR
   {
      if (singleInstance == null) construct new instance of T
      return singleInstance;
   }
}
```

If this could be done, then a program could declare a `Singleton<Random>` to share a random number generator and a `Singleton<JFileChooser>` to share a file chooser dialog. But it can't work. After type erasure there is only one `Singleton` class, and only one `singleInstance` field. For that reason, static fields and methods with type variables are simply outlawed.

8.6.8 You Cannot Throw or Catch Instances of a Generic Class

You can neither throw nor catch objects of a generic class. In fact, it is not even legal for a generic class to extend `Throwable`. For example, the following definition will not compile:

```
public class Problem<T> extends Exception { /* . . . */ }
   // ERROR--can't extend Throwable
```

You cannot use a type variable in a `catch` clause. For example, the following method will not compile:

```
public static <T extends Throwable> void doWork(Class<T> t)
{
   try
   {
      do work
   }
   catch (T e) // ERROR--can't catch type variable
   {
      Logger.global.info(. . .);
   }
}
```

However, it is OK to use type variables in exception specifications. The following method is legal:

```
public static <T extends Throwable> void doWork(T t) throws T
// OK
{
   try
```

```
   {
      do work
   }
   catch (Throwable realCause)
   {
      t.initCause(realCause);
      throw t;
   }
}
```

8.6.9 You Can Defeat Checked Exception Checking

A bedrock principle of Java exception handling is that you must provide a handler for all checked exceptions. You can use generics to defeat this scheme. The key ingredient is this method:

```
@SuppressWarnings("unchecked")
static <T extends Throwable> void throwAs(Throwable t) throws T
{   throw (T) t;
}
```

Suppose this method is contained in an interface `Task`. When you have a checked exception `e` and call

```
Task.<RuntimeException>throwAs(e);
```

then the compiler will believe that `e` becomes an unchecked exception. The following turns all exceptions into those that the compiler believes to be unchecked:

```
try
{
   do work
}
catch (Throwable t)
{
```

```
      Task.<RuntimeException>throwAs(t);
   }
```

Let's use this to solve a vexing problem. To run code in a thread, you have to place it into the `run` method of a class that implements the `Runnable` interface. But that method is not allowed to throw checked exceptions. We will provide an adaptor from a `Task`, whose `run` method is allowed to throw arbitrary exceptions, to a `Runnable`:

```
   interface Task
   {
      void run() throws Exception;

      @SuppressWarnings("unchecked")
      static <T extends Throwable> void throwAs(Throwable t)
   throws T
      {
         throw (T) t;
      }

      static Runnable asRunnable(Task task)
      {
         return () ->
            {
               try
               {
                  task.run();
               }
               catch (Exception e)
               {
                  Task.<RuntimeException>throwAs(e);
               }
            };   }
   }
```

For example, this program runs a thread that will throw a checked exception:

```
public class Test
{
   public static void main(String[] args)
   {
      var thread = new Thread(Task.asRunnable(() ->
         {
            Thread.sleep(1000);
            System.out.println("Hello, World!");
            throw new Exception("Check this out!");
         }));
      thread.start();
   }
}
```

The `Thread.sleep` method is declared to throw an `InterruptedException`, and we no longer have to catch it. Since we don't interrupt the thread, that exception won't be thrown. However, the program throws a checked exception. When you run the program, you will get a stack trace.

What's so remarkable about that? Normally, you have to catch all checked exceptions inside the `run` method of a `Runnable` and *wrap them* into unchecked exceptions—the `run` method is declared to throw no checked exceptions.

But here, we don't wrap. We simply throw the exception, tricking the compiler into believing that it is not a checked exception.

Using generic classes, erasure, and the `@SuppressWarnings` annotation, we were able to defeat an essential part of the Java type system.

8.6.10 Beware of Clashes after Erasure

It is illegal to create conditions that cause clashes when generic types are erased. Here is an example. Suppose we add an `equals` method to the `Pair` class, like this:

```
public class Pair<T>
{
   public boolean equals(T value) { return first.equals(value)
&& second.equals(value); }
   . . .
}
```

Consider a `Pair<String>`. Conceptually, it has two `equals` methods:

```
boolean equals(String) // defined in Pair<T>
boolean equals(Object) // inherited from Object
```

But the intuition leads us astray. The erasure of the method

```
boolean equals(T)
```

is

```
boolean equals(Object)
```

which clashes with the `Object.equals` method.

The remedy is, of course, to rename the offending method.

The generics specification cites another rule: “To support translation by erasure, we impose the restriction that a class or type variable may not at the same time be a subtype of two interface types which are different parameterizations of the same interface.” For example, the following is illegal:

```
class Employee implements Comparable<Employee> { . . . }
class Manager extends Employee implements Comparable<Manager> {
. . . } // ERROR
```

`Manager` would then implement both `Comparable<Employee>` and `Comparable<Manager>`, which are different parameterizations of the same interface.

It is not obvious what this restriction has to do with type erasure. After all, the nongeneric version

```
class Employee implements Comparable { . . . }
class Manager extends Employee implements Comparable { . . . }
```

is legal. The reason is far more subtle. There would be a conflict with the synthesized bridge methods. A class that implements `Comparable<X>` gets a bridge method

```
public int compareTo(Object other) { return compareTo((X)
other); }
```

You cannot have two such methods for different types `X`.

8.7 Inheritance Rules for Generic Types

When you work with generic classes, you need to learn a few rules about inheritance and subtypes. Let's start with a situation which many programmers find unintuitive. Consider a class and a subclass, such as `Employee` and `Manager`. Is `Pair<Manager>` a subtype of `Pair<Employee>`? Perhaps surprisingly, the answer is "no." For example, the following code will not compile:

```
Pair<Employee> buddies = new Pair<Manager>(ceo, cfo); //
illegal
```

In general, there is *no* relationship between `Pair<S>` and `Pair<T>`, no matter how `S` and `T` are related (see Figure 8.1).

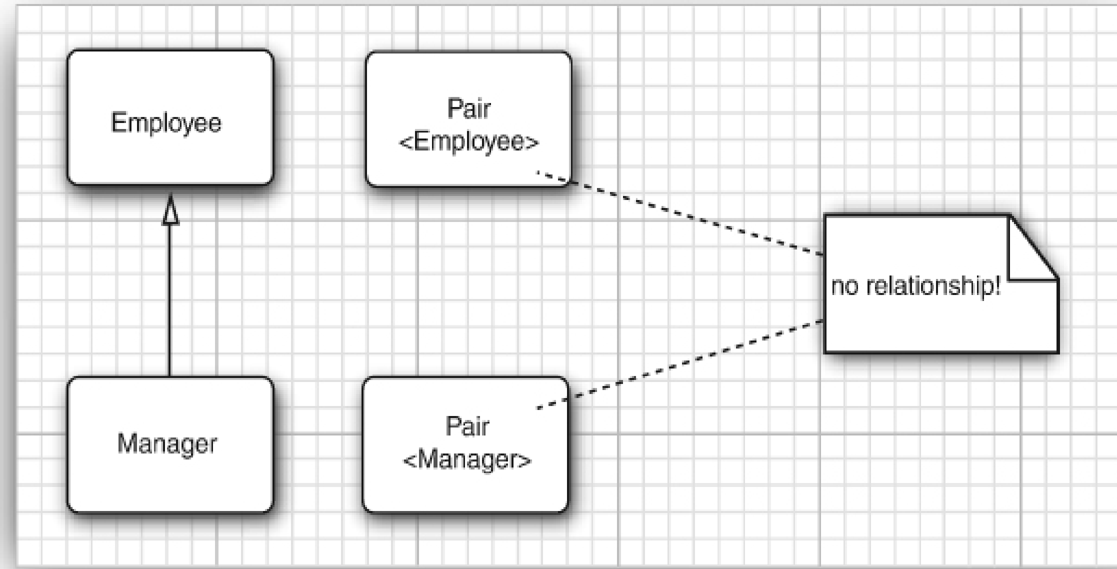


Figure 8.1 No inheritance relationship between `Pair` classes

This seems like a cruel restriction, but it is necessary for type safety. Suppose we were allowed to convert a `Pair<Manager>` to a `Pair<Employee>`. Consider this code:

```
var managerBuddies = new Pair<Manager>(ceo, cfo);
Pair<Employee> employeeBuddies = managerBuddies; // illegal,
but suppose it wasn't
employeeBuddies.setFirst(lowlyEmployee);
```

Clearly, the last statement is legal. But `employeeBuddies` and `managerBuddies` refer to the *same object*. We now managed to pair up the CFO with a lowly employee, which should not be possible for a `Pair<Manager>`.

NOTE:

You just saw an important difference between generic types and Java arrays. You can assign a `Manager[]` array to a variable of type `Employee[]`:

```
Manager[] managerBuddies = { ceo, cfo };
Employee[] employeeBuddies = managerBuddies; // OK
```

However, arrays come with special protection. If you try to store a lowly employee into `employeeBuddies[0]`, the virtual machine throws an `ArrayStoreException`.

You can always convert a parameterized type to a raw type. For example, `Pair<Employee>` is a subtype of the raw type `Pair`. This conversion is necessary for interfacing with legacy code.

Can you convert to the raw type and then cause a type error? Unfortunately, you can. Consider this example:

```
var managerBuddies = new Pair<Manager>(ceo, cfo);
Pair rawBuddies = managerBuddies; // OK
rawBuddies.setFirst(new File(". . .")); // only a compile-time
warning
```

This sounds scary. However, keep in mind that you are no worse off than you were with older versions of Java. The security of the virtual machine is not at stake. When the foreign object is retrieved with `getFirst` and assigned to a `Manager` variable, a `ClassCastException` is thrown, just as in the good old days. You merely lose the added safety that generic programming normally provides.

Finally, generic classes can extend or implement other generic classes. In this regard, they are no different from ordinary classes. For example, the class `ArrayList<T>` implements the interface `List<T>`. That means an `ArrayList<Manager>` can be converted to a `List<Manager>`. However, as you just saw, an `ArrayList<Manager>` is *not* an `ArrayList<Employee>` or `List<Employee>`. Figure 8.2 shows these relationships.

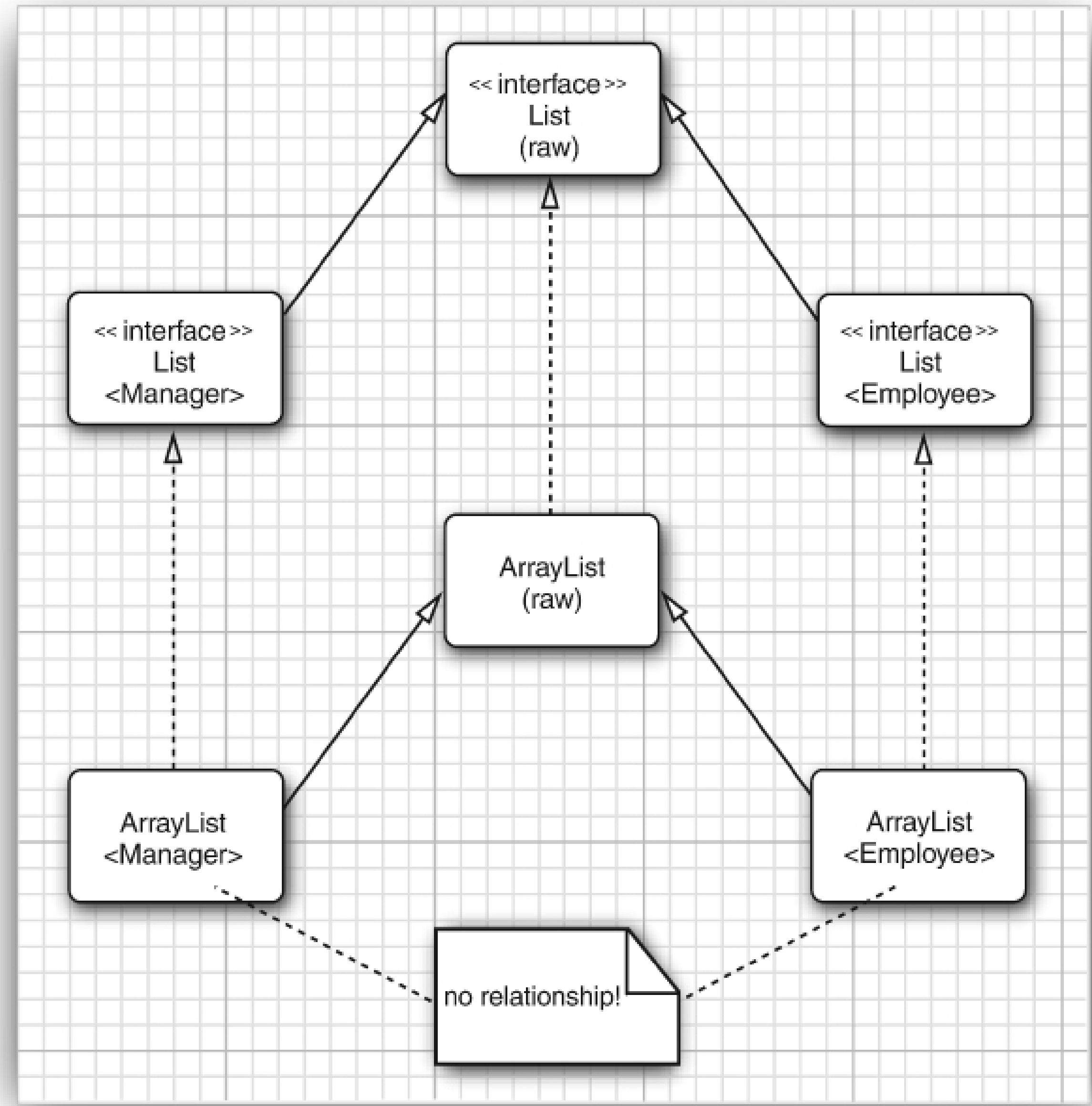


Figure 8.2 Subtype relationships among generic list types

8.8 Wildcard Types

It was known for some time among researchers of type systems that a rigid system of generic types is quite unpleasant to use. The Java designers invented an ingenious (but nevertheless safe) “escape hatch”: the *wildcard type*. The following sections show you how to work with wildcards.

8.8.1 The Wildcard Concept

In a wildcard type, a type parameter is allowed to vary. For example, the wildcard type

```
Pair<? extends Employee>
```

denotes any generic `Pair` type whose type parameter is a subclass of `Employee`, such as `Pair<Manager>`, but not `Pair<String>`.

Let's say you want to write a method that prints out pairs of employees, like this:

```
public static void printBuddies(Pair<Employee> p)
{
   Employee first = p.getFirst();
   Employee second = p.getSecond();
   System.out.println(first.getName() + " and " +
second.getName() + " are buddies.");
}
```

As you saw in the preceding section, you cannot pass a `Pair<Manager>` to that method, which is rather limiting. But the solution is simple—use a wildcard type:

```
public static void printBuddies(Pair<? extends Employee> p)
```

The type `Pair<Manager>` is a subtype of `Pair<? extends Employee>` (see Figure 8.3).

Can we use wildcards to corrupt a `Pair<Manager>` through a `Pair<? extends Employee>` reference?

```
var managerBuddies = new Pair<Manager>(ceo, cfo);
Pair<? extends Employee> wildcardBuddies = managerBuddies; //
```

```
OK
wildcardBuddies.setFirst(lowlyEmployee); // compile-time error
```

No corruption is possible. The call to `setFirst` is a type error. To see why, let us have a closer look at the type `Pair<? extends Employee>`. Its methods look like this:

```
? extends Employee getFirst()
void setFirst(? extends Employee)
```

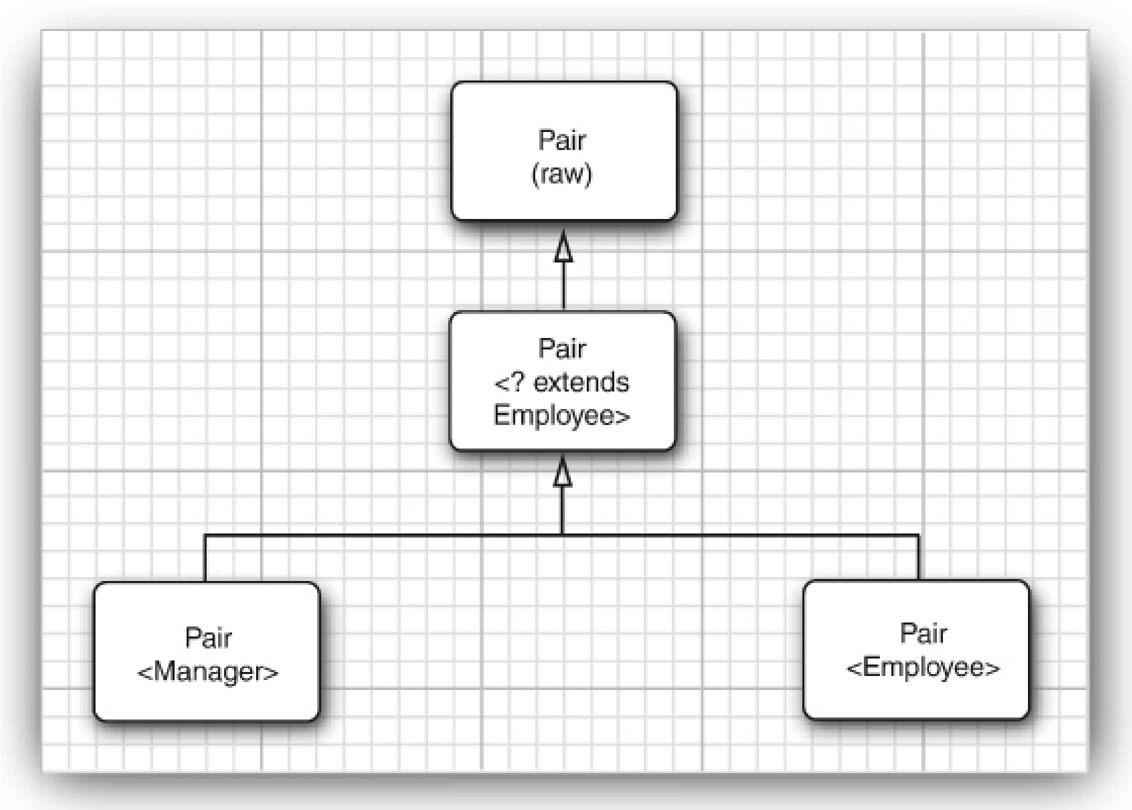


Figure 8.3 Subtype relationships with wildcards

It is impossible to call the `setFirst` method! Consider the call `wildcardBuddies.setFirst(lowlyEmployee)` The compiler knows that the parameter of `setFirst` has some specific type, which extends `Employee`. Is that specific type `Employee`? Is it `Manager`, or some other subclass? There is no way for the compiler to know. Therefore, the compiler cannot accept `lowlyEmployee`. For the same reason, the call `wildcardBuddies.setFirst(cio)`, where `cio` is a `Manager` instance, also fails. The compiler must reject all arguments to `setFirst` other than `null`.

The `getFirst` method continues to work. The return value of `getFirst` is an instance of some specific type, which is a subtype of `Employee`. The compiler doesn't know what that specific type is, but it can guarantee that the assignment to an `Employee` reference is safe.

This is the key idea behind bounded wildcards. We now have a way of distinguishing between the safe accessor methods and the unsafe mutator methods.

8.8.2 Supertype Bounds for Wildcards

Wildcard bounds are similar to type variable bounds, but they have an added capability—you can specify a *supertype bound*, like this:

```
? super Manager
```

This wildcard is restricted to all supertypes of `Manager`. (It was a stroke of good luck that the existing `super` keyword describes the relationship so accurately.)

Why would you want to do this? A wildcard with a supertype bound gives you a behavior that is opposite to that of the wildcards described in Section 8.8, "Wildcard Types," on p. 475. You can supply parameters to methods, but you can't use the return values. For example, `Pair<? super Manager>` has methods that can be described as follows:

```
void setFirst(? super Manager)
? super Manager getFirst()
```

This is not actual Java syntax, but it shows what the compiler knows. The `setFirst` parameter type, denoted as `? super Manager`, is some specific type *T*, and `Manager` is a subtype of *T*. There are exactly three choices for *T*: `Object`, `Employee`, or `Manager`. (There would have been more choices if `Manager` or `Employee` had implemented interfaces.) However, the compiler cannot know which of these choices applies. Therefore, the compiler cannot accept a call with an argument of type Employee or Object. After all, *T* might have been Manager. It is only possible to pass an object of type Manager or a subtype such as Executive.

Conversely, if you call getFirst, there is no guarantee about the type of the returned object. You can only assign it to an Object.

Here is a typical example. We have an array of managers and want to put the manager with the lowest and highest bonus into a Pair object. What kind of Pair? A Pair<Employee> should be fair game or, for that matter, a Pair<Object> (see Figure 8.4). The following method will accept any appropriate Pair:

```
public static void minmaxBonus(Manager[] a, Pair<? super
Manager> result)
{
   if (a.length == 0) return;
   Manager min = a[0];
   Manager max = a[0];
   for (int i = 1; i < a.length; i++)
   {
      if (min.getBonus() > a[i].getBonus()) min = a[i];
      if (max.getBonus() < a[i].getBonus()) max = a[i];
   }
   result.setFirst(min);
   result.setSecond(max);
}
```

Intuitively speaking, wildcards with supertype bounds let you write to a generic object, while wildcards with subtype bounds let you read from a generic object.

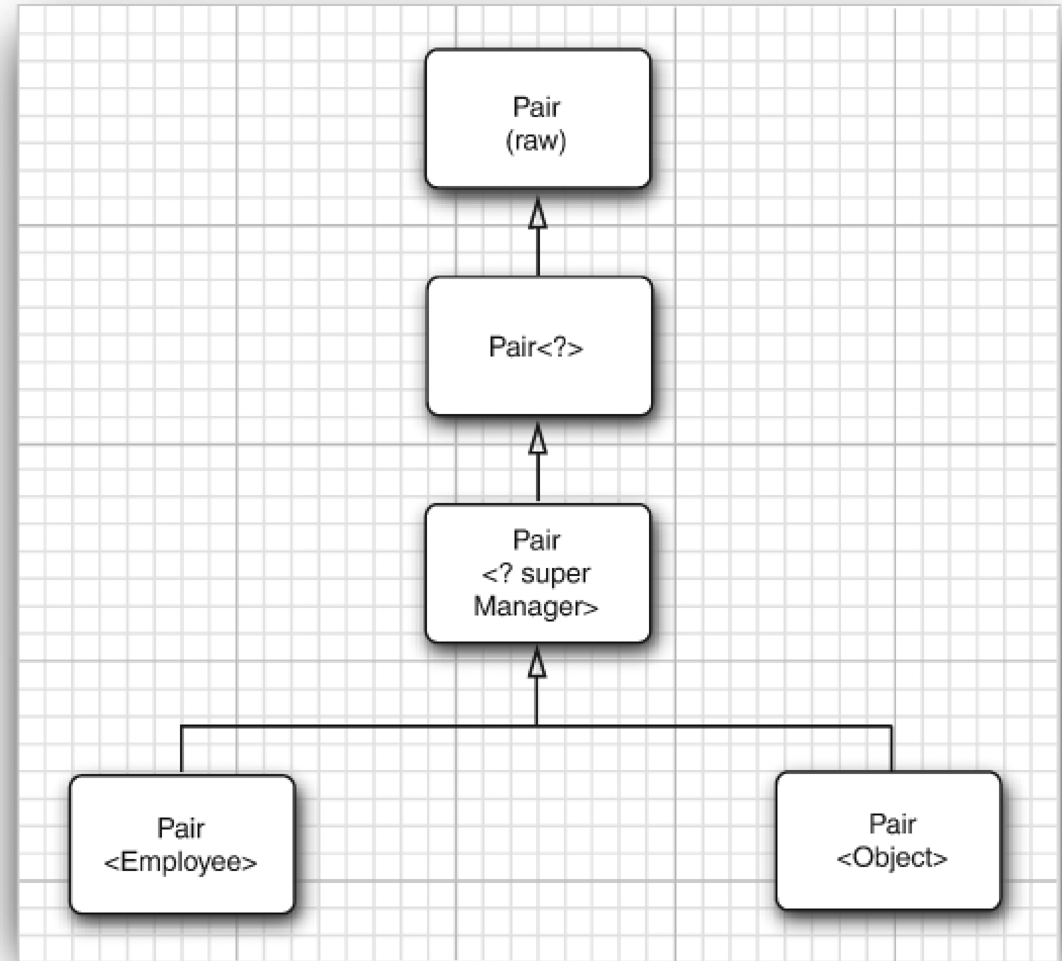


Figure 8.4 A wildcard with a supertype bound

Here is another use for supertype bounds. The `Comparable` interface is itself a generic type. It is declared as follows:

```
public interface Comparable<T>
{
   public int compareTo(T other);
}
```

Here, the type variable indicates the type of the `other` parameter. For example, the `String` class implements `Comparable<String>`, and its `compareTo` method is declared as

```
public int compareTo(String other)
```

This is nice—the explicit parameter has the correct type. Before the interface was generic, other was an Object, and a cast was necessary in the implementation of the method.

Now that Comparable is a generic type, perhaps we should have done a better job with the minmax method of the ArrayAlg class? We could have declared it as

```
public static <T extends Comparable<T>> Pair<T> minmax(T[] a)
```

This looks more thorough than just using T extends Comparable, and it would work fine for many classes. For example, if you compute the minimum of a String array, then T is the type String, and String is a subtype of Comparable<String>. But we run into a problem when processing an array of LocalDate objects. As it happens, LocalDate implements ChronoLocalDate, and ChronoLocalDate extends Comparable<ChronoLocalDate>. Thus, LocalDate implements Comparable<ChronoLocalDate> but *not* Comparable<LocalDate>.

In a situation such as this one, supertypes come to the rescue:

```
public static <T extends Comparable<? super T>> Pair<T>
minmax(T[] a)
```

Now the compareTo method has the form

```
int compareTo(? super T)
```

Maybe it is declared to take an object of type T, or—for example, when T is LocalDate—a supertype of T. At any rate, it is safe to pass an object of type T to the compareTo method.

To the uninitiated, a declaration such as <T **extends Comparable<? super T>**> is bound to look intimidating. This is unfortunate, because the intent of this declaration is to help application programmers by removing unnecessary restrictions on the call parameters. Application programmers with no interest in generics will probably learn quickly to gloss over these declarations and just take for granted that library programmers will do the right thing. If you are a library programmer, you'll need to get used to wildcards, or your users will curse you and throw random casts at their code until it compiles.

NOTE:

Another common use for supertype bounds is an argument type of a functional interface. For example, the `Collection` interface has a method

```
default boolean removeIf(Predicate<? super E> filter)
```

The method removes all elements that fulfill the given predicate. For example, if you hate employees with odd hash codes, you can remove them like this:

```
ArrayList<Employee> staff = . . .;
Predicate<Object> oddHashCode = obj -> obj.hashCode() %2 != 0;
staff.removeIf(oddHashCode);
```

You want to be able to pass a `Predicate<Object>`, not just a `Predicate<Employee>`. The `super` wildcard makes that possible.

8.8.3 Unbounded Wildcards

You can even use wildcards with no bounds at all—for example, `Pair<?>`. At first glance, this looks identical to the raw `Pair` type. Actually, the types are very different. The type `Pair<?>` has methods such as

```
? getFirst()
void setFirst(?)
```

The return value of `getFirst` can only be assigned to an `Object`. The `setFirst` method can never be called, *not even with an* `Object`. That's the essential difference between `Pair<?>` and `Pair`: you can call the `setFirst` method of the raw `Pair` class with *any* `Object`.

NOTE:

You can call `setFirst(null)`.

Why would you ever want such a wimpy type? It is useful for very simple operations. For example, the following method tests whether a pair contains a `null` reference. It never needs the actual type.

```
public static boolean hasNulls(Pair<?> p)
{
   return p.getFirst() == null || p.getSecond() == null;
}
```

You could have avoided the wildcard type by turning `hasNulls` into a generic method:

```
public static <T> boolean hasNulls(Pair<T> p)
```

However, the version with the wildcard type seems easier to read.

8.8.4 Wildcard Capture

Let us write a method that swaps the elements of a pair:

```
public static void swap(Pair<?> p)
```

A wildcard is not a type variable, so we can't write code that uses `?` as a type. In other words, the following would be illegal:

```
? t = p.getFirst(); // ERROR
p.setFirst(p.getSecond());
p.setSecond(t);
```

That's a problem because we need to temporarily hold the first element when we do the swapping. Fortunately, there is an interesting solution to this problem. We can write a helper method, `swapHelper`, like this:

```
public static <T> void swapHelper(Pair<T> p)
{
   T t = p.getFirst();
   p.setFirst(p.getSecond());
   p.setSecond(t);
}
```

Note that `swapHelper` is a generic method, whereas `swap` is not—it has a fixed parameter of type `Pair<?>`.

Now we can call `swapHelper` from `swap`:

```
public static void swap(Pair<?> p) { swapHelper(p); }
```

In this case, the parameter `T` of the `swapHelper` method *captures the wildcard*. It isn't known what type the wildcard denotes, but it is a definite type, and the definition of `<T>swapHelper` makes perfect sense when `T` denotes that type.

Of course, in this case, we were not compelled to use a wildcard. We could have directly implemented `<T> void swap(Pair<T> p)` as a generic method without wildcards. However, consider this example in which a wildcard type occurs naturally in the middle of a computation:

```
public static void maxminBonus(Manager[] a, Pair<? super
Manager> result)
{
   minmaxBonus(a, result);
```

```
   PairAlg.swapHelper(result); // OK--swapHelper captures
wildcard type
}
```

Here, the wildcard capture mechanism cannot be avoided.

Wildcard capture is only legal in very limited circumstances. The compiler must be able to guarantee that the wildcard represents a single, definite type. For example, the `T` in `ArrayList<Pair<T>>` can never capture the wildcard in `ArrayList<Pair<?>>`. The array list might hold two `Pair<?>`, each of which has a different type for `?`.

The test program in Listing 8.3 gathers up the various methods discussed in the preceding sections so you can see them in context.

Listing 8.3 `pair3/PairTest3.java`

```
package pair3;

/**
 * @version 1.01 2012-01-26
 * @author Cay Horstmann
 */
public class PairTest3
{
   public static void main(String[] args)
    {
       var ceo = new Manager("Gus Greedy", 800000, 2003, 12,
15);
       var cfo = new Manager("Sid Sneaky", 600000, 2003, 12,
15);
       var buddies = new Pair<Manager>(ceo, cfo);
       printBuddies(buddies);

       ceo.setBonus(1000000);
       cfo.setBonus(500000);
       Manager[] managers = { ceo, cfo };

```

```
      var result = new Pair<Employee>();
      minmaxBonus(managers, result);
      System.out.println("first: " + result.getFirst().getName()
         + ", second: " + result.getSecond().getName());
      maxminBonus(managers, result);
      System.out.println("first: " + result.getFirst().getName()
         + ", second: " + result.getSecond().getName());
}

public static void printBuddies(Pair<? extends Employee> p)
{
   Employee first = p.getFirst();
   Employee second = p.getSecond();
   System.out.println(first.getName() + " and " + second.getName() + " are buddies.");
}

public static void minmaxBonus(Manager[] a, Pair<? super Manager> result)
{
   if (a.length == 0) return;
   Manager min = a[0];
   Manager max = a[0];
   for (int i = 1; i < a.length; i++)
   {
      if (min.getBonus() > a[i].getBonus()) min = a[i];
      if (max.getBonus() < a[i].getBonus()) max = a[i];
   }
   result.setFirst(min);
   result.setSecond(max);
}

public static void maxminBonus(Manager[] a, Pair<? super Manager> result)
{
   minmaxBonus(a, result);
   PairAlg.swapHelper(result); // OK--swapHelper captures wildcard type
```

```
 }
 // can't write public static <T super manager> . . .
}

class PairAlg
{
   public static boolean hasNulls(Pair<?> p)
   {
      return p.getFirst() == null || p.getSecond() == null;
   }

   public static void swap(Pair<?> p) { swapHelper(p); }

   public static <T> void swapHelper(Pair<T> p)
   {
      T t = p.getFirst();
      p.setFirst(p.getSecond());
      p.setSecond(t);
   }
}
```

8.9 Reflection and Generics

Reflection lets you analyze arbitrary objects at runtime. If the objects are instances of generic classes, you don't get much information about the generic type parameters because they have been erased. In the following sections, you will learn what you can nevertheless find out about generic classes with reflection.

8.9.1 The Generic `Class` Class

The `Class` class is now generic. For example, `String.class` is actually an object (in fact, the sole object) of the class `Class<String>`.

The type parameter is useful because it allows the methods of `Class<T>` to be more specific about their return types. The following methods of `Class<T>` take advantage of the type parameter:

```
T newInstance()
T cast(Object obj)
T[] getEnumConstants()
Class<? super T> getSuperclass()Constructor<T>
getConstructor(Class... parameterTypes)
Constructor<T> getDeclaredConstructor(Class... parameterTypes)
```

The `newInstance` method returns an instance of the class, obtained from the no-argument constructor. Its return type can now be declared to be `T`, the same type as the class that is being described by `Class<T>`. That saves a cast.

The `cast` method returns the given object, now declared as type `T` if its type is indeed a subtype of `T`. Otherwise, it throws a `BadCastException`.

The `getEnumConstants` method returns `null` if this class is not an `enum` class or an array of the enumeration values which are known to be of type `T`.

Finally, the `getConstructor` and `getDeclaredConstructor` methods return a `Constructor<T>` object. The `Constructor` class has also been made generic so that its `newInstance` method has the correct return type.

java.lang.Class<T> 1.0

- `T newInstance()`

  returns a new instance constructed with the no-argument constructor.

- `T cast(Object obj)`

  returns `obj` if it is `null` or can be converted to the type `T`, or throws a `BadCastException` otherwise.

- `T[] getEnumConstants()` 5

  returns an array of all values if `T` is an enumerated type, `null` otherwise.

- `Class<? super T> getSuperclass()`

returns the superclass of this class, or `null` if `T` is not a class or the class `Object`.

- `Constructor<T> getConstructor(Class... parameterTypes)` 1.1
- `Constructor<T> getDeclaredConstructor(Class... parameterTypes)` 1.1

gets the public constructor, or the constructor with the given parameter types.

`java.lang.reflect.Constructor<T>` 1.1

- `T newInstance(Object... parameters)`

returns a new instance constructed with the given parameters.

8.9.2 Using `Class<T>` Parameters for Type Matching

It is sometimes useful to match the type variable of a `Class<T>` parameter in a generic method. Here is the canonical example:

```
public static <T> Pair<T> makePair(Class<T> c) throws
InstantiationException,
      IllegalAccessException
{
   return new Pair<>(c.newInstance(), c.newInstance());
}
```

If you call

```
makePair(Employee.class)
```

then `Employee.class` is an object of type `Class<Employee>`. The type parameter `T` of the `makePair` method matches `Employee`, and the compiler can infer that the method returns a `Pair<Employee>`.

8.9.3 Generic Type Information in the Virtual Machine

One of the notable features of Java generics is the erasure of generic types in the virtual machine. Perhaps surprisingly, the erased classes still retain some faint memory of their generic origin. For example, the raw `Pair` class knows that it originated from the generic class `Pair<T>`, even though an object of type `Pair` can't tell whether it was constructed as a `Pair<String>` or `Pair<Employee>`.

Similarly, consider a method

```
public static Comparable min(Comparable[] a)
```

that is the erasure of a generic method

```
public static <T extends Comparable<? super T>> T min(T[] a)
```

You can use the reflection API to determine that

- The generic method has a type parameter called `T`;
- The type parameter has a subtype bound that is itself a generic type;
- The bounding type has a wildcard parameter;
- The wildcard parameter has a supertype bound; and
- The generic method has a generic array parameter.

In other words, you can reconstruct everything about generic classes and methods that their implementors declared. However, you won't know how the type parameters were resolved for specific objects or method calls.

In order to express generic type declarations, use the interface `Type` in the `java.lang.reflect` package. The interface has the following subtypes:

- The `Class` class, describing concrete types

- The `TypeVariable` interface, describing type variables (such as `T extends Comparable<? super T>`)
- The `WildcardType` interface, describing wildcards (such as `? super T`)
- The `ParameterizedType` interface, describing generic class or interface types (such as `Comparable<? super T>`)
- The `GenericArrayType` interface, describing generic arrays (such as `T[]`)

Figure 8.5 shows the inheritance hierarchy. Note that the last four subtypes are interfaces—the virtual machine instantiates suitable classes that implement these interfaces.

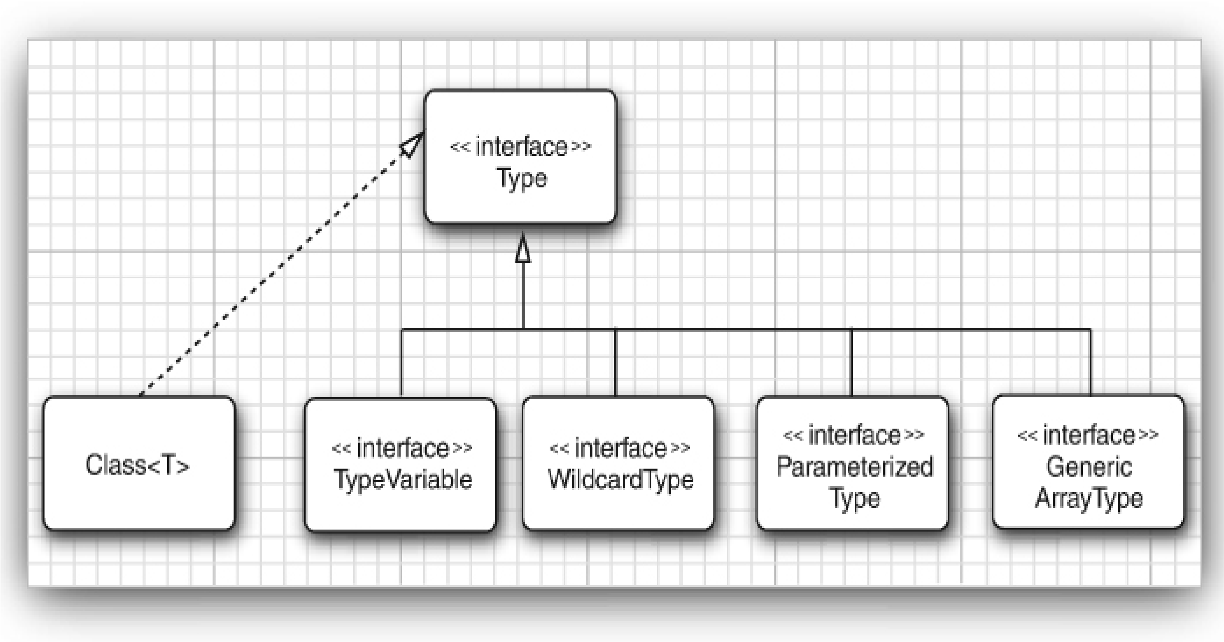


Figure 8.5 The `Type` interface and its descendants

Listing 8.4 uses the generic reflection API to print out what it discovers about a given class. If you run it with the `Pair` class, you get this report:

```
class Pair<T> extends java.lang.Object
public T getFirst()
public T getSecond()
public void setFirst(T)
public void setSecond(T)
```

If you run it with `ArrayAlg` in the `PairTest2` directory, the report displays the following method:

```
public static <T extends java.lang.Comparable> Pair<T>
minmax(T[])
```

Listing 8.4 `genericReflection/GenericReflectionTest.java`

```
package genericReflection;

import java.lang.reflect.*;
import java.util.*;

/**
 * @version 1.12 2021-05-30
 * @author Cay Horstmann
 */
public class GenericReflectionTest
{
   public static void main(String[] args)
   {
      // read class name from command line args or user input
      String name;
      if (args.length > 0) name = args[0];
      else
      {
         try (var in = new Scanner(System.in))
         {
            System.out.println("Enter class name (e.g., java.util.Collections): ");
            name = in.next();
         }
      }

      try
      {
         // print generic info for class and public methods
         Class<?> cl = Class.forName(name);
         printClass(cl);
```

```
         for (Method m : cl.getDeclaredMethods())
            printMethod(m);
      }
      catch (ClassNotFoundException e)
      {
         e.printStackTrace();
      }
   }

   public static void printClass(Class<?> cl)
   {
      System.out.print(cl);
      printTypes(cl.getTypeParameters(), "<", ", ", ">", true);
      Type sc = cl.getGenericSuperclass();
      if (sc != null)
      {
         System.out.print(" extends ");
         printType(sc, false);
      }
      printTypes(cl.getGenericInterfaces(), " implements ", ", ", "", false);
      System.out.println();
   }

   public static void printMethod(Method m)
   {
      String name = m.getName();
      System.out.print(Modifier.toString(m.getModifiers()));
      System.out.print(" ");
      printTypes(m.getTypeParameters(), "<", ", ", "> ", true);

      printType(m.getGenericReturnType(), false);
      System.out.print(" ");
      System.out.print(name);
      System.out.print("(");
      printTypes(m.getGenericParameterTypes(), "", ", ", "", false);
      System.out.println(")");
```

```
   }

   public static void printTypes(Type[] types, String pre, String sep, String suf,
         boolean isDefinition)
   {
      if (pre.equals(" extends ") && Arrays.equals(types, new Type[] { Object.class }))
         return;
      if (types.length > 0) System.out.print(pre);
      for (int i = 0; i < types.length; i++)
      {
         if (i > 0) System.out.print(sep);
         printType(types[i], isDefinition);
      }
      if (types.length > 0) System.out.print(suf);
   }

   public static void printType(Type type, boolean isDefinition)
   {
      if (type instanceof Class t)
      {
         System.out.print(t.getName());
      }
         else if (type instanceof TypeVariable t)
      {
         System.out.print(t.getName());
         if (isDefinition)
            printTypes(t.getBounds(), " extends ", " & ", "", false);
      }
      else if (type instanceof WildcardType t)
      {
         System.out.print("?");
         printTypes(t.getUpperBounds(), " extends ", " & ", "", false);
         printTypes(t.getLowerBounds(), " super ", " & ", "", false);
```

```
      }
      else if (type instanceof ParameterizedType t)
      {
         Type owner = t.getOwnerType();
         if (owner != null)
         {
            printType(owner, false);
            System.out.print(".");
         }
         printType(t.getRawType(), false);
         printTypes(t.getActualTypeArguments(), "<", ", ", ">", false);
      }
      else if (type instanceof GenericArrayType t)
      {
         System.out.print("");
         printType(t.getGenericComponentType(), isDefinition);
         System.out.print("[]");
      }
   }
}
```

8.9.4 Type Literals

Sometimes, you want to drive program behavior by the type of a value. For example, in a persistence mechanism, you may want the user to specify a way of saving an object of a particular class. This is typically implemented by associating the `Class` object with an action.

However, with generic classes, erasure poses a problem. How can you have different actions for, say, `ArrayList<Integer>` and `ArrayList<String>` when both erase to the same raw `ArrayList` type?

There is a trick that can offer relief in some situations. You can capture an instance of the `Type` interface that you encountered in the preceding section. Construct an anonymous subclass like this:

```
var type = new TypeLiteral<ArrayList<Integer>>(){} // note the
{}
```

The `TypeLiteral` constructor captures the generic supertype:

```
class TypeLiteral
{
   public TypeLiteral()
   {
      Type parentType = getClass().getGenericSuperclass();
      if (parentType instanceof ParameterizedType paramType)
         type = paramType.getActualTypeArguments()
[0];      else
         throw new UnsupportedOperationException(
            "Construct as new TypeLiteral<. . .>(){}");
   }
   . . .
}
```

If we have a generic type available at runtime, we can match it against the `TypeLiteral`. We can't get a generic type from an object—it is erased. But, as you have seen in the preceding section, generic types of fields and method parameters survive in the virtual machine.

Injection frameworks such as CDI and Guice use type literals to control injection of generic types. The example program in the book's companion code shows a simpler example. Given an object, we enumerate its fields, whose generic types are available, and look up associated formatting actions.

We format an `ArrayList<Integer>` by separating the values with spaces, an `ArrayList<Character>` by joining the characters to a string. Any other array lists are formatted by `ArrayList.toString`.

Listing 8.5 `genericReflection/TypeLiterals.java`

```
package genericReflection;

```

```
/**
   @version 1.02 2021-05-30
   @author Cay Horstmann
*/

import java.lang.reflect.*;
import java.util.*;
import java.util.function.*;

/**
 * A type literal describes a type that can be generic, such as
 * ArrayList<String>.
 */
class TypeLiteral<T>
{
   private Type type;

   /**
    * This constructor must be invoked from an anonymous subclass
    * as new TypeLiteral<. . .>(){}.
    */
   public TypeLiteral()
   {
      Type parentType = getClass().getGenericSuperclass();
      if (parentType instanceof ParameterizedType paramType)
         type = paramType.getActualTypeArguments()[0];
      else
         throw new UnsupportedOperationException(
            "Construct as new TypeLiteral<. . .>(){}");
 }

 private TypeLiteral(Type type)
 {
 this.type = type;
 }

 /**
```

```
    * Yields a type literal that describes the given type.
    */
   public static TypeLiteral<?> of(Type type)
   {
      return new TypeLiteral<Object>(type);
   }

   public String toString()
   {
      if (type instanceof Class clazz) return clazz.getName();
      else return type.toString();
   }

   public boolean equals(Object otherObject)
   {
      return otherObject instanceof TypeLiteral otherLiteral
         && type.equals(otherLiteral.type);
   }

   public int hashCode()
   {
      return type.hashCode();
   }
}

/**
 * Formats objects, using rules that associate types with formatting functions.
 */
class Formatter
{
   private Map<TypeLiteral<?>, Function<?, String>> rules = new HashMap<>();

   /**
    * Add a formatting rule to this formatter.
    * @param type the type to which this rule applies
    * @param formatterForType the function that formats objects of this type
```

```
    */
   public <T> void forType(TypeLiteral<T> type, Function<T, String> formatterForType)
   {
      rules.put(type,  formatterForType);
   }

   /**
    * Formats all fields of an object using the rules of this formatter.
    * @param obj an object
    * @return a string with all field names and formatted values
    */
   public String formatFields(Object obj)
         throws IllegalArgumentException, IllegalAccessException
   {
      var result = new StringBuilder();
      for (Field f : obj.getClass().getDeclaredFields())
      {
         result.append(f.getName());
         result.append("=");
         f.setAccessible(true);
         Function<?, String> formatterForType = rules.get(TypeLiteral.of(f.getGenericType()));
         if (formatterForType != null)
         {
            // formatterForType has parameter type ?. Nothing can be passed to its apply
            // method. Cast makes the parameter type to Object so we can invoke it.
            @SuppressWarnings("unchecked")
            Function<Object, String> objectFormatter
               = (Function<Object, String>) formatterForType;
            result.append(objectFormatter.apply(f.get(obj)));
         }
         else
            result.append(f.get(obj).toString());
```

```
         result.append("\n");
      }
      return result.toString();
   }
}

public class TypeLiterals
{
   public static class Sample
   {
      ArrayList<Integer> nums;
      ArrayList<Character> chars;
      ArrayList<String> strings;
      public Sample()
      {
         nums = new ArrayList<>();
         nums.add(42); nums.add(1729);
         chars = new ArrayList<>();
         chars.add('H'); chars.add('i');
         strings = new ArrayList<>();
         strings.add("Hello"); strings.add("World");
      }
   }

   private static <T> String join(String separator,
ArrayList<T> elements)
   {
      var result = new StringBuilder();
      for (T e : elements)
      {
         if (result.length() > 0) result.append(separator);
         result.append(e.toString());
      }
      return result.toString();
   }

   public static void main(String[] args) throws Exception
   {
      var formatter = new Formatter();
      formatter.forType(new TypeLiteral<ArrayList<Integer>>()
```

```
{},
            lst -> join(" ", lst));
        formatter.forType(new TypeLiteral<ArrayList<Character>>(){},
            lst -> "\"" + join("", lst) + "\"");
        System.out.println(formatter.formatFields(new Sample()));
    }
}
```

java.lang.Class<T> 1.0

- `TypeVariable[] getTypeParameters()` 5

  gets the generic type variables if this type was declared as a generic type, or an array of length 0 otherwise.

- `Type getGenericSuperclass()` 5

  gets the generic type of the superclass that was declared for this type, or `null` if this type is `Object` or not a class type.

- `Type[] getGenericInterfaces()` 5

  gets the generic types of the interfaces that were declared for this type, in declaration order, or an array of length 0 if this type doesn't implement interfaces.

java.lang.reflect.Method 1.1

- `TypeVariable[] getTypeParameters()` 5

  gets the generic type variables if this method was declared as a generic method, or an array of length 0 otherwise.

- `Type getGenericReturnType()` 5

  gets the generic return type with which this method was declared.

- `Type[] getGenericParameterTypes()` 5

  gets the generic parameter types with which this method was declared. If the method has no parameters, an array of length 0 is returned.

`java.lang.reflect.TypeVariable` 5

- `String getName()`

  gets the name of this type variable.

- `Type[] getBounds()`

  gets the subclass bounds of this type variable, or an array of length 0 if the variable is unbounded.

`java.lang.reflect.WildcardType` 5

- `Type[] getUpperBounds()`

  gets the subclass (`extends`) bounds of this type variable, or an array of length 0 if the variable has no subclass bounds.

- `Type[] getLowerBounds()`

  gets the superclass (`super`) bounds of this type variable, or an array of length 0 if the variable has no superclass bounds.

`java.lang.reflect.ParameterizedType` 5

- `Type getRawType()`

  gets the raw type of this parameterized type.

- `Type[] getActualTypeArguments()`

  gets the type parameters with which this parameterized type was declared.

- `Type getOwnerType()`

  gets the outer class type if this is an inner type, or `null` if this is a top-level type.

`java.lang.reflect.GenericArrayType` 5

- `Type getGenericComponentType()`

  gets the generic component type with which this array type was declared.

You now know how to use generic classes and how to program your own generic classes and methods if the need arises. Just as importantly, you know how to decipher the generic type declarations that you may encounter in the API documentation and in error messages. For an exhaustive discussion of everything there is to know about Java generics, turn to Angelika Langer's excellent list of frequently (and not so frequently) asked questions at `http://angelikalanger.com/GenericsFAQ/JavaGenericsFAQ.html`.

In the next chapter, you will see how the Java collections framework puts generics to work.

Chapter 9. Collections

In this chapter

The data structures that you choose can make a big difference when you try to implement methods in a natural style or are concerned with performance. Do you need to search quickly through thousands (or even millions) of sorted items? Do you need to rapidly insert and remove elements in the middle of an ordered sequence? Do you need to establish associations between keys and values?

This chapter shows how the Java library can help you accomplish the traditional data structuring needed for serious programming. In college computer science programs, a course called *Data Structures* usually takes a semester to complete, and there are many, many books devoted to this important topic. Our coverage differs from that of a college course; we will skip the theory and just look at how to use the collection classes in the standard library.

9.1 The Java Collections Framework

The initial release of Java supplied only a small set of classes for the most useful data structures: `Vector`, `Stack`, `Hashtable`, `BitSet`, and the `Enumeration` interface that provides an abstract mechanism for visiting elements in an arbitrary container. That was certainly a wise choice—it takes time and skill to come up with a comprehensive collection class library.

With the advent of Java 1.2, the designers felt that the time had come to roll out a full-fledged set of data structures. They faced a number of conflicting design challenges. They wanted the library to be small and easy to learn. They did not want the complexity of the Standard Template Library (or STL) of C++, but they wanted the benefit of "generic algorithms" that STL pioneered. They wanted the legacy classes to fit into the new framework. As all designers of collections libraries do, they had to make some hard choices, and they came up with a number of idiosyncratic design decisions along the way. In this section, we will explore the basic design of the Java collections framework, demonstrate how to put it to work, and explain the reasoning behind some of the more controversial features.

9.1.1 Separating Collection Interfaces and Implementation

As is common with modern data structure libraries, the Java collection library separates *interfaces* and *implementations*. Let us look at that separation with a familiar data structure, the *queue*.

A *queue interface* specifies that you can add elements at the tail end of the queue, remove them at the head, and find out how many elements are in the queue. You use a queue when you need to collect objects and retrieve them in a "first in, first out" fashion (see Figure 9.1).

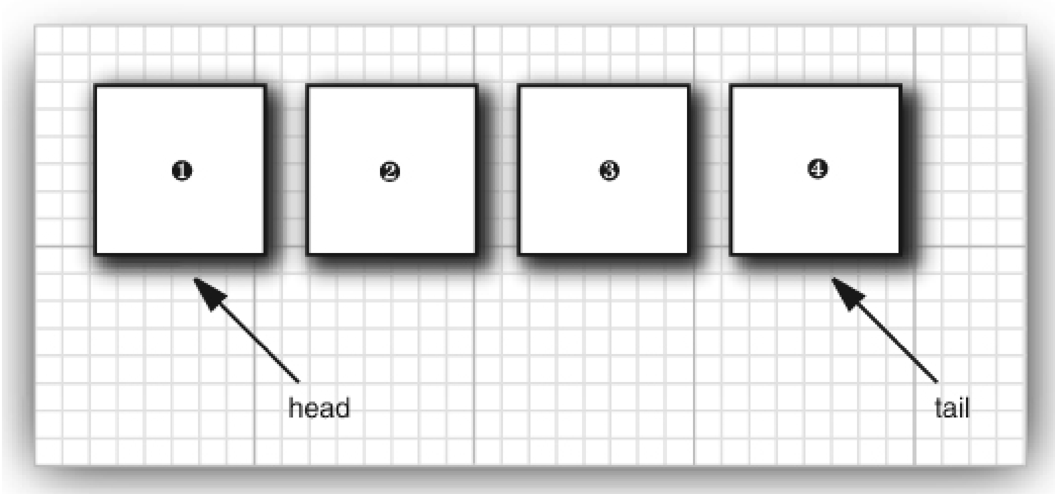


Figure 9.1 A queue

A minimal form of a queue interface might look like this:

```
public interface Queue<E> // a simplified form of the interface
in the standard library
{
   void add(E element);
   E remove();
   int size();
}
```

The interface tells you nothing about how the queue is implemented. Of the two common implementations of a queue, one uses a “circular array” and one uses a linked list (see Figure 9.2).

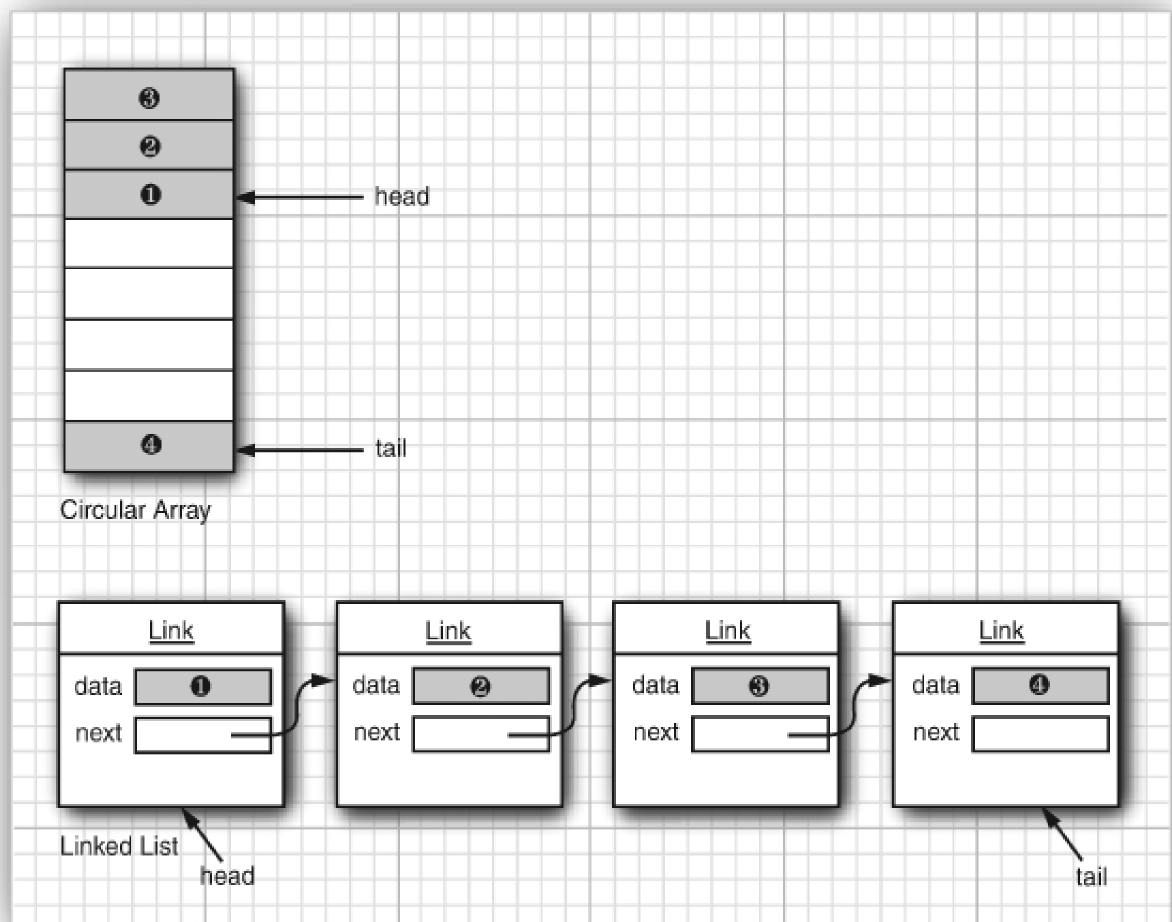


Figure 9.2 Queue implementations

Each implementation can be expressed by a class that implements the `Queue` interface.

```
public class CircularArrayQueue<E> implements Queue<E> // not
an actual library class
{
   private int head;
   private int tail;

   CircularArrayQueue(int capacity) { . . . }   public void
add(E element) { . . . }
   public E remove() { . . . }
   public int size() { . . . }
   private E[] elements;
}

public class LinkedListQueue<E> implements Queue<E> // not an
actual library class
{
   private Link head;
   private Link tail;

   LinkedListQueue() { . . . }
   public void add(E element) { . . . }
   public E remove() { . . . }
   public int size() { . . . }
}
```

NOTE:

The Java library doesn't actually have classes named `CircularArrayQueue` and `LinkedListQueue`. I use these classes as examples to explain the conceptual distinction between collection interfaces and implementations. If you need a circular array queue, use the `ArrayDeque` class. For a linked list queue, simply use the `LinkedList` class—it implements the `Queue` interface.

When you use a queue in your program, you don't need to know which implementation is actually used once the collection has been constructed. Therefore, it makes sense to use the concrete class *only* when you construct the collection object. Use the *interface type* to hold the collection reference.

```
Queue<Customer> expressLane = new CircularArrayQueue<>(100);
expressLane.add(new Customer("Harry"));
```

With this approach, if you change your mind, you can easily use a different implementation. You only need to change your program in one place—in the constructor call. If you decide that a `LinkedListQueue` is a better choice after all, your code becomes

```
Queue<Customer> expressLane = new LinkedListQueue<>();
expressLane.add(new Customer("Harry"));
```

Why would you choose one implementation over another? The interface says nothing about the efficiency of an implementation. A circular array is somewhat more efficient than a linked list, so it is generally preferable. However, as usual, there is a price to pay.

The circular array is a *bounded* collection—it has a finite capacity. If you don't have an upper limit on the number of objects that your program will collect, you may be better off with a linked list implementation after all.

When you study the API documentation, you will find another set of classes whose name begins with `Abstract`, such as `AbstractQueue`. These classes are intended for library implementors. In the (perhaps unlikely) event that you want to implement your own queue class, you will find it easier to extend `AbstractQueue` than to implement all the methods of the `Queue` interface.

9.1.2 The `Collection` Interface

The fundamental interface for collection classes in the Java library is the `Collection` interface. The interface has two fundamental methods:

```
public interface Collection<E>
{
   boolean add(E element);
   Iterator<E> iterator();
   . . .
}
```

There are several methods in addition to these two; we will discuss them later.

The `add` method adds an element to the collection. The `add` method returns `true` if adding the element actually changes the collection, and `false` if the collection is unchanged. For example, if you try to add an object to a set and the object is already present, the `add` request has no effect because sets reject duplicates.

The `iterator` method returns an object that implements the `Iterator` interface. You can use the iterator object to visit the elements in the collection one by one. We discuss iterators in the next section.

9.1.3 Iterators

The `Iterator` interface has four methods:

```
public interface Iterator<E>
{
   E next();
   boolean hasNext();
   void remove();
   default void forEachRemaining(Consumer<? super E> action);
}
```

By repeatedly calling the `next` method, you can visit the elements from the collection one by one. However, if you reach the end of the collection, the `next` method throws a `NoSuchElementException`. Therefore, you need to call the `hasNext` method before calling `next`. That method returns `true` if the iterator object still has more elements to visit. If you want to inspect all elements in a collection, request an iterator and then keep calling the `next` method while `hasNext` returns `true`. For example:

```
Collection<String> c = . . .;
Iterator<String> iter = c.iterator();
while (iter.hasNext())
{
  String element = iter.next();
do something with element
}
```

You can write such a loop more concisely as the “for each” loop:

```
for (String element : c)
{
do something with element
}
```

The compiler simply translates the “for each” loop into a loop with an iterator.

The “for each” loop works with any object that implements the `Iterable` interface, an interface with a single abstract method:

```
public interface Iterable<E>
{
   Iterator<E> iterator();
   . . .
}
```

The `Collection` interface extends the `Iterable` interface. Therefore, you can use the “for each” loop with any collection in the standard library.

Instead of writing a loop, you can call the `forEachRemaining` method with a lambda expression that consumes an element. The lambda expression is invoked with each element of the iterator, until there are none left.

```
iterator.forEachRemaining(element -> do something with element);
```

The order in which the elements are visited depends on the collection type. If you iterate over an `ArrayList`, the iterator starts at index `0` and increments the index in each step. However, if you visit the elements in a `HashSet`, you will get them in an essentially random order. You can be assured that you will encounter all elements of the collection during the course of the iteration, but you cannot make any assumptions about their ordering. This is usually not a problem because the ordering does not matter for computations such as computing totals or counting matches.

NOTE:

Old-timers will notice that the `next` and `hasNext` methods of the `Iterator` interface serve the same purpose as the `nextElement` and `hasMoreElements` methods of an `Enumeration`. The designers of the Java collections library could have chosen to make use of the `Enumeration` interface. But they disliked the cumbersome method names and instead introduced a new interface with shorter method names.

There is an important conceptual difference between iterators in the Java collections library and iterators in other libraries. In traditional collections libraries, such as the Standard Template Library of C++, iterators are modeled after array indexes. Given such an iterator, you can look up the element that is stored at that position, much like you can look up an array element `a[i]` if you have an array index `i`. Independently of the lookup, you can advance the iterator to the next position. This is the same operation as advancing an array index by calling `i++`, without performing a lookup. However, the Java iterators do not work like that. The lookup and position change are tightly coupled. The only way to look up an element is to call `next`, and that lookup advances the position.

Instead, think of Java iterators as being *between elements*. When you call `next`, the iterator *jumps over* the next element, and it returns a reference to the element that it just passed (see Figure 9.3).

NOTE:

Here is another useful analogy. You can think of `Iterator.next` as the equivalent of `InputStream.read`. Reading a byte from a stream automatically "consumes" the byte. The next call to `read` consumes and returns the next byte from the input. Similarly, repeated calls to `next` let you read all elements in a collection.

The `remove` method of the `Iterator` interface removes the element that was returned by the last call to `next`. In many situations, that makes sense—you need to see the element before you can decide that it is the one that should be removed. But if you want to remove an element in a particular position, you still need to skip past the element. For example, here is how you remove the first element in a collection of strings:

```
Iterator<String>
it = c.iterator(); it.next(); // skip over the first element
it.remove(); // now remove it
```

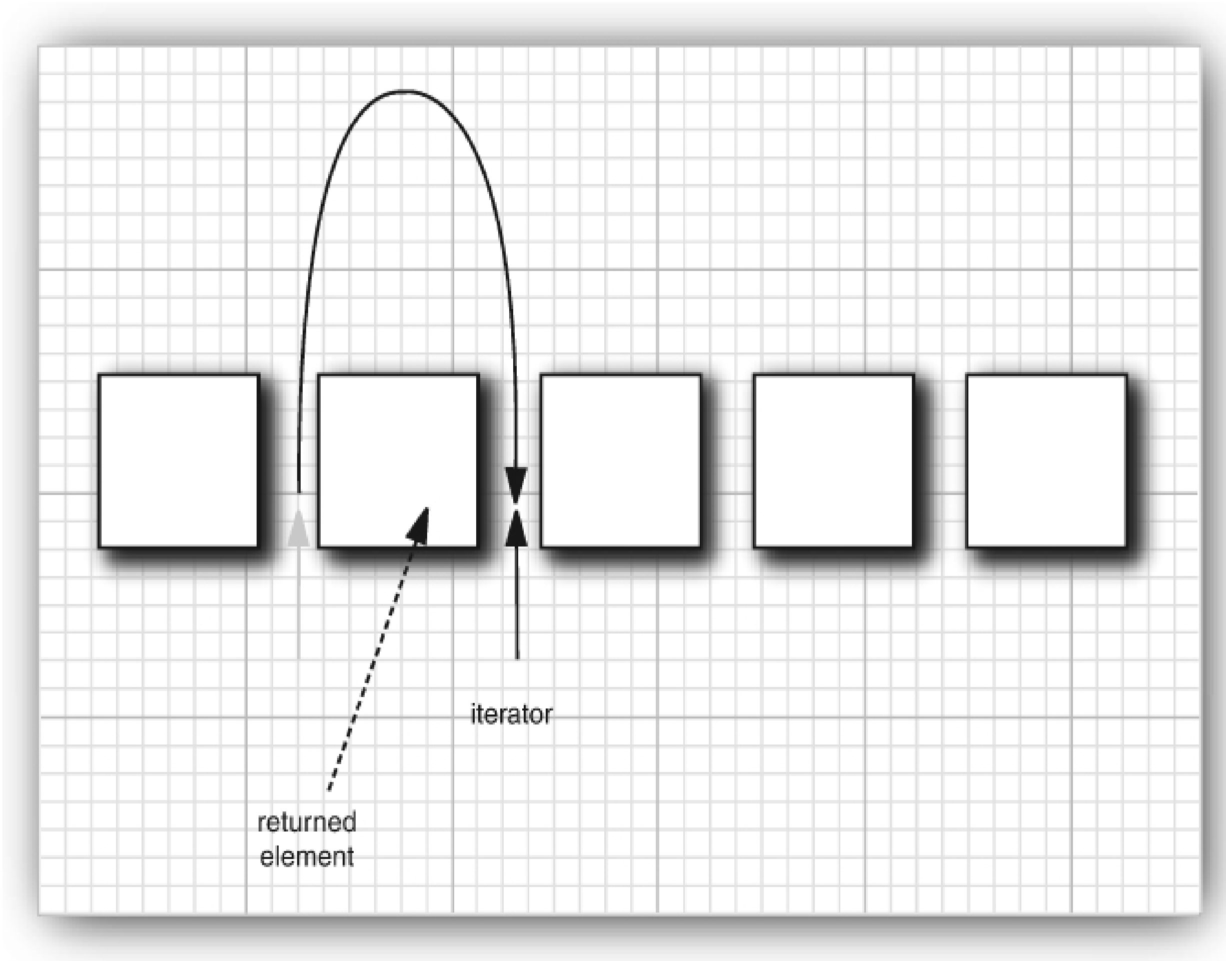


Figure 9.3 Advancing an iterator

More importantly, there is a dependency between the calls to the `next` and `remove` methods. It is illegal to call `remove` if it wasn't preceded by a call to `next`. If you try, an `IllegalStateException` is thrown.

If you want to remove two adjacent elements, you cannot simply call

```
it.remove();
it.remove(); // ERROR
```

Instead, you must first call `next` to jump over the element to be removed.

```
it.remove();
it.next();
it.remove(); // OK
```

9.1.4 Generic Utility Methods

The `Collection` and `Iterator` interfaces are generic, which means you can write utility methods that operate on any kind of collection. For example, here is a generic method that tests whether an arbitrary collection contains a given element:

```
public static <E> boolean contains(Collection<E> c, Object obj)
{   for (E element : c)
      if (element.equals(obj))
         return true;
   return false;
}
```

The designers of the Java library decided that some of these utility methods are so useful that the library should make them available. That way, library users don't have to keep reinventing the wheel. The `contains` method is one such method.

In fact, the `Collection` interface declares quite a few useful methods that all implementing classes must supply. Among them are

```
int size()
boolean isEmpty()
boolean contains(Object obj)
boolean containsAll(Collection<?> c)
boolean equals(Object other)
boolean addAll(Collection<? extends E> from)
boolean remove(Object obj)
boolean removeAll(Collection<?> c)
void clear()
boolean retainAll(Collection<?> c)
Object[] toArray()
```

Many of these methods are self-explanatory; you will find full documentation in the API notes at the end of this section.

Of course, it is a bother if every class that implements the `Collection` interface has to supply so many routine methods. To make life easier for implementors, the library supplies a class `AbstractCollection` that leaves the fundamental methods `size` and `iterator` abstract but implements the routine methods in terms of them. For example:

```
public abstract class AbstractCollection<E>
      implements Collection<E>
{
   . . .
   public abstract Iterator<E> iterator();

   public boolean contains(Object obj)
   {
      for (E element : this) // calls iterator()
         if (element.equals(obj))
            return true;
      return false;
   }
   . . .
}
```

A concrete collection class can now extend the `AbstractCollection` class. It is up to the concrete collection class to supply an `iterator` method, but the `contains` method has been taken care of by the `AbstractCollection` superclass. However, if the subclass has a more efficient way of implementing `contains`, it is free to do so.

This approach is a bit outdated. It would be nicer if the methods were default methods of the `Collection` interface. This has not happened. However, several default methods have been added. Most of them deal with streams (discussed in Volume II). In addition, there is a useful method

```
default boolean removeIf(Predicate<? super E> filter)
```

for removing elements that fulfill a condition.

java.util.Collection<E> 1.2

- `Iterator<E> iterator()`

  returns an iterator that can be used to visit the elements in the collection.

- `int size()`

  returns the number of elements currently stored in the collection.

- `boolean isEmpty()`

  returns `true` if this collection contains no elements.

- `boolean contains(Object obj)`

  returns `true` if this collection contains an object equal to `obj`.

- `boolean containsAll(Collection<?> other)`

  returns `true` if this collection contains all elements in the other collection.

- `boolean add(E element)`

  adds an element to the collection. Returns `true` if the collection changed as a result of this call.

- `boolean addAll(Collection<? extends E> other)`

  adds all elements from the other collection to this collection. Returns `true` if the collection changed as a result of this call.

- `boolean remove(Object obj)`

  removes an object equal to `obj` from this collection. Returns `true` if a matching object was removed.

- `boolean removeAll(Collection<?> other)` removes from this collection all elements from the other collection. Returns `true` if the collection changed as a result of this call.

- `default boolean removeIf(Predicate<? super E> filter)` **8**

  removes all elements for which `filter` returns `true`. Returns `true` if the collection changed as a result of this call.

- `void clear()`

  removes all elements from this collection.

- `boolean retainAll(Collection<?> other)`

  removes all elements from this collection that do not equal one of the elements in the other collection. Returns `true` if the collection changed as a result of this call.

- `Object[] toArray()`

  returns an array of the objects in the collection.

- `<T> T[] toArray(IntFunction<T[]> generator)` **11**

  returns an array of the objects in the collection. The array is constructed with the `generator`, which is typically a constructor expression `T[]::new`.

java.util.Iterator<E> **1.2**

- `boolean hasNext()`

  returns `true` if there is another element to visit.

- `E next()`

  returns the next object to visit. Throws a `NoSuchElementException` if the end of the collection has been reached.

- `void remove()`

  removes the last visited object. This method must immediately follow an element visit. If the collection has been modified since the last element visit, this method throws an `IllegalStateException`.

- `default void forEachRemaining(Consumer<? super E> action)` 8

  visits elements and passes them to the given action until no elements remain or the action throws an exception.

9.2 Interfaces in the Collections Framework

The Java collections framework defines a number of interfaces for different types of collections, shown in Figure 9.4.

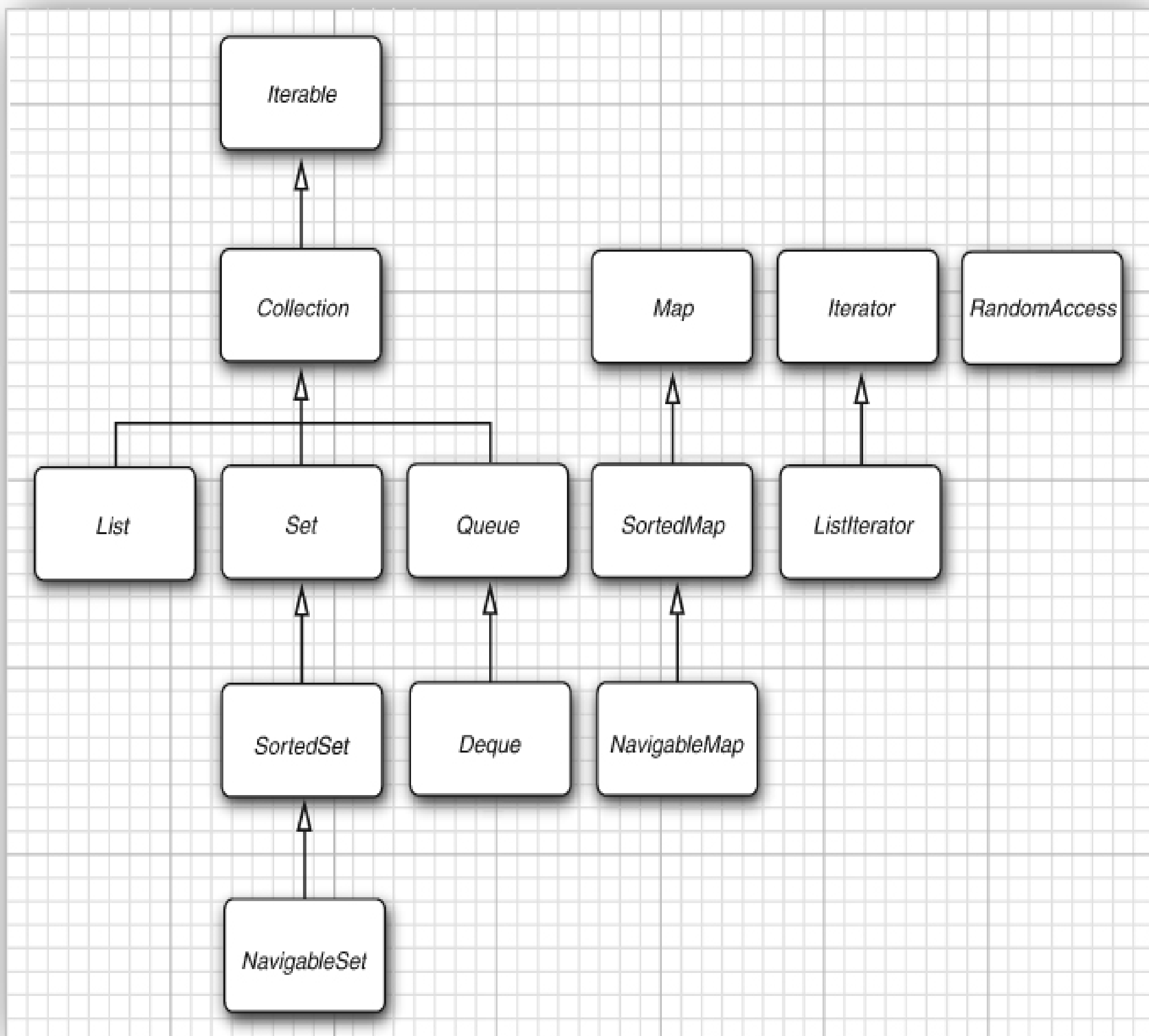


Figure 9.4 The interfaces of the collections framework

There are two fundamental interfaces for collections: `Collection` and `Map`. As you already saw, you insert elements into a collection with a method

```
boolean add(E element)
```

However, maps hold key/value pairs, and you use the `put` method to insert them:

```
V put(K key, V value)
```

To read elements from a collection, visit them with an iterator. However, you can read values from a map with the `get` method:

```
V get(K key)
```

A `List` is an *ordered collection*. Elements are added into a particular position in the container. An element can be accessed in two ways: by an iterator or by an integer index. The latter is called *random access* because elements can be visited in any order. In contrast, when using an iterator, one must visit them sequentially.

The `List` interface defines several methods for random access:

```
void add(int index, E element)
void remove(int index)
E get(int index)
E set(int index, E element)
```

The `ListIterator` interface is a subinterface of `Iterator`. It defines a method for adding an element before the iterator position:

```
void add(E element)
```

Frankly, this aspect of the collections framework is poorly designed. In practice, there are two kinds of ordered collections, with very different performance tradeoffs. An ordered collection that is backed by an array has fast random access, and it makes sense to use the `List` methods with an integer index. In contrast, a linked list, while also ordered, has slow random access, and it is best traversed with an iterator. It would have been an easy matter to provide two interfaces.

NOTE:

To avoid carrying out random access operations for linked lists, Java 1.4 introduced a tagging interface, `RandomAccess`. That interface has no methods, but you can use it to test whether a particular collection supports efficient random access:

```
if (c instanceof RandomAccess)
{
   use random access algorithm
}
else
{
   use sequential access algorithm
}
```

The `Set` interface is identical to the `Collection` interface, but the behavior of the methods is more tightly defined. The `add` method of a set should reject duplicates. The `equals` method of a set should be defined so that two sets are identical if they have the same elements, but not necessarily in the same order. The `hashCode` method should be defined so that two sets with the same elements yield the same hash code.

Why make a separate interface if the method signatures are the same? Conceptually, not all collections are sets. Making a `Set` interface enables programmers to write methods that accept only sets.

The `SortedSet` and `SortedMap` interfaces expose the comparator object used for sorting, and they define methods to obtain views of subsets of the collections. We discuss these in Section 9.5, “Copies and Views,” on p. 548.

Finally, Java 6 introduced interfaces `NavigableSet` and `NavigableMap` that contain additional methods for searching and traversal in sorted sets and maps. (Ideally, these methods should have simply been included in the `SortedSet` and `SortedMap` interface.) The `TreeSet` and `TreeMap` classes implement these interfaces.

9.3 Concrete Collections

Table 9.1 shows the collections in the Java library and briefly describes the purpose of each collection class. (For simplicity, I omit the thread-safe collections that will be discussed in Chapter 12.)

All classes in Table 9.1 implement the `Collection` interface, with the exception of the classes with names ending in `Map`. Those classes implement the `Map` interface instead. We will discuss maps in Section 9.4, “Maps,” on p. 535.

Figure 9.5 shows the relationships between these classes.

Table 9.1 Concrete Collections in the Java Library

Collection Type	Description	See Page
`ArrayList`	An indexed sequence that grows and shrinks dynamically	523
`LinkedList`	An ordered sequence that allows efficient insertion and removal at any location	512
`ArrayDeque`	A double-ended queue that is implemented as a circular array	532
`HashSet`	An unordered collection that rejects duplicates	523
`TreeSet`	A sorted set	527
`EnumSet`	A set of enumerated type values	545
`LinkedHashSet`	A set that remembers the order in which elements were inserted	543
`PriorityQueue`	A collection that allows efficient removal of the smallest element	533
`HashMap`	A data structure that stores key/value associations	542
`TreeMap`	A map in which the keys are sorted	535
`EnumMap`	A map in which the keys belong to an enumerated type	545
`LinkedHashMap`	A map that remembers the order in which entries were added	543
`WeakHashMap`	A map with values that can be reclaimed by the garbage collector if they are not used elsewhere	542
`IdentityHashMap`	A map with keys that are compared by `==`, not `equals`	545

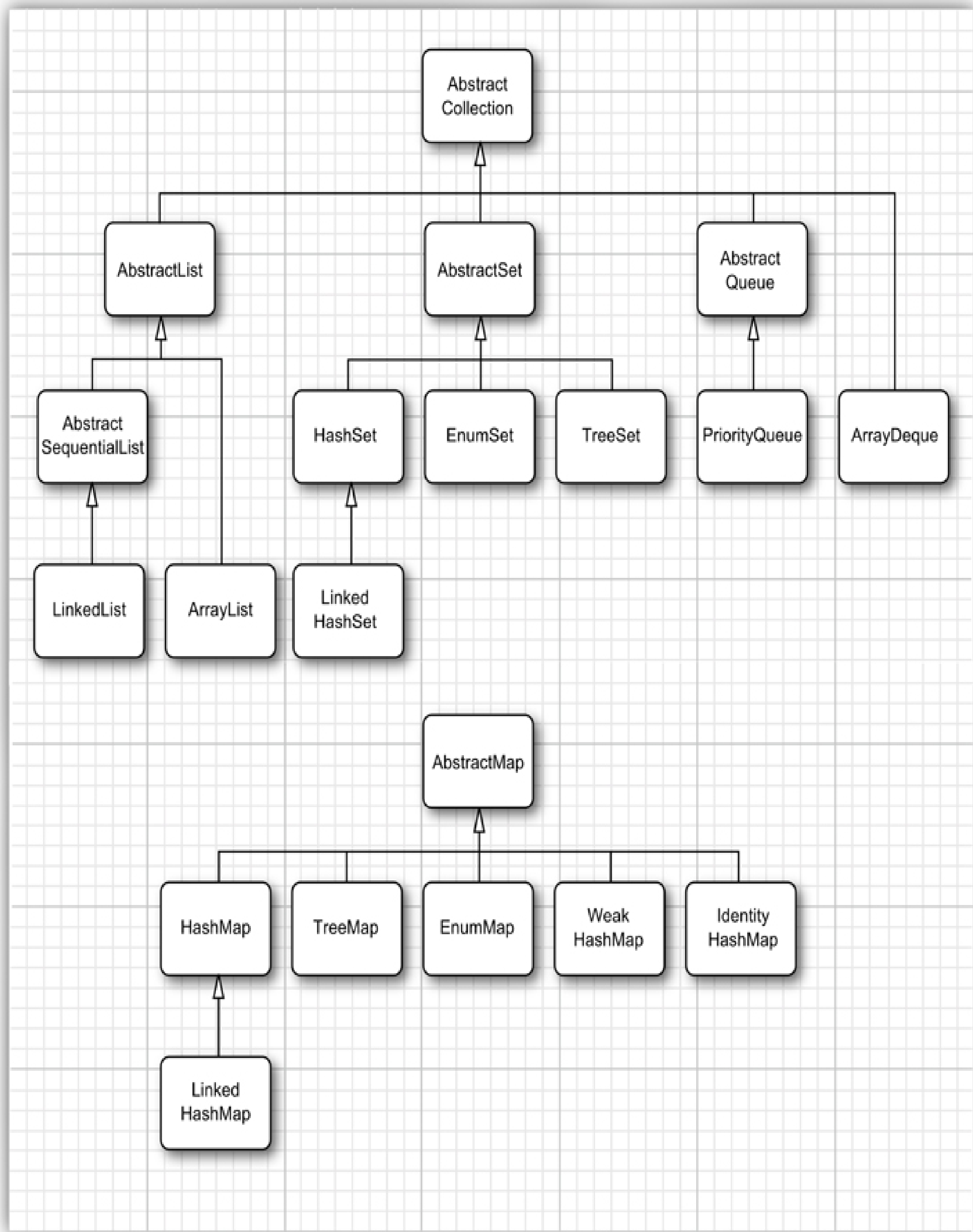


Figure 9.5 Classes in the collections framework

9.3.1 Linked Lists

We already used arrays and their dynamic cousin, the `ArrayList` class, for many examples in this book. However, arrays and array lists suffer from a major drawback. Removing an element from the middle of an array is expensive since all array elements beyond the removed one must be moved toward the beginning of the array (see Figure 9.6). The same is true for inserting elements in the middle.

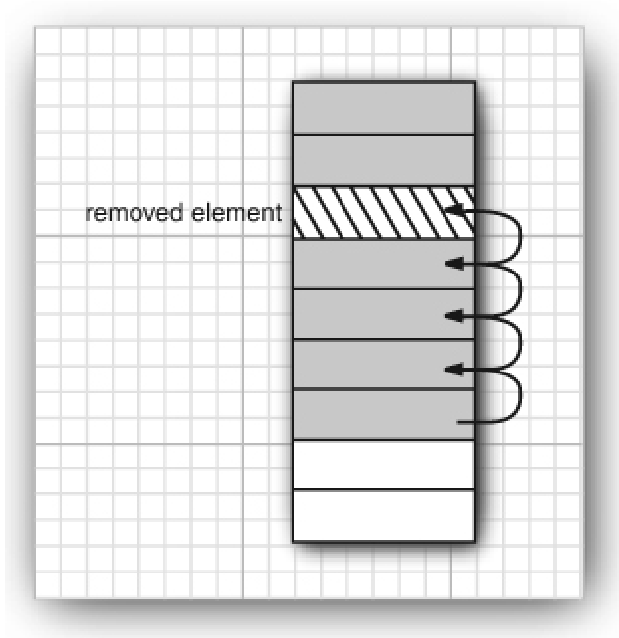


Figure 9.6 Removing an element from an array

Another well-known data structure, the *linked list*, solves this problem. Where an array stores object references in consecutive memory locations, a linked list stores each object in a separate *link*. Each link also stores a reference to the next link in the sequence. In the Java programming language, all linked lists are actually *doubly linked*; that is, each link also stores a reference to its predecessor (see Figure 9.7).

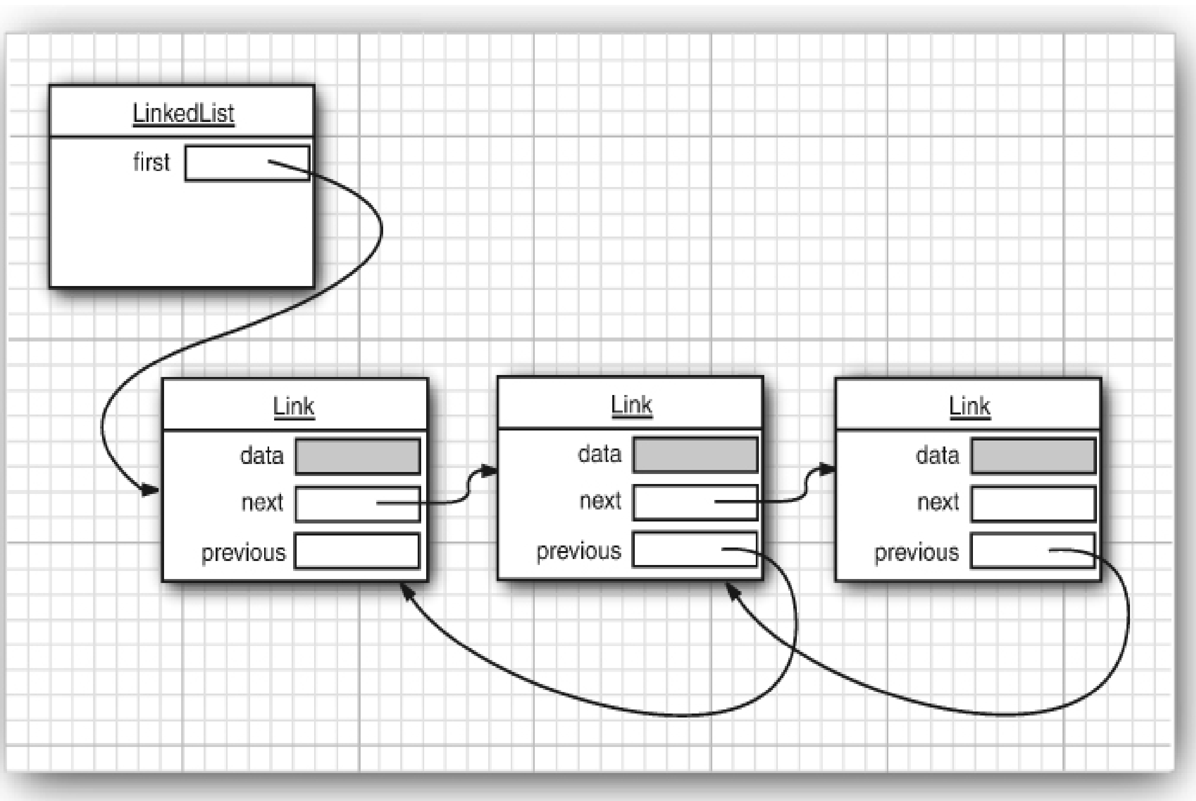


Figure 9.7 A doubly linked list

Removing an element from the middle of a linked list is an inexpensive operation—only the links around the element to be removed need to be updated (see Figure 9.8).

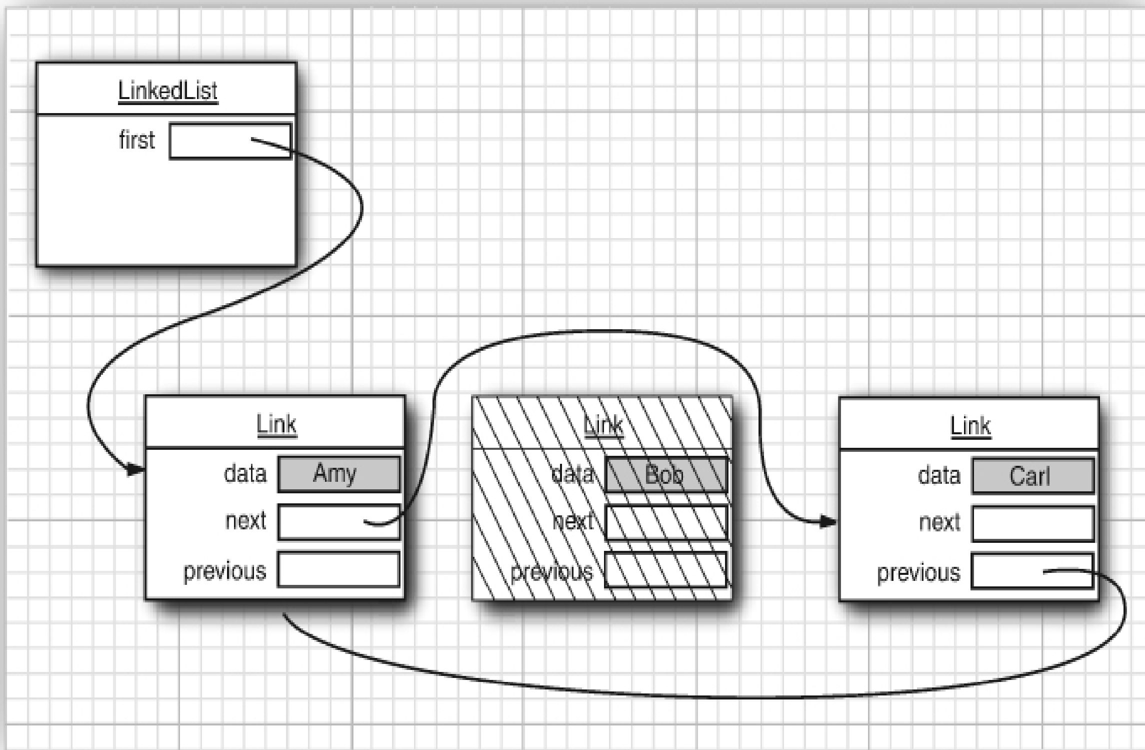


Figure 9.8 Removing an element from a linked list

Perhaps you once took a data structures course in which you learned how to implement linked lists. You may have bad memories of tangling up the links when removing or adding elements in the linked list. If so, you will be pleased to learn that the Java collections library supplies a class `LinkedList` ready for you to use.

The following code example adds three elements and then removes the second one:

```
var staff = new LinkedList<String>();
staff.add("Amy");
staff.add("Bob");
staff.add("Carl");
Iterator<String> iter = staff.iterator();
String first = iter.next(); // visit first element
String second = iter.next(); // visit second element
iter.remove(); // remove last visited element
```

There is, however, an important difference between linked lists and generic collections. A linked list is an *ordered collection* in which the position of the objects matters. The `LinkedList.add` method adds the object to the end of the list. But you will often want to add objects somewhere in the middle of a list. This position-dependent `add` method is the responsibility of an iterator, since iterators describe positions in collections. Using iterators to add elements makes sense only for collections that have a natural ordering. For example, the *set* data type that we discuss in the next section does not impose any ordering on its elements. Therefore, there is no `add` method in the `Iterator` inter-face. Instead, the collections library supplies a subinterface `ListIterator` that contains an `add` method:

```
interface ListIterator<E> extends Iterator<E>
{
   void add(E element);
   . . .
}
```

Unlike `Collection.add`, this method does not return a `boolean`—it is assumed that the `add` operation always modifies the list.

In addition, the `ListIterator` interface has two methods that you can use for traversing a list backwards.

```
E previous()
boolean hasPrevious()
```

Like the `next` method, the `previous` method returns the object that it skipped over.

The `listIterator` method of the `LinkedList` class returns an iterator object that implements the `ListIterator` interface.

```
ListIterator<String> iter = staff.listIterator();
```

The `add` method adds the new element *before* the iterator position. For example, the following code skips past the first element in the linked list and adds `"Juliet"` before the second element (see Figure 9.9):

```
var staff = new LinkedList<String>();
staff.add("Amy");
staff.add("Bob");
staff.add("Carl");
ListIterator<String> iter = staff.listIterator();
iter.next(); // skip past first element
iter.add("Juliet");
```

If you call the `add` method multiple times, the elements are simply added in the order in which you supplied them. They are all added in turn before the current iterator position.

When you use the `add` operation with an iterator that was freshly returned from the `listIterator` method and that points to the beginning of the linked list, the newly added element becomes the new head of the list. When the iterator has passed the last element of the list (that is, when `hasNext` returns `false`), the added element becomes the new tail of the list. If the linked list has n elements, there are $n + 1$ spots for adding a new element. These spots correspond to the $n + 1$ possible positions of the iterator. For example, if a linked list contains three elements, A, B, and C, there are four possible positions (marked as `|`) for inserting a new element:

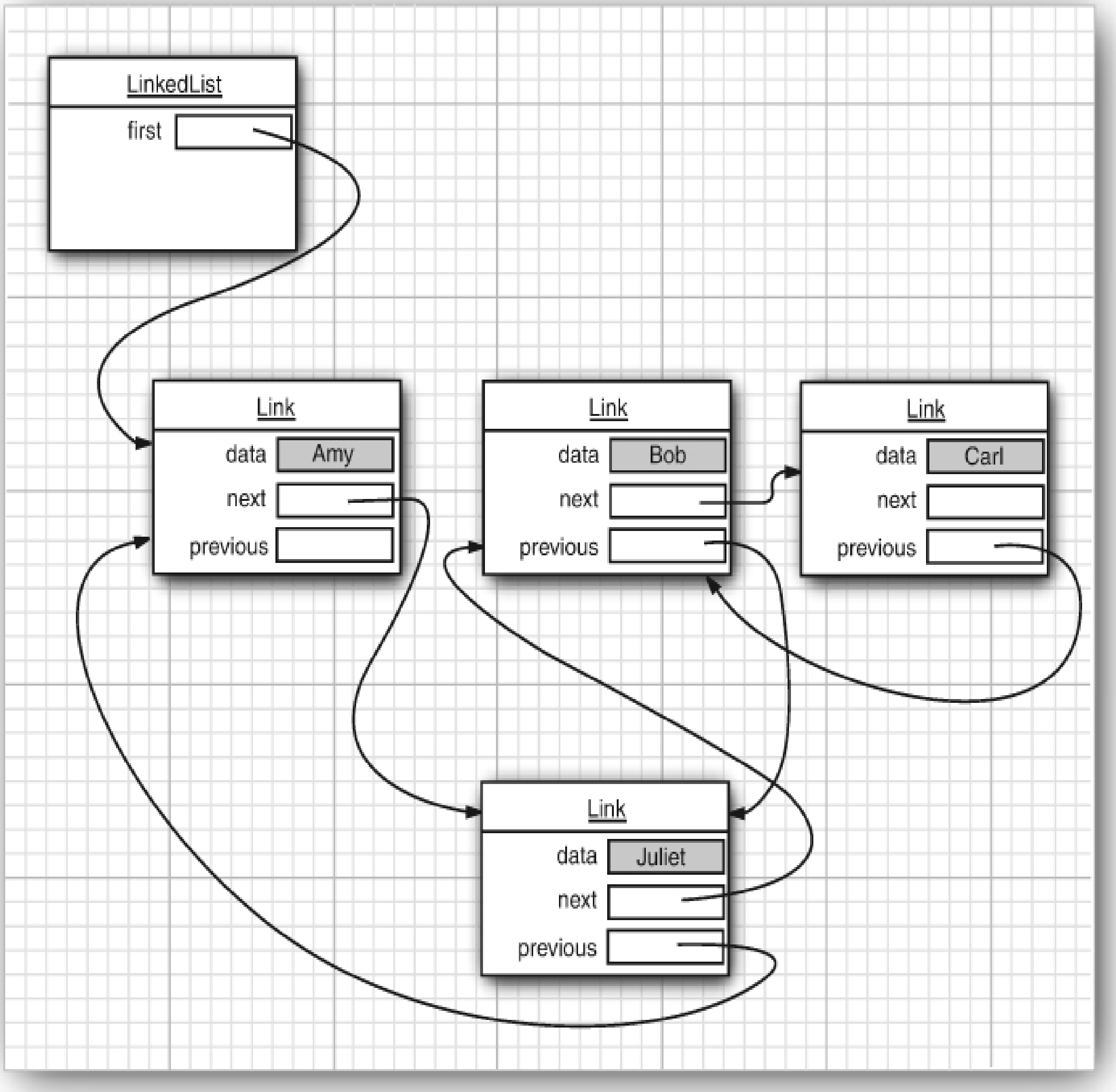


Figure 9.9 Adding an element to a linked list

```
|ABC
A|BC
AB|C
ABC|
```

NOTE:

Be careful with the "cursor" analogy. The `remove` operation does not work exactly like the Backspace key. Immediately after a call to `next`, the `remove` method indeed removes the element to the left of the iterator, just like the Backspace key would. However, if you have just called `previous`, the element to the right will be removed. And you can't call `remove` twice in a row.

Unlike the `add` method, which depends only on the iterator position, the `remove` method depends on the iterator state.

Finally, a `set` method replaces the last element, returned by a call to `next` or `previous`, with a new element. For example, the following code replaces the first element of a list with a new value:

```
ListIterator<String> iter = list.listIterator();
String oldValue = iter.next(); // returns first element
iter.set(newValue); // sets first element to newValue
```

As you might imagine, if an iterator traverses a collection while another iterator is modifying it, confusing situations can occur. For example, suppose an iterator points before an element that another iterator has just removed. The iterator is now invalid and should no longer be used. The linked list iterators have been designed to detect such modifications. If an iterator finds that its collection has been modified by another iterator or by a method of the collection itself, it throws a `ConcurrentModificationException`. For example, consider the following code:

```
List<String> list = . . .;
ListIterator<String> iter1 = list.listIterator();
ListIterator<String> iter2 = list.listIterator();
iter1.next();
iter1.remove();
iter2.next(); // throws ConcurrentModificationException
```

The call to `iter2.next` throws a `ConcurrentModificationException` since `iter2` detects that the list was modified externally.

To avoid concurrent modification exceptions, follow this simple rule: You can attach as many iterators to a collection as you like, provided that all of them are only readers. Alternatively, you can attach a single iterator that can both read and write.

Concurrent modification detection is done in a simple way. The collection keeps track of the number of mutating operations (such as adding and removing elements). Each iterator keeps a separate count of the number of mutating operations that *it* was responsible for. At the beginning of each iterator method, the iterator simply checks whether its own mutation count equals that of the collection. If not, it throws a `ConcurrentModificationException`.

NOTE:

There is, however, a curious exception to the detection of concurrent modifications. The linked list only keeps track of *structural* modifications to the list, such as adding and removing links. The `set` method does *not* count as a structural modification. You can attach multiple iterators to a linked list, all of which call `set` to change the contents of existing links. This capability is required for a number of algorithms in the `Collections` class that we discuss later in this chapter.

Now you have seen the fundamental methods of the `LinkedList` class. Use a `ListIterator` to traverse the elements of the linked list in either direction and to add and remove elements.

As you saw in Section 9.2, "Interfaces in the Collections Framework," on p. 508, many other useful methods for operating on linked lists are declared in the `Collection` interface. These are, for the most part, implemented in the `AbstractCollection` superclass of the `LinkedList` class. For example, the `toString` method invokes `toString` on all elements and produces one long string of the format `[A, B, C]`. This is handy for debugging. Use the `contains` method to check whether an element is present in a linked list. For example, the call `staff.contains("Harry")` returns `true` if the linked list already contains a string equal to the string `"Harry"`.

The library also supplies a number of methods that are, from a theoretical perspective, somewhat dubious. Linked lists do not support fast random access. If you want to see the *n*th element of a linked list, you have to start at the beginning and skip past the first $n - 1$ elements. There is no shortcut. For that reason, programmers don't usually use linked lists in situations where elements need to be accessed by an integer index.

Nevertheless, the `LinkedList` class supplies a `get` method that lets you access a particular element:

```
LinkedList<String> list = . . .;
String obj = list.get(n);
```

Of course, this method is not very efficient. If you find yourself using it, you are probably using a wrong data structure for your problem.

You should *never* use this illusory random access method to step through a linked list. The code

```
for (int i = 0; i < list.size(); i++)
do something with list.get(i);
```

is staggeringly inefficient. Each time you look up another element, the search starts again from the beginning of the list. The `LinkedList` object makes no effort to cache the position information.

NOTE:

The `get` method has one slight optimization: If the index is at least `size() / 2`, the search for the element starts at the end of the list.

The list iterator interface also has a method to tell you the index of the current position. In fact, since Java iterators conceptually point between elements, it has two of them: The `nextIndex` method returns the integer index of the element that would be returned by the next call to `next`; the `previousIndex` method returns the index of the element that would be returned by the next call to `previous`. Of course, that is simply one less than `nextIndex`. These methods are efficient—an iterator keeps a count of its current position. Finally, if you have an integer index `n`, then `list.listIterator(n)` returns an iterator that points just before the element with index `n`. That is, calling `next` yields the same element as `list.get(n)`; obtaining that iterator is inefficient.

If you have a linked list with only a handful of elements, you don't have to be overly paranoid about the cost of the `get` and `set` methods. But then, why use a linked list in the first place? The only reason to use a linked list is to minimize the cost of insertion and removal in the middle of the list. If you have only a few elements, you can just use an `ArrayList`.

I recommend that you simply stay away from all methods that use an integer index to denote a position in a linked list. If you want random access into a collection, use an array or `ArrayList`, not a linked list.

The program in Listing 9.1 puts linked lists to work. It simply creates two lists, merges them, then removes every second element from the second list, and finally tests the `removeAll` method. I recommend that you trace the program flow and pay special attention to the iterators. You may find it helpful to draw diagrams of the iterator positions, like this:

```
|ACE   |BDFG
A|CE   |BDFG
AB|CE B|DFG
. . .
```

Note that the call

```
System.out.println(a);
```

prints all elements in the linked list `a` by invoking the `toString` method in `AbstractCollection`.

Listing 9.1 `linkedList/LinkedListTest.java`

```
package linkedList;

import java.util.*;

/**
 * This program demonstrates operations on linked lists.
 * @version 1.12 2018-04-10
 * @author Cay Horstmann
 */
public class LinkedListTest
{
   public static void main(String[] args)
   {
      var a = new LinkedList<String>();
      a.add("Amy");
      a.add("Carl");
      a.add("Erica");

      var b = new LinkedList<String>();
      b.add("Bob");
      b.add("Doug");
      b.add("Frances");
      b.add("Gloria");

      // merge the words from b into a

      ListIterator<String> aIter = a.listIterator();
      Iterator<String> bIter = b.iterator();

      while (bIter.hasNext())
      {
         if (aIter.hasNext()) aIter.next();
         aIter.add(bIter.next());
      }
```

```

       System.out.println(a);

       // remove every second word from b

       bIter = b.iterator();
       while (bIter.hasNext())
       {
          bIter.next(); // skip one element
          if (bIter.hasNext())
          {              bIter.next(); // skip next element
          bIter.remove(); // remove that element
       }
    }

    System.out.println(b);

    // bulk operation: remove all words in b from a

    a.removeAll(b);

    System.out.println(a);
  }
}
```

---

java.util.List<E> 1.2

- `ListIterator<E> listIterator()`

  returns a list iterator for visiting the elements of the list.

- `ListIterator<E> listIterator(int index)`

  returns a list iterator for visiting the elements of the list whose first call to `next` will return the element with the given index.

- `void add(int i, E element)`

  adds an element at the specified position.

- `void addAll(int i, Collection<? extends E> elements)`

  adds all elements from a collection to the specified position.

- `E remove(int i)`

  removes and returns the element at the specified position.

- `E get(int i)`

  gets the element at the specified position.

- `E set(int i, E element)`

  replaces the element at the specified position with a new element and returns the old element.

- `int indexOf(Object element)`

  returns the position of the first occurrence of an element equal to the specified element, or `-1` if no matching element is found.

- `int lastIndexOf(Object element)`

  returns the position of the last occurrence of an element equal to the specified element, or `-1` if no matching element is found.

java.util.ListIterator<E> 1.2

- `void add(E newElement)`

  adds an element before the current position.

- `void set(E newElement)`

  replaces the last element visited by `next` or `previous` with a new element. Throws an `IllegalStateException` if the list structure was modified since the last call to `next` or `previous`.

- `boolean hasPrevious()`

  returns `true` if there is another element to visit when iterating backwards through the list.

- `E previous()`

returns the previous object. Throws a `NoSuchElementException` if the beginning of the list has been reached.

- `int nextIndex()`

  returns the index of the element that would be returned by the next call to `next`.

- `int previousIndex()`

  returns the index of the element that would be returned by the next call to `previous`.

`java.util.LinkedList<E>` 1.2

- `LinkedList()`

  constructs an empty linked list.

- `LinkedList(Collection<? extends E> elements)`

  constructs a linked list and adds all elements from a collection.

- `void addFirst(E element)`
- `void addLast(E element)`

  adds an element to the beginning or the end of the list.

- `E getFirst()`
- `E getLast()`

  returns the element at the beginning or the end of the list.

- `E removeFirst()`
- `E removeLast()`

  removes and returns the element at the beginning or the end of the list.

9.3.2 Array Lists

In the preceding section, you saw the `List` interface and the `LinkedList` class that implements it. The `List` interface describes an ordered collection in which the position of elements matters. There are two protocols for visiting the elements: through an iterator and by random access with methods `get` and `set`. The latter is not appropriate for linked lists, but of course `get` and `set` make a lot of sense for arrays. The collections library supplies the familiar `ArrayList` class that also implements the `List` interface. An `ArrayList` encapsulates a dynamically reallocated array of objects.

NOTE:

If you are a veteran Java programmer, you may have used the `Vector` class whenever you need a dynamic array. Why use an `ArrayList` instead of a `Vector`? For one simple reason: All methods of the `Vector` class are *synchronized*. It is safe to access a `Vector` object from two threads. But if you access a vector from only a single thread—by far the more common case—your code wastes quite a bit of time with synchronization. In contrast, the `ArrayList` methods are not synchronized. I recommend that you use an `ArrayList` instead of a `Vector` whenever you don't need synchronization.

9.3.3 Hash Sets

Linked lists and arrays let you specify the order in which you want to arrange the elements. However, if you are looking for a particular element and don't remember its position, you need to visit all elements until you find a match. That can be time consuming if the collection contains many elements. If you don't care about the ordering of the elements, there are data structures that let you find elements much faster. The drawback is that those data structures give you no control over the order in which the elements appear. These data structures organize the elements in an order that is convenient for their own purposes.

A well-known data structure for finding objects quickly is the *hash table*. A hash table computes an integer, called the *hash code*, for each object. A hash code is somehow derived from the instance fields of an object, preferably in such a way that objects with different data yield different codes. Table 9.2 lists a few examples of hash codes that result from the `hashCode` method of the `String` class.

If you define your own classes, you are responsible for implementing your own `hashCode` method—see Chapter 5 for more information. Your implementation needs to be compatible with the `equals` method: If `a.equals(b)`, then `a` and `b` must have the same hash code.

Table 9.2 Hash Codes Resulting from the `hashCode` Method

String	Hash Code
"Lee"	76268
"lee"	107020
"eel"	100300

What's important for now is that hash codes can be computed quickly and that the computation depends only on the state of the object that needs to be hashed, not on the other objects in the hash table.

In Java, hash tables are implemented as arrays of linked lists. Each list is called a *bucket* (see Figure 9.10). To find the place of an object in the table, compute its hash code and reduce it modulo the total number of buckets. The resulting number is the index of the bucket that holds the element. For example, if an object has hash code 76268 and there are 128 buckets, then the object is placed in bucket 108 (because the remainder 76268 `%` 128 is 108). Perhaps you are lucky and there is no other element in that bucket. Then, you simply insert the element into that bucket. Of course, sometimes you will hit a bucket that is already filled. This is called a *hash collision*. Then, compare the new object with all objects in that bucket to see if it is already present. If the hash codes are reasonably randomly distributed and the number of buckets is large enough, only a few comparisons should be necessary.

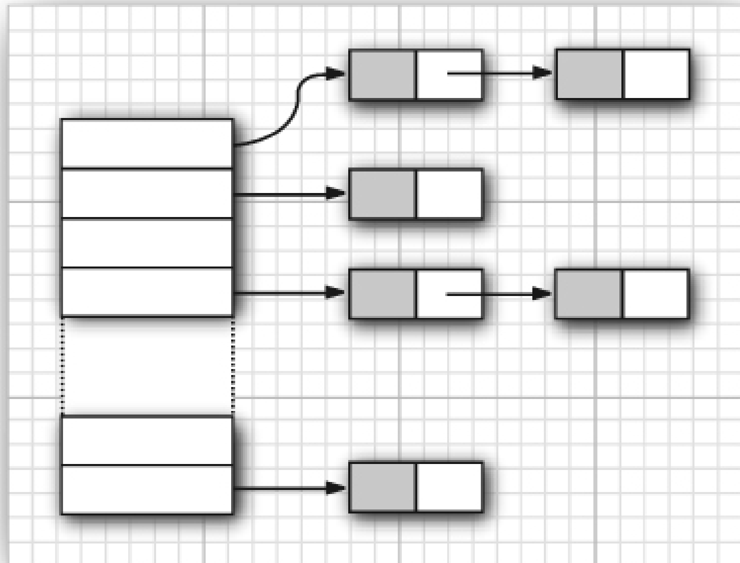


Figure 9.10 A hash table

NOTE:

As of Java 8, the buckets change from linked lists into balanced binary trees when they get full. This improves performance if a hash function was poorly chosen and yields many collisions, or if malicious code tries to flood a hash table with many values that have identical hash codes.

TIP:

If at all possible, the keys of a hash table should belong to a class that implements the `Comparable` interface. Then you are guaranteed not to suffer poor performance due to poorly distributed hash codes.

If you want more control over the performance of the hash table, you can specify the initial bucket count. The bucket count gives the number of buckets used to collect objects with identical hash values. If too many elements are inserted into a hash table, the number of collisions increases and retrieval performance suffers.

If you know how many elements, approximately, will eventually be in the table, you can set the bucket count. Typically, you should set it to somewhere between 75% and 150% of the expected element count. Some researchers believe that it is a good idea to make the bucket count a prime number to prevent a clustering of keys. The evidence for this isn't conclusive, however. The standard library uses bucket counts that are powers of 2, with a default of `16`. (Any value you supply for the table size is automatically rounded to the next power of 2.)

Of course, you do not always know how many elements you need to store, or your initial guess may be too low. If the hash table gets too full, it needs to be *rehashed*. To rehash the table, a table with more buckets is created, all elements are inserted into the new table, and the original table is discarded. The *load factor* determines when a hash table is rehashed. For example, if the load factor is `0.75` (which is the default) and the table is more than 75% full, it is automatically rehashed with twice as many buckets. For most applications, it is reasonable to leave the load factor at `0.75`.

Hash tables can be used to implement several important data structures. The simplest among them is the *set* type. A set is a collection of elements without duplicates. The `add` method of a set first tries to find the object to be added, and adds it only if it is not yet present.

The Java collections library supplies a `HashSet` class that implements a set based on a hash table. You add elements with the `add` method. The `contains` method is redefined to make a fast lookup to see if an element is already present in the set. It checks only the elements in one bucket and not all elements in the collection.

The hash set iterator visits all buckets in turn. Since hashing scatters the elements around in the table, they are visited in a seemingly random order. You would only use a `HashSet` if you don't care about the ordering of the elements in the collection.

The sample program at the end of this section (Listing 9.2) reads words from `System.in`, adds them to a set, and finally prints out the first twenty words in the set. For example, you can feed the program the text from *Alice in Wonder-land* (which you can obtain from `www.gutenberg.org`) by launching it from a command shell as

```
java SetTest < alice30.txt
```

The program reads all words from the input and adds them to the hash set. It then iterates through the unique words in the set and finally prints out a count. (*Alice in Wonderland* has 5,909 unique words, including the copyright notice at the beginning.) The words appear in random order.

CAUTION:

Be careful when you mutate set elements. If the hash code of an element were to change, the element would no longer be in the correct position in the data structure.

Listing 9.2 `set/SetTest.java`

```
package set;

import java.util.*;

/**
 * This program uses a set to print all unique words in System.in.
 * @version 1.12 2015-06-21
 * @author Cay Horstmann
 */
public class SetTest
{
   public static void main(String[] args)
```

```java
    {
       var words = new HashSet<String>();
       long totalTime = 0;

       try (var in = new Scanner(System.in))
       {
          while (in.hasNext())
          {
             String word = in.next();
             long callTime = System.currentTimeMillis();
             words.add(word);
             callTime = System.currentTimeMillis() - callTime;
             totalTime += callTime;
          }
       }

       Iterator<String> iter = words.iterator();
       for (int i = 1; i <= 20 && iter.hasNext(); i++)
          System.out.println(iter.next());
       System.out.println(". . .");
       System.out.println(words.size() + " distinct words. " + totalTime + " milliseconds.");
    }
 }
```

`java.util.HashSet<E>` 1.2

- `HashSet()`

  constructs an empty hash set.

- `HashSet(Collection<? extends E> elements)`

  constructs a hash set and adds all elements from a collection.

- `HashSet(int initialCapacity)`

  constructs an empty hash set with the specified capacity (number of buckets).

• `HashSet(int initialCapacity, float loadFactor)`

constructs an empty hash set with the specified capacity and load factor. If the ratio size/capacity exceeds the load factor, the hash table will be rehashed into a larger one.

`java.lang.Object` 1.0

• `int hashCode()`

returns a hash code for this object. A hash code can be any integer, positive or negative. The definitions of `equals` and `hashCode` must be compatible: If `x.equals(y)` is `true`, then `x.hashCode()` must be the same value as `y.hashCode()`.

9.3.4 Tree Sets

The `TreeSet` class is similar to the hash set, with one added improvement. A tree set is a *sorted collection*. You insert elements into the collection in any order. When you iterate through the collection, the values are automatically presented in sorted order. For example, suppose you insert three strings and then visit all elements that you added.

```
var sorter = new TreeSet<String>();
sorter.add("Bob");
sorter.add("Amy");
sorter.add("Carl");
for (String s : sorter) System.out.println(s);
```

Then, the values are printed in sorted order: `Amy Bob Carl`. As the name of the class suggests, the sorting is accomplished by a tree data structure. (The current implementation uses a *red-black tree*. For a detailed description of red-black trees see, for example, *Introduction to Algorithms* by Thomas Cormen, Charles Leiserson, Ronald Rivest, and Clifford Stein, The MIT Press, 2009.) Every time an element is added to a tree, it is placed into its proper sorting position. Therefore, the iterator always visits the elements in sorted order.

Adding an element to a tree is slower than adding it to a hash table—see Table 9.3 for a comparison. But it is still much faster than checking for duplicates in an array or linked list. If the tree contains n elements, then an average of $\log_2 n$ comparisons are required to find the correct position for the new element. For example, if the tree already contains 1,000 elements, adding a new element requires about 10 comparisons.

NOTE:

In order to use a tree set, you must be able to compare the elements. The elements must implement the `Comparable` interface, or you must supply a `Comparator` when constructing the set. (The `Comparable` and `Comparator` interfaces were introduced in Chapter 6.)

Table 9.3 Adding Elements into Hash and Tree Sets

Document	Total Number of Words	Number of Distinct Words	HashSet	TreeSet
Alice in Wonderland	28195	5909	5 sec	7 sec
The Count of Monte Cristo	466300	37545	75 sec	98 sec

If you look back at Table 9.3, you may well wonder if you should always use a tree set instead of a hash set. After all, adding elements does not seem to take much longer, and the elements are automatically sorted. The answer depends on the data that you are collecting. If you don't need the data sorted, there is no reason to pay for the sorting overhead. More important, with some data it is much more difficult to come up with a sort order than a hash function. A hash function only needs to do a reasonably good job of scrambling the objects, whereas a comparison function must tell objects apart with complete precision.

To make this distinction more concrete, consider the task of collecting a set of rectangles. If you use a `TreeSet`, you need to supply a `Comparator<Rectangle>`. How do you compare two rectangles? By area? That doesn't work. You can have two different rectangles with different coordinates but the same area. The sort order for a tree must be a *total ordering*. Any two elements must be comparable, and the comparison can only be zero if the elements are equal. There is such a sort order for rectangles (the lexicographic ordering on its coordinates), but it is unnatural and cumbersome to compute. In contrast, a hash function is already defined for the `Rectangle` class. It simply hashes the coordinates.

NOTE:

As of Java 6, the `TreeSet` class implements the `NavigableSet` interface. That interface adds several convenient methods for locating elements and for backward traversal. See the API notes for details.

The program in Listing 9.3 builds two tree sets of `Item` objects. The first one is sorted by part number, the default sort order of `Item` objects. The second set is sorted by description, using a custom comparator.

Listing 9.3 `treeSet/TreeSetTest.java`

```
package treeSet;

import java.util.*;

/**
 * This program sorts a set of Item objects by comparing their descriptions.
 * @version 1.13 2018-04-10
 * @author Cay Horstmann
 */
public class TreeSetTest
{
```

```java
    public static void main(String[] args)
    {
       var parts = new TreeSet<Item>();
       parts.add(new Item("Toaster", 1234));
       parts.add(new Item("Widget", 4562));
       parts.add(new Item("Modem", 9912));
       System.out.println(parts);

       var sortByDescription = new TreeSet<Item>
(Comparator.comparing(Item::getDescription));

       sortByDescription.addAll(parts);
       System.out.println(sortByDescription);
    }
}
```

Listing 9.4 `treeSet/Item.java`

```java
package treeSet;

import java.util.*;

/**
 * An item with a description and a part number.
 */
public class Item implements Comparable<Item>
{
   private String description;
   private int partNumber;

   /**
    * Constructs an item.
    * @param aDescription the item's description
    * @param aPartNumber the item's part number
    */
   public Item(String aDescription, int aPartNumber)
   {
      description = aDescription;
```

```
      partNumber = aPartNumber;
   }

   /**
    * Gets the description of this item.
    * @return the description
    */
   public String getDescription()
   {
      return description;
   }

   public String toString()
   {
      return "[description=" + description + ", partNumber=" + partNumber + "]";
   }

   public boolean equals(Object otherObject)
   {
      if (this == otherObject) return true;
      if (otherObject == null) return false;
      if (getClass() != otherObject.getClass()) return false;
      var other = (Item) otherObject;
      return Objects.equals(description, other.description) && partNumber == other.partNumber;
   }

   public int hashCode()
   {
      return Objects.hash(description, partNumber);
   }

   public int compareTo(Item other)
   {
      int diff = Integer.compare(partNumber, other.partNumber);
      return diff != 0 ? diff : description.compareTo(other.description);
```

```
    }
}
```

---

java.util.TreeSet<E> 1.2

- TreeSet()
- TreeSet(Comparator<? super E> comparator)

  constructs an empty tree set.

- TreeSet(Collection<? extends E> elements)
- TreeSet(SortedSet<E> s)

  constructs a tree set and adds all elements from a collection or sorted set (in the latter case, using the same ordering).

java.util.SortedSet<E> 1.2

- Comparator<? super E> comparator()

  returns the comparator used for sorting the elements, or null if the elements are compared with the compareTo method of the Comparable interface.

- E first()
- E last()

  returns the smallest or largest element in the sorted set.

java.util.NavigableSet<E> 6

- E higher(E value)

- `E lower(E value)`

  returns the least element > `value` or the largest element < `value`, or `null` if there is no such element.

- `E ceiling(E value)`
- `E floor(E value)`

  returns the least element ≢ `value` or the largest element ≤ `value`, or `null` if there is no such element.

- `E pollFirst()`
- `E pollLast()`

  removes and returns the smallest or largest element in this set, or `null` if the set is empty.

- `Iterator<E> descendingIterator()`

  returns an iterator that traverses this set in descending direction.

9.3.5 Queues and Deques

As we already discussed, a queue lets you efficiently add elements at the tail and remove elements from the head. A double-ended queue, or *deque*, lets you efficiently add or remove elements at the head and tail. Adding elements in the middle is not supported. Java 6 introduced a `Deque` interface. It is implemented by the `ArrayDeque` and `LinkedList` classes, both of which provide deques whose size grows as needed. In Chapter 12, you will see bounded queues and deques.

`java.util.Queue<E>` 5

- `boolean add(E element)`
- `boolean offer(E element)`

  adds the given element to the tail of this queue and returns `true`, provided the queue is not full. If the queue is full, the first method throws an `IllegalStateException`, whereas the second method returns `false`.

- `E remove()`
- `E poll()`

removes and returns the element at the head of this queue, provided the queue is not empty. If the queue is empty, the first method throws a `NoSuchElementException`, whereas the second method returns `null`.

- `E element()`
- `E peek()`

returns the element at the head of this queue without removing it, provided the queue is not empty. If the queue is empty, the first method throws a `NoSuchElementException`, whereas the second method returns `null`.

java.util.Deque<E> 6

- `void addFirst(E element)`
- `void addLast(E element)`
- `boolean offerFirst(E element)`
- `boolean offerLast(E element)`

adds the given element to the head or tail of this deque. If the deque is full, the first two methods throw an `IllegalStateException`, whereas the last two methods return `false`.

- `E removeFirst()`
- `E removeLast()`
- `E pollFirst()`
- `E pollLast()`

removes and returns the element at the head of this deque, provided the deque is not empty. If the deque is empty, the first two methods throw a `NoSuchElementException`, whereas the last two methods return `null`.

- `E getFirst()`
- `E getLast()`
- `E peekFirst()`
- `E peekLast()`

returns the element at the head of this deque without removing it, provided the deque is not empty. If the deque is empty, the first two methods throw a `NoSuchElementException`, whereas the last two methods return `null`.

`java.util.ArrayDeque<E>` 6

- `ArrayDeque()`
- `ArrayDeque(int initialCapacity)`

constructs an unbounded deque with an initial capacity of 16 or the given initial capacity.

9.3.6 Priority Queues

A priority queue retrieves elements in sorted order after they were inserted in arbitrary order. That is, whenever you call the `remove` method, you get the smallest element currently in the priority queue. However, the priority queue does not sort all its elements. If you iterate over the elements, they are not necessarily sorted. The priority queue makes use of an elegant and efficient data structure called a *heap*. A heap is a self-organizing binary tree in which the `add` and `remove` operations cause the smallest element to gravitate to the root, without wasting time on sorting all elements.

Just like a `TreeSet`, a priority queue can either hold elements of a class that implements the `Comparable` interface or a `Comparator` object you supply in the constructor.

A typical use for a priority queue is job scheduling. Each job has a priority. Jobs are added in random order. Whenever a new job can be started, the highest priority job is removed from the queue. (Since it is traditional for priority 1 to be the “highest” priority, the `remove` operation yields the minimum element.)

Listing 9.5 shows a priority queue in action. Unlike iteration in a `TreeSet`, the iteration here does not visit the elements in sorted order. However, removal always yields the smallest remaining element.

Listing 9.5 `priorityQueue/PriorityQueueTest.java`

```
package priorityQueue;

import java.util.*;
import java.time.*;

/**
 * This program demonstrates the use of a priority queue.
 * @version 1.02 2015-06-20
 * @author Cay Horstmann
 */
public class PriorityQueueTest
{
   public static void main(String[] args)
   {
      var pq = new PriorityQueue<LocalDate>();
      pq.add(LocalDate.of(1906, 12, 9)); // G. Hopper
      pq.add(LocalDate.of(1815, 12, 10)); // A. Lovelace
      pq.add(LocalDate.of(1903, 12, 3)); // J. von Neumann
      pq.add(LocalDate.of(1910, 6, 22)); // K. Zuse

      System.out.println("Iterating over elements . . .");
      for (LocalDate date : pq)
         System.out.println(date);
      System.out.println("Removing elements . . .");
```

```
      while (!pq.isEmpty())
         System.out.println(pq.remove());
   }
}
```

`java.util.PriorityQueue` 5

- `PriorityQueue()`
- `PriorityQueue(int initialCapacity)`

  constructs a priority queue for storing `Comparable` objects.

- `PriorityQueue(int initialCapacity, Comparator<? super E> c)`

  constructs a priority queue and uses the specified comparator for sorting its elements.

9.4 Maps

A set is a collection that lets you quickly find an existing element. However, to look up an element, you need to have an exact copy of the element to find. That isn't a very common lookup—usually, you have some key information, and you want to look up the associated element. The *map* data structure serves that purpose. A map stores key/value pairs. You can find a value if you provide the key. For example, you may store a table of employee records, where the keys are the employee IDs and the values are `Employee` objects. In the following sections, you will learn how to work with maps.

9.4.1 Basic Map Operations

The Java library supplies two general-purpose implementations for maps: `HashMap` and `TreeMap`. Both classes implement the `Map` interface.

A hash map hashes the keys, and a tree map uses an ordering on the keys to organize them in a search tree. The hash or comparison function is applied *only to the keys*. The values associated with the keys are not hashed or compared.

Should you choose a hash map or a tree map? As with sets, hashing is usually a bit faster, and it is the preferred choice if you don't need to visit the keys in sorted order.

Here is how you set up a hash map for storing employees:

```
var staff = new HashMap<String, Employee>(); // HashMap
implements Map
var harry = new Employee("Harry Hacker");
staff.put("987-98-9996", harry);
. . .
```

Whenever you add an object to a map, you must supply a key as well. In our case, the key is a string, and the corresponding value is an `Employee` object.

To retrieve an object, you must use (and, therefore, remember) the key.

```
var id = "987-98-9996";
Employee e = staff.get(id); // gets harry
```

If no information is stored in the map with the particular key specified, `get` returns `null`.

The `null` return value can be inconvenient. Sometimes, you have a good default that can be used for keys that are not present in the map. Then use the `getOrDefault` method.

```
Map<String, Integer> scores = . . .;
int score = scores.getOrDefault(id, 0); // gets 0 if the id is
not present
```

Keys must be unique. You cannot store two values with the same key. If you call the `put` method twice with the same key, the second value replaces the first one. In fact, `put` returns the previous value associated with its key parameter.

The `remove` method removes an element with a given key from the map. The `size` method returns the number of entries in the map.

The easiest way of iterating over the keys and values of a map is the `forEach` method. Provide a lambda expression that receives a key and a value. That expression is invoked for each map entry in turn.

```
scores.forEach((k, v) ->
   System.out.println("key=" + k + ", value=" + v));
```

Listing 9.6 illustrates a map at work. We first add key/value pairs to a map. Then, we remove one key from the map, which removes its associated value as well. Next, we change the value that is associated with a key and call the `get` method to look up a value. Finally, we iterate through the entry set.

Listing 9.6 `map/MapTest.java`

```
package map;

import java.util.*;

/**
 * This program demonstrates the use of a map with key type
String and value type Employee.
 * @version 1.12 2015-06-21
 * @author Cay Horstmann
 */
public class MapTest
{
   public static void main(String[] args)
   {
      var staff = new HashMap<String, Employee>();
      staff.put("144-25-5464", new Employee("Amy Lee"));
      staff.put("567-24-2546", new Employee("Harry Hacker"));
      staff.put("157-62-7935", new Employee("Gary Cooper"));
      staff.put("456-62-5527", new Employee("Francesca
```

```
Cruz"));

        // print all entries

        System.out.println(staff);

        // remove an entry

        staff.remove("567-24-2546");

        // replace an entry

        staff.put("456-62-5527", new Employee("Francesca
Miller"));

        // look up a value

        System.out.println(staff.get("157-62-7935"));

        // iterate through all entries

        staff.forEach((k, v) ->
           System.out.println("key=" + k + ", value=" + v));
     }
  }
```

java.util.Map<K, V> 1.2

- `V get(Object key)`

  gets the value associated with the key; returns the object associated with the key, or `null` if the key is not found in the map. Implementing classes may forbid `null` keys.

- `default V getOrDefault(Object key, V defaultValue)`

  gets the value associated with the key; returns the object associated with the key, or `defaultValue` if the key is not found in the map.

- V put(K key, V value)

  puts the association of a key and a value into the map. If the key is already present, the new object replaces the old one previously associated with the key. This method returns the old value of the key, or null if the key was not previously present. Implementing classes may forbid null keys or values.

- void putAll(Map<? extends K, ? extends V> entries)

  adds all entries from the specified map to this map.

- boolean containsKey(Object key)

  returns true if the key is present in the map.

- boolean containsValue(Object value)

  returns true if the value is present in the map.

- default void forEach(BiConsumer<? super K,? super V> action) 8

  applies the action to all key/value pairs of this map.

java.util.HashMap<K, V> 1.2

- HashMap()
- HashMap(int initialCapacity)
- HashMap(int initialCapacity, float loadFactor)

  constructs an empty hash map with the specified capacity and load factor (a number between 0.0 and 1.0 that determines at what percentage of fullness the hash table will be rehashed into a larger one). The default load factor is 0.75.

java.util.TreeMap<K,V> 1.2

- `TreeMap()`

  constructs an empty tree map for keys that implement the `Comparable` interface.

- `TreeMap(Comparator<? super K> c)`

  constructs a tree map and uses the specified comparator for sorting its keys.

- `TreeMap(Map<? extends K, ? extends V> entries)`

  constructs a tree map and adds all entries from a map.

- `TreeMap(SortedMap<? extends K, ? extends V> entries)`

  constructs a tree map, adds all entries from a sorted map, and uses the same element comparator as the given sorted map.

`java.util.SortedMap<K, V>` 1.2

- `Comparator<? super K> comparator()`

  returns the comparator used for sorting the keys, or `null` if the keys are compared with the `compareTo` method of the `Comparable` interface.

- `K firstKey()`
- `K lastKey()`

  returns the smallest or largest key in the map.

9.4.2 Updating Map Entries

A tricky part of dealing with maps is updating an entry. Normally, you get the old value associated with a key, update it, and put back the updated value. But you have to worry about the special case of the first occurrence of a key. Consider using a map for counting how often a word occurs in a file. When we see a word, we'd like to increment a counter like this:

```
counts.put(word, counts.get(word) + 1);
```

That works, except in the case when `word` is encountered for the first time. Then `get` returns `null`, and a `NullPointerException` occurs.

A simple remedy is to use the `getOrDefault` method:

```
counts.put(word, counts.getOrDefault(word, 0) + 1);
```

Another approach is to first call the `putIfAbsent` method. It only puts a value if the key was previously absent (or mapped to `null`).

```
counts.putIfAbsent(word, 0);
counts.put(word, counts.get(word) + 1); // now we know that get
will succeed
```

But you can do better than that. The `merge` method simplifies this common operation. The call

```
counts.merge(word, 1, Integer::sum);
```

associates `word` with `1` if the key wasn't previously present, and otherwise combines the previous value and `1`, using the `Integer::sum` function.

The API notes describe other methods for updating map entries that are less commonly used.

java.util.Map<K, V> 1.2

- `default V merge(K key, V value, BiFunction<? super V,? super V,? extends V> remappingFunction)` 8

  If `key` is associated with a non-`null` value `v`, applies the function to `v` and `value` and either associates `key` with the result or, if the result is null, removes the key. Otherwise, associates key with value. Returns get(key).

- default V compute(K key, BiFunction<? super K,? super V,? extends V> remappingFunction) 8

  Applies the function to key and get(key). Either associates key with the result or, if the result is null, removes the key. Returns get(key).

- default V computeIfPresent(K key, BiFunction<? super K,? super V,? extends V> remappingFunction) 8

  If key is associated with a non-null value v, applies the function to key and v and either associates key with the result or, if the result is null, removes the key. Returns get(key).

- default V computeIfAbsent(K key, Function<? super K,? extends V> mappingFunction) 8

  Applies the function to key unless key is associated with a non-null value. Either associates key with the result or, if the result is null, removes the key. Returns get(key).

- default void replaceAll(BiFunction<? super K,? super V,? extends V> function) 8

  Calls the function on all entries. Associates keys with non-null results and removes keys with null results.

- default V putIfAbsent(K key, V value) 8

  If key is absent or associated with null, associates it with value and returns null. Otherwise returns the associated value.

9.4.3 Map Views

The collections framework does not consider a map itself as a collection. (Other frameworks for data structures consider a map as a collection of key/value pairs, or as a collection of values indexed by the keys.) However, you can obtain *views* of the map—objects that implement the Collection interface or one of its subinterfaces.

There are three views: the set of keys, the collection of values (which is not a set), and the set of key/value pairs. The keys and key/value pairs form a set because there can be only one copy of a key in a map. The methods

```
Set<K> keySet()
Collection<V> values()
Set<Map.Entry<K, V>> entrySet()
```

return these three views. (The elements of the entry set are objects of a class implementing the `Map.Entry` interface.)

Note that the `keySet` is *not* a `HashSet` or `TreeSet`, but an object of some other class that implements the `Set` interface. The `Set` interface extends the `Collection` interface. Therefore, you can use a `keySet` as you would use any collection.

For example, you can enumerate all keys of a map:

```
Set<String> keys = map.keySet();
for (String key : keys)
{
do something with key
}
```

If you want to look at both keys and values, you can avoid value lookups by enumerating the *entries*. Use the following code skeleton:

```
for (Map.Entry<String, Employee> entry : staff.entrySet())
{
   String k = entry.getKey();
   Employee v = entry.getValue();
do something with k, v
}
```

TIP:

You can avoid the cumbersome `Map.Entry` by using a `var` declaration.

```
for (var entry : map.entrySet())
{
   do something with entry.getKey(), entry.getValue()
}
```

Or simply use the `forEach` method:

```
map.forEach((k, v) ->
   {
      do something with k, v
   });
```

If you invoke the `remove` method of the iterator on the key set view, you actually remove the key *and its associated value* from the map. However, you cannot *add* an element to the key set view. It makes no sense to add a key without also adding a value. If you try to invoke the `add` method, it throws an `UnsupportedOperationException`. The entry set view has the same restriction, even though it would make conceptual sense to add a new key/value pair.

`java.util.Map<K, V>` 1.2

- `Set<Map.Entry<K, V>> entrySet()`

  returns a set view of `Map.Entry` objects, the key/value pairs in the map. You can remove elements from this set and they are removed from the map, but you cannot add any elements.

- `Set<K> keySet()`

  returns a set view of all keys in the map. You can remove elements from this set and the keys and associated values are removed from the map, but you cannot add any elements.

- Collection<V> values()

returns a collection view of all values in the map. You can remove elements from this set and the removed value and its key are removed from the map, but you cannot add any elements.

java.util.Map.Entry<K, V> 1.2

- K getKey()
- V getValue()

returns the key or value of this entry.

- V setValue(V newValue)

changes the value *in the associated map* to the new value and returns the old value.

- static <K, V> Map.Entry<K,V> copyOf(Map.Entry<? extends K,? extends V> map) 17

yields a copy of the given map entry. Unlike the elements of a map's entry set, the copy is not "live." Calling setValue does not update any map.

9.4.4 Weak Hash Maps

The collection class library has several map classes for specialized needs that we briefly discuss in this and the following sections.

The WeakHashMap class was designed to solve an interesting problem. What happens with a value whose key is no longer used anywhere in your program? Suppose the last reference to a key has gone away. Then, there is no longer any way to refer to the value object. But, as no part of the program has the key any more, the key/value pair cannot be removed from the map.

Why can't the garbage collector remove it? Isn't it the job of the garbage collector to remove unused objects?

Unfortunately, it isn't quite so simple. The garbage collector traces *live* objects. As long as the map object is live, *all* buckets in it are live and won't be reclaimed. Thus, your program should take care to remove unused values from long-lived maps. Or, you can use a `WeakHashMap` instead. This data structure cooperates with the garbage collector to remove key/value pairs when the only reference to the key is the one from the hash table entry.

Here are the inner workings of this mechanism. The `WeakHashMap` uses *weak references* to hold keys. A `WeakReference` object holds a reference to another object—in our case, a hash table key. Objects of this type are treated in a special way by the garbage collector. Normally, if the garbage collector finds that a particular object has no references to it, it simply reclaims the object. However, if the object is reachable *only* by a `WeakReference`, the garbage collector still reclaims the object, but places the weak reference that led to it into a queue. The operations of the `WeakHashMap` periodically check that queue for newly arrived weak references. The arrival of a weak reference in the queue signifies that the key was no longer used by anyone and has been collected. The `WeakHashMap` then removes the associated entry.

9.4.5 Linked Hash Sets and Maps

The `LinkedHashSet` and `LinkedHashMap` classes remember in which order you inserted items. That way, you can avoid the seemingly random order of items in a hash table. As entries are inserted into the table, they are joined in a doubly linked list (see Figure 9.11).

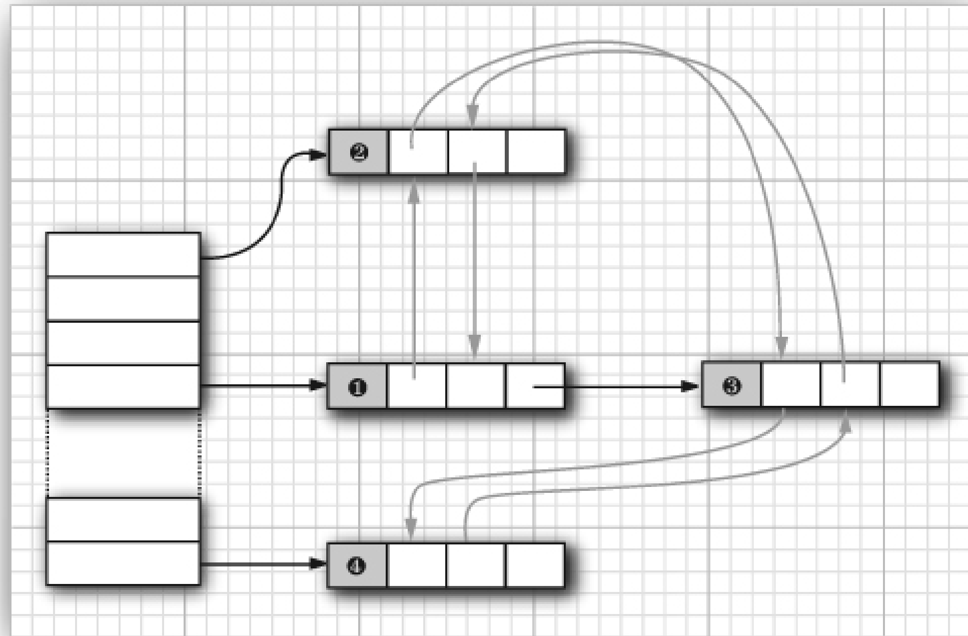


Figure 9.11 A linked hash table

For example, consider the following map insertions from Listing 9.6:

```
var staff = new LinkedHashMap<String, Employee>();
staff.put("144-25-5464", new Employee("Amy Lee"));
staff.put("567-24-2546", new Employee("Harry Hacker"));
staff.put("157-62-7935", new Employee("Gary Cooper"));
staff.put("456-62-5527", new Employee("Francesca Cruz"));
```

Then, `staff.keySet().iterator()` enumerates the keys in this order:

```
144-25-5464
567-24-2546
157-62-7935
456-62-5527
```

and `staff.values().iterator()` enumerates the values in this order:

```
Amy Lee
Harry Hacker Gary Cooper Francesca Cruz
```

A linked hash map can alternatively use *access order*, not insertion order, to iterate through the map entries. Every time you call `get` or `put`, the affected entry is removed from its current position and placed at the *end* of the linked list of entries. (Only the position in the linked list of entries is affected, not the hash table bucket. An entry always stays in the bucket that corresponds to the hash code of the key.) To construct such a hash map, call

```
LinkedHashMap<K, V>(initialCapacity, loadFactor, true)
```

Access order is useful for implementing a “least recently used” discipline for a cache. For example, you may want to keep frequently accessed entries in memory and read less frequently accessed objects from a database. When you don’t find an entry in the table, and the table is already pretty full, you can get an iterator into the table and remove the first few elements that it enumerates. Those entries were the least recently used ones.

You can even automate that process. Form a subclass of `LinkedHashMap` and override the method

```
protected boolean removeEldestEntry(Map.Entry<K, V> eldest)
```

Adding a new entry then causes the `eldest` entry to be removed whenever your method returns `true`. For example, the following cache is kept at a size of at most 100 elements:

```
var cache = new LinkedHashMap<K, V>(128, 0.75F, true)
   {      protected boolean removeEldestEntry(Map.Entry<K, V>
eldest)
      {
         return size() > 100;
      }
   };
```

Alternatively, you can consider the `eldest` entry to decide whether to remove it. For example, you may want to check a time stamp stored with the entry.

9.4.6 Enumeration Sets and Maps

The `EnumSet` is an efficient set implementation with elements that belong to an enumerated type. Since an enumerated type has a finite number of instances, the `EnumSet` is internally implemented simply as a sequence of bits. A bit is turned on if the corresponding value is present in the set.

The `EnumSet` class has no public constructors. Use a static factory method to construct the set:

```
enum Weekday { MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY,
SATURDAY, SUNDAY };
EnumSet<Weekday> always = EnumSet.allOf(Weekday.class);
EnumSet<Weekday> never = EnumSet.noneOf(Weekday.class);
EnumSet<Weekday> workday = EnumSet.range(Weekday.MONDAY,
Weekday.FRIDAY);
EnumSet<Weekday> mwf = EnumSet.of(Weekday.MONDAY,
Weekday.WEDNESDAY, Weekday.FRIDAY);
```

You can use the usual methods of the `Set` interface to modify an `EnumSet`.

An `EnumMap` is a map with keys that belong to an enumerated type. It is simply and efficiently implemented as an array of values. You need to specify the key type in the constructor:

```
var personInCharge = new EnumMap<Weekday, Employee>
(Weekday.class);
```

NOTE:

In the API documentation for `EnumSet`, you will see odd-looking type parameters of the form E extends Enum<E>. This simply means “`E` is an enumerated type." All enumerated types extend the generic `Enum` class. For example, `Weekday` extends `Enum<Weekday>`.

9.4.7 Identity Hash Maps

The `IdentityHashMap` has a quite specialized purpose. Here, the hash values for the keys should not be computed by the `hashCode` method but by the `System.identityHashCode` method. That's the method that `Object.hashCode` uses to compute a hash code from the object's memory address. Also, for comparison of objects, the `IdentityHashMap` uses `==`, not `equals`.

In other words, different key objects are considered distinct even if they have equal contents. This class is useful for implementing object traversal algorithms, such as object serialization, in which you want to keep track of which objects have already been traversed.

`java.util.WeakHashMap<K, V>` 1.2

- `WeakHashMap()`
- `WeakHashMap(int initialCapacity)`
- `WeakHashMap(int initialCapacity, float loadFactor)`

  constructs an empty hash map with the specified capacity and load factor.

`java.util.LinkedHashSet<E>` 1.4

- `LinkedHashSet()`
- `LinkedHashSet(int initialCapacity)`
- `LinkedHashSet(int initialCapacity, float loadFactor)`

constructs an empty linked hash set with the specified capacity and load factor.

java.util.LinkedHashMap<K, V> 1.4

- `LinkedHashMap()`
- `LinkedHashMap(int initialCapacity)`
- `LinkedHashMap(int initialCapacity, float loadFactor)`
- `LinkedHashMap(int initialCapacity, float loadFactor, boolean accessOrder)`

  constructs an empty linked hash map with the specified capacity, load factor, and ordering. The `accessOrder` parameter is `true` for access order, `false` for insertion order.

- `protected boolean removeEldestEntry(Map.Entry<K, V> eldest)`

  should be overridden to return `true` if you want the `eldest` entry to be removed. The `eldest` parameter is the entry whose removal is being contemplated. This method is called after an entry has been added to the map. The default implementation returns `false`—old elements are not removed by default. However, you can redefine this method to selectively return `true`—for example, if the eldest entry fits a certain condition or if the map exceeds a certain size.

java.util.EnumSet<E extends Enum<E>> 5

- `static <E extends Enum<E>> EnumSet<E> allOf(Class<E> enumType)`

  returns a mutable set that contains all values of the given enumerated type.

- `static <E extends Enum<E>> EnumSet<E> noneOf(Class<E> enumType)`

  returns a mutable set that is initially empty.

- `static <E extends Enum<E>> EnumSet<E> range(E from, E to)`

  returns a mutable set that contains all values between `from` and `to` (inclusive).

- `static <E extends Enum<E>> EnumSet<E> of(E e)`

  . . .

- `static <E extends Enum<E>> EnumSet<E> of(E e1, E e2, E e3, E e4, E e5)`
- `static <E extends Enum<E>> EnumSet<E> of(E first, E... rest)`

  returns a mutable set containing the given elements which must not be `null`.

- `public static <E extends Enum<E>> EnumSet<E> copyOf(EnumSet<E> s)`

  `public static <E extends Enum<E>> EnumSet<E> copyOf(Collection<E> c)`

  creates a mutable set initially containing the given elements. In the second method, `c` must either be an `EnumSet` or be nonempty (in order to determine the element type).

java.util.EnumMap<K extends Enum<K>, V> 5

- `EnumMap(Class<K> keyType)`

  constructs an empty mutable map whose keys have the given type.

java.util.IdentityHashMap<K, V> 1.4

- `IdentityHashMap()`
- `IdentityHashMap(int expectedMaxSize)`

  constructs an empty identity hash map whose capacity is the smallest power of 2 exceeding 1.5 × `expectedMaxSize`. (The default for `expectedMaxSize` is `21`.)

`java.lang.System` 1.0

- `static int identityHashCode(Object obj)` 1.1

  returns the same hash code (derived from the object's memory address) that `Object.hashCode` computes, even if the class to which `obj` belongs has redefined the `hashCode` method.

9.5 Copies and Views

If you look at Figures 9.4 and 9.5, you might think it is overkill to have lots of interfaces and abstract classes to implement a modest number of concrete collection classes. However, these figures don't tell the whole story. By using *views*, you can obtain other objects that implement the `Collection` or `Map` inter-faces. You saw one example of this with the `keySet` method of the map classes. At first glance, it appears as if the method creates a new set, fills it with all the keys of the map, and returns it. However, that is not the case. Instead, the `keySet` method returns an object of a class that implements the `Set` interface and whose methods manipulate the original map. Such a collection is called a *view*.

The technique of views has a number of useful applications in the collections framework. We will discuss these applications in the following sections.

9.5.1 Small Collections

Java 9 introduces static methods yielding a set or list with given elements, and a map with given key/value pairs.

For example,

```
List<String> names = List.of("Peter", "Paul", "Mary");
Set<Integer> numbers = Set.of(2, 3, 5);
```

yield a list and a set with three elements. For a map, you specify the keys and values, like this:

```
Map<String, Integer> scores = Map.of("Peter", 2, "Paul", 3,
"Mary", 5);
```

The elements, keys, or values may not be `null`. Set and map keys may not be duplicated:

```
numbers = Set.of(13, null); // Error—null element
scores = Map.of("Peter", 4, "Peter", 2); // Error—duplicate key
```

CAUTION:

No guarantee is made about the iteration order of these sets and maps. In fact, the order is deliberately scrambled with a seed that is randomized at each virtual machine startup. Look at these two `jshell` runs:

```
$ jshell -q
jshell> Set.of("Peter", "Paul", "Mary")
$1 ==> [Peter, Mary, Paul]
jshell> /exit
$ jshell -q
jshell> Set.of("Peter", "Paul", "Mary")
$1 ==> [Paul, Mary, Peter]
```

Some Java programmers write programs whose correctness depends on the assumption that implementation details will never change. That can make it very difficult for the library implementors to make useful implementation changes. In this case, the message is clear—don't write programs that assume anything about the element order.

The `List` and `Set` interfaces have eleven `of` methods with zero to ten arguments, and an `of` method with a variable number of arguments. The specializations are provided for efficiency.

For the `Map` interface, it is not possible to provide a version with variable arguments since the argument types alternate between the key and value types. There is a static method `ofEntries` that accepts an arbitrary number of `Map.Entry<K, V>` objects, which you can create with the static `entry` method. For example,

```
import static java.util.Map.*;
. . .
Map<String, Integer> scores = ofEntries(
   entry("Peter", 2),
   entry("Paul", 3),
   entry("Mary", 5));
```

The `of` and `ofEntries` methods produce objects of classes that have an instance variable for each element, or that are backed by an array.

These collection objects are *unmodifiable*. Any attempt to change their contents results in an `UnsupportedOperationException`.

If you want a mutable collection, you can pass the unmodifiable collection to the constructor:

```
var names = new ArrayList<>(List.of("Peter", "Paul", "Mary"));
// A mutable list of names
```

The method call

```
Collections.nCopies(n, anObject)
```

returns an immutable object that implements the `List` interface and gives the illusion of having `n` elements, each of which appears as `anObject`.

For example, the following call creates a `List` containing 100 strings, all set to `"DEFAULT"`:

```
List<String> settings = Collections.nCopies(100, "DEFAULT");
```

There is very little storage cost—the object is stored only once.

NOTE:

The `of` methods were introduced in Java 9. Previously, there was a static `Arrays.asList` method that returns a list that is mutable but not resizable. That is, you can call `set` but not `add` or `remove` on the list. There are also legacy methods `Collections.emptySet` and `Collections.singleton`.

NOTE:

The `Collections` class contains a number of utility methods with parameters or return values that are collections. Do not confuse it with the `Collection` interface.

TIP:

Java doesn't have a `Pair` class, and some programmers use a `Map.Entry` as a poor man's pair. Before Java 9, this was painful—you had to construct a `new AbstractMap.SimpleImmutableEntry<>(first, second)`. Nowadays, you can call `Map.entry(first, second)`.

9.5.2 Unmodifiable Copies and Views

To make an *unmodifiable copy* of a collection, use the `copyOf` method of the collection type:

```
ArrayList<String> names = . . .;
Set<String> nameSet = Set.copyOf(names); // The names as an
unmodifiable set
List<String> nameList = List.copyOf(names); // The names as an
unmodifiable list
```

Each `copyOf` method makes a copy of the collection. If the original collection is modified, the copy is not affected.

If the original collection happens to be unmodifiable and of the correct type, then `copyOf` simply returns it:

```
Set<String> names = Set.of("Peter", "Paul", "Mary");
Set<String> nameSet = Set.copyOf(names); // No need to make a
copy: names == nameSet
```

The `Collections` class has methods that produce *unmodifiable views* of collections. These views add a runtime check to an existing collection. If an attempt to modify the unmodifiable collection is detected, an exception is thrown.

However, if the original collection changes, the view reflects those changes. That is what makes views different from copies.

You obtain unmodifiable views by eight methods:

```
Collections.unmodifiableCollection
Collections.unmodifiableList Collections.unmodifiableSet
Collections.unmodifiableSortedSet
Collections.unmodifiableNavigableSet
Collections.unmodifiableMap Collections.unmodifiableSortedMap
Collections.unmodifiableNavigableMap
```

Each method is defined to work on an interface. For example, `Collections.unmodifiableList` works with an `ArrayList`, a `LinkedList`, or any other class that implements the `List` interface.

For example, suppose you want to let some part of your code look at, but not touch, the contents of a collection. Here is what you could do:

```
var staff = new LinkedList<String>();
 . . .
lookAt(Collections.unmodifiableList(staff));
```

The `Collections.unmodifiableList` method returns an object of a class implementing the `List` interface. Its accessor methods retrieve values from the `staff` collection. Of course, the `lookAt` method can call all methods of the `List` interface, not just the accessors. But all mutator methods (such as `add`) have been redefined to throw an `UnsupportedOperationException` instead of forwarding the call to the underlying collection.

The unmodifiable view does not make the collection itself immutable. You can still modify the collection through its original reference (`staff`, in our case). And you can still call mutator methods on the elements of the collection.

The views wrap the *interface* and not the actual collection object, so you only have access to those methods that are defined in the interface. For example, the `LinkedList` class has convenience methods, `addFirst` and `addLast`, that are not part of the `List` interface. These methods are not accessible through the unmodifiable view.

CAUTION:

The `unmodifiableCollection` method (as well as the `synchronizedCollection` and `checkedCollection` methods discussed later in this section) returns a collection whose `equals` method does *not* invoke the `equals` method of the underlying collection. Instead, it inherits the `equals` method of the `Object` class, which just tests whether the objects are identical. If you turn a set or list into just a collection, you can no longer test for equal contents. The view acts in this way because equality testing is not well defined at this level of the hierarchy. The views treat the `hashCode` method in the same way.

However, the `unmodifiableSet` and `unmodifiableList` methods use the `equals` and `hashCode` methods of the underlying collections.

9.5.3 Subranges

You can form subrange views for a number of collections. For example, suppose you have a list `staff` and want to extract elements 10 to 19. Use the `subList` method to obtain a view into the subrange of the list:

```
List<Employee> group2 = staff.subList(10, 20);
```

The first index is inclusive, the second exclusive—just like the parameters for the `substring` operation of the `String` class.

You can apply any operations to the subrange, and they automatically reflect the entire list. For example, you can erase the entire subrange:

```
group2.clear(); // staff reduction
```

The elements get automatically cleared from the `staff` list, and `group2` becomes empty.

For sorted sets and maps, you use the sort order, not the element position, to form subranges. The `SortedSet` interface declares three methods:

```
SortedSet<E> subSet(E from, E to)
SortedSet<E> headSet(E to)
SortedSet<E> tailSet(E from)
```

These return the subsets of all elements that are larger than or equal to `from` and strictly smaller than `to`. For sorted maps, the similar methods

```
SortedMap<K, V> subMap(K from, K to)
SortedMap<K, V> headMap(K to)
SortedMap<K, V> tailMap(K from)
```

return views into the maps consisting of all entries in which the *keys* fall into the specified ranges.

The `NavigableSet` interface introduced in Java 6 gives more control over these subrange operations. You can specify whether the bounds are included:

```
NavigableSet<E> subSet(E from, boolean fromInclusive, E to,
boolean toInclusive)
NavigableSet<E> headSet(E to, boolean toInclusive)
NavigableSet<E> tailSet(E from, boolean fromInclusive)
```

9.5.4 Checked Views

Checked views are intended as debugging support for a problem that can occur with generic types. As explained in Chapter 8, it is actually possible to smuggle elements of the wrong type into a generic collection. For example:

```
var strings = new ArrayList<String>();
ArrayList rawList = strings; // warning only, not an error,
                             // for compatibility with legacy
code
rawList.add(new Date()); // now strings contains a Date object!
```

The erroneous `add` command is not detected at runtime. Instead, a class cast exception will happen later when another part of the code calls `get` and casts the result to a `String`.

A checked view can detect this problem. Define a safe list as follows:

```
List<String> safeStrings = Collections.checkedList(strings,
String.class);
```

The view's `add` method checks that the inserted object belongs to the given class and immediately throws a `ClassCastException` if it does not. The advantage is that the error is reported at the correct location:

```
ArrayList rawList = safeStrings;
rawList.add(new Date()); // checked list throws a
ClassCastException
```

CAUTION:

The checked views are limited by the runtime checks that the virtual machine can carry out. For example, if you have an `ArrayList<Pair<String>>`, you cannot protect it from inserting a `Pair<Date>` since the virtual machine has a single "raw" `Pair` class.

9.5.5 Synchronized Views

If you access a collection from multiple threads, you need to ensure that the collection is not accidentally damaged. For example, it would be disastrous if one thread tried to add to a hash table while another thread was rehashing the elements.

Instead of implementing thread-safe collection classes, the library designers used the view mechanism to make regular collections thread-safe. For example, the static `synchronizedMap` method in the `Collections` class can turn any map into a `Map` with synchronized access methods:

```
var map = Collections.synchronizedMap(new HashMap<String,
Employee>());
```

You can now access the `map` object from multiple threads. The methods such as `get` and `put` are synchronized—each method call must be finished completely before another thread can call another method. We discuss the issue of synchronized access to data structures in greater detail in Chapter 12.

9.5.6 A Note on Optional Operations

A view usually has some restriction—it may be read-only, it may not be able to change the size, or it may support removal but not insertion (as is the case for the key view of a map). A restricted view throws an `UnsupportedOperationException` if you attempt an inappropriate operation.

In the API documentation for the collection and iterator interfaces, many methods are described as "optional operations." This seems to be in conflict with the notion of an interface. After all, isn't the purpose of an interface to lay out the methods that a class *must* implement? Indeed, this arrangement is unsatisfactory from a theoretical perspective. A better solution might have been to design separate interfaces for read-only views and views that can't change the size of a collection. However, that would have tripled the number of interfaces, which the designers of the library found unacceptable.

Should you extend the technique of "optional" methods to your own designs? I think not. Even though collections are used frequently, the coding style for implementing them is not typical for other problem domains. The designers of a collection class library have to resolve a particularly brutal set of conflicting requirements. Users want the library to be easy to learn, convenient to use, completely generic, idiot-proof, and at the same time as efficient as hand-coded algorithms. It is plainly impossible to achieve all these goals simultaneously, or even to come close. But in your own programming problems, you will rarely encounter such an extreme set of constraints. You should be able to find solutions that do not rely on the extreme measure of "optional" interface operations.

`java.util.List` 1.2

- static <E> List<E> of() 9
- static <E> List<E> of(E e1) 9

  . . .

- static <E> List<E> of(E e1, E e2, E e3, E e4, E e5, E e6, E e7, E e8, E e9, E e10) 9
- static <E> List<E> of(E... elements) 9

  yields an unmodifiable list of the given elements, which must not be null.

- static <E> List<E> copyOf(Collection<? extends E> coll) 10

  yields an unmodifiable copy of the given collection.

java.util.Set 1.2

- static <E> Set<E> of() 9
- static <E> Set<E> of(E e1) 9

  . . .

- static <E> Set<E> of(E e1, E e2, E e3, E e4, E e5, E e6, E e7, E e8, E e9, E e10) 9
- static <E> Set<E> of(E... elements) 9

  yields an unmodifiable set of the given elements, which must not be null.

- static <E> Set<E> copyOf(Collection<? extends E> coll) 10

  yields an unmodifiable copy of the given collection.

java.util.Map 1.2

- static <K, V> Map<K, V> of() 9

- static <K, V> Map<K, V> of(K k1, V v1) 9

  . . .

- static <K,V> Map<K,V> of(K k1, V v1, K k2, V v2, K k3, V v3, K k4, V v4, K k5, V v5, K k6, V v6, K k7, V v7, K k8, V v8, K k9, V v9, K k10, V v10) 9

  yields an unmodifiable map of the given keys and values, which must not be null.

- static <K,V> Map.Entry<K,V> entry(K k, V v) 9

  yields an unmodifiable map entry of the given key and value, which must not be null.

- static <K,V> Map<K,V> ofEntries(Map.Entry<? extends K,? extends V>... entries) 9

  yields an unmodifiable map of the given entries.

- static <K, V> Map<K,V> copyOf(Map<? extends K,? extends V> map) 10

  yields an unmodifiable copy of the given map.

java.util.Collections 1.2

- static <E> Collection unmodifiableCollection(Collection<E> c)
- static <E> List unmodifiableList(List<E> c)
- static <E> Set unmodifiableSet(Set<E> c)
- static <E> SortedSet unmodifiableSortedSet(SortedSet<E> c)
- static <E> SortedSet unmodifiableNavigableSet(NavigableSet<E> c) 8
- static <K, V> Map unmodifiableMap(Map<K, V> c)
- static <K, V> SortedMap unmodifiableSortedMap(SortedMap<K, V> c)

- static <K, V> SortedMap unmodifiableNavigableMap(NavigableMap<K, V> c) 8

  constructs a view of the collection; the view’s mutator methods throw an UnsupportedOperationException.

- static <E> Collection<E> synchronizedCollection(Collection<E> c)
- static <E> List synchronizedList(List<E> c)
- static <E> Set synchronizedSet(Set<E> c)
- static <E> SortedSet synchronizedSortedSet(SortedSet<E> c)
- static <E> NavigableSet synchronizedNavigableSet(NavigableSet<E> c) 8
- static <K, V> Map<K, V> synchronizedMap(Map<K, V> c)
- static <K, V> SortedMap<K, V> synchronizedSortedMap(SortedMap<K, V> c)
- static <K, V> NavigableMap<K, V> synchronizedNavigableMap(NavigableMap<K, V> c) 8

  constructs a view of the collection; the view’s methods are synchronized.

- static <E> Collection checkedCollection(Collection<E> c, Class<E> elementType)
- static <E> List checkedList(List<E> c, Class<E> elementType)
- static <E> Set checkedSet(Set<E> c, Class<E> elementType)
- static <E> SortedSet checkedSortedSet(SortedSet<E> c, Class<E> elementType)
- static <E> NavigableSet checkedNavigableSet(NavigableSet<E> c, Class<E> elementType) 8
- static <K, V> Map checkedMap(Map<K, V> c, Class<K> keyType, Class<V> valueType)
- static <K, V> SortedMap checkedSortedMap(SortedMap<K, V> c, Class<K> keyType, Class<V> valueType)

- static <K, V> NavigableMap checkedNavigableMap(NavigableMap<K, V> c, Class<K> keyType, Class<V> valueType) 8
- static <E> Queue<E> checkedQueue(Queue<E> queue, Class<E> elementType) 8

  constructs a view of the collection; the view's methods throw a ClassCastException if an element of the wrong type is inserted.

- static <E> List<E> nCopies(int n, E value)

  yields an unmodifiable list with n identical values.

- static <E> List<E> singletonList(E value)
- static <E> Set<E> singleton(E value)
- static <K, V> Map<K, V> singletonMap(K key, V value)

  yields a singleton list, set, or map. As of Java 9, use one of the of methods instead.

- static <E> List<E> emptyList()
- static <T> Set<T> emptySet()
- static <E> SortedSet<E> emptySortedSet()
- static NavigableSet<E> emptyNavigableSet()
- static <K,V> Map<K,V> emptyMap()
- static <K,V> SortedMap<K,V> emptySortedMap()
- static <K,V> NavigableMap<K,V> emptyNavigableMap()
- static <T> Enumeration<T> emptyEnumeration()
- static <T> Iterator<T> emptyIterator()
- static <T> ListIterator<T> emptyListIterator()

  yields an empty collection, map, or iterator.

java.util.Arrays 1.2

- `static <E> List<E> asList(E... array)`

  returns a list view of the elements in an array that is modifiable but not resizable.

`java.util.List<E>` 1.2

- `List<E> subList(int firstIncluded, int firstExcluded)`

  returns a list view of the elements within a range of positions.

`java.util.SortedSet<E>` 1.2

- `SortedSet<E> subSet(E firstIncluded, E firstExcluded)`
- `SortedSet<E> headSet(E firstExcluded)`
- `SortedSet<E> tailSet(E firstIncluded)`

  returns a view of the elements within a range.

`java.util.NavigableSet<E>` 6

- `NavigableSet<E> subSet(E from, boolean fromIncluded, E to, boolean toIncluded)`
- `NavigableSet<E> headSet(E to, boolean toIncluded)`
- `NavigableSet<E> tailSet(E from, boolean fromIncluded)`

  returns a view of the elements within a range. The `boolean` flags determine whether the bounds are included in the view.

java.util.SortedMap<K, V> 1.2

- `SortedMap<K, V> subMap(K firstIncluded, K firstExcluded)`
- `SortedMap<K, V> headMap(K firstExcluded)`
- `SortedMap<K, V> tailMap(K firstIncluded)`

  returns a map view of the entries whose keys are within a range.

java.util.NavigableMap<K, V> 6

- `NavigableMap<K, V> subMap(K from, boolean fromIncluded, K to, boolean toIncluded)`
- `NavigableMap<K, V> headMap(K from, boolean fromIncluded)`
- `NavigableMap<K, V> tailMap(K to, boolean toIncluded)`

  returns a map view of the entries whose keys are within a range. The `boolean` flags determine whether the bounds are included in the view.

9.6 Algorithms

In addition to implementing collection classes, the Java collections framework also provides a number of useful algorithms. In the following sections, you will see how to use these algorithms and how to write your own algorithms that work well with the collections framework.

9.6.1 Why Generic Algorithms?

Generic collection interfaces have a great advantage—you only need to implement your algorithms once. For example, consider a simple algorithm to compute the maximum element in a collection. Traditionally, programmers would implement such an algorithm as a loop. Here is how you can find the largest element of an array.

```
if (a.length == 0) throw new NoSuchElementException();
T largest = a[0];for (int i = 1; i < a.length; i++)
   if (largest.compareTo(a[i]) < 0)
   largest = a[i];
```

Of course, to find the maximum of an array list, you would write the code slightly differently.

```
if (v.size() == 0) throw new NoSuchElementException();
T largest = v.get(0);
for (int i = 1; i < v.size(); i++)
   if (largest.compareTo(v.get(i)) < 0)
      largest = v.get(i);
```

What about a linked list? You don't have efficient random access in a linked list, but you can use an iterator.

```
if (l.isEmpty()) throw new NoSuchElementException();
Iterator<T> iter = l.iterator();
T largest = iter.next();
while (iter.hasNext())
{
   T next = iter.next();
   if (largest.compareTo(next) < 0)
      largest = next;
}
```

These loops are tedious to write, and just a bit error-prone. Is there an offby-one error? Do the loops work correctly for empty containers? For containers with only one element? You don't want to test and debug this code every time, but you also don't want to implement a whole slew of methods, such as these:

```
static <T extends Comparable> T max(T[] a)
static <T extends Comparable> T max(ArrayList<T> v)
static <T extends Comparable> T max(LinkedList<T> l)
```

That's where the collection interfaces come in. Think of the *minimal* collection interface that you need to efficiently carry out the algorithm. Random access with `get` and `set` comes higher in the food chain than simple iteration. As you have seen in the computation of the maximum element in a linked list, random access is not required for this task. Computing the maximum can be done simply by iterating through the elements. Therefore, you can implement the `max` method to take *any* object that implements the `Collection` interface.

```
public static <T extends Comparable> T max(Collection<T> c)
{
   if (c.isEmpty()) throw new NoSuchElementException();
   Iterator<T> iter = c.iterator();
   T largest = iter.next();   while (iter.hasNext())
   {
      T next = iter.next();
      if (largest.compareTo(next) < 0)
         largest = next;
   }
   return largest;
}
```

Now you can compute the maximum of a linked list, an array list, or an array, with a single method.

That's a powerful concept. In fact, the standard C++ library has dozens of useful algorithms, each operating on a generic collection. The Java library is not quite so rich, but it does contain the basics: sorting, binary search, and some utility algorithms.

9.6.2 Sorting and Shuffling

Computer old-timers will sometimes reminisce about how they had to use punched cards and to actually program, by hand, algorithms for sorting. Nowadays, of course, sorting algorithms are part of the standard library for most programming languages, and the Java programming language is no exception.

The `sort` method in the `Collections` class sorts a collection that implements the `List` interface.

```
var staff = new LinkedList<String>();
fill collection Collections.sort(staff);
```

This method assumes that the list elements implement the `Comparable` interface. If you want to sort the list in some other way, you can use the `sort` method of the `List` interface and pass a `Comparator` object. Here is how you can sort a list of employees by salary:

```
staff.sort(Comparator.comparingDouble(Employee::getSalary));
```

If you want to sort a list in *descending* order, use the static convenience method `Comparator.reverseOrder()`. It returns a comparator that returns `b.compareTo(a)`. For example,

```
staff.sort(Comparator.reverseOrder())
```

sorts the elements in the list `staff` in reverse order, according to the ordering given by the `compareTo` method of the element type. Similarly,

```
staff.sort(Comparator.comparingDouble(Employee::getSalary).reve
rsed())
```

sorts by descending salary.

You may wonder how the `sort` method sorts a list. Typically, when you look at a sorting algorithm in a book on algorithms, it is presented for arrays and uses random element access. However, random access in a linked list is inefficient. You can actually sort linked lists efficiently by using a form of merge sort. However, the implementation in the Java programming language does not do that. It simply dumps all elements into an array, sorts the array, and then copies the sorted sequence back into the list.

The sort algorithm used in the collections library is a bit slower than QuickSort, the traditional choice for a general-purpose sorting algorithm. However, it has one major advantage: It is *stable*, that is, it doesn't switch equal elements. Why do you care about the order of equal elements? Here is a common scenario. Suppose you have an employee list that you already sorted by name. Now you sort by salary. What happens to employees with equal salary? With a stable sort, the ordering by name is preserved. In other words, the outcome is a list that is sorted first by salary, then by name.

Collections need not implement all of their "optional" methods, so all methods that receive collection parameters must describe when it is safe to pass a collection to an algorithm. For example, you clearly cannot pass an `unmodifiableList` list to the `sort` algorithm. What kind of list *can* you pass? According to the documentation, the list must be modifiable but need not be resizable.

The terms are defined as follows:

- A list is *modifiable* if it supports the `set` method.
- A list is *resizable* if it supports the `add` and `remove` operations.

The `Collections` class has an algorithm `shuffle` that does the opposite of sorting—it randomly permutes the order of the elements in a list. For example:

```
ArrayList<Card> cards = . . .;
Collections.shuffle(cards);
```

If you supply a list that does not implement the `RandomAccess` interface, the `shuffle` method copies the elements into an array, shuffles the array, and copies the shuffled elements back into the list.

The program in Listing 9.7 fills an array list with 49 `Integer` objects containing the numbers 1 through 49. It then randomly shuffles the list and selects the first six values from the shuffled list. Finally, it sorts the selected values and prints them.

Listing 9.7 shuffle/ShuffleTest.java

```
package shuffle;

import java.util.*;

/**
 * This program demonstrates the random shuffle and sort algorithms.
 * @version 1.12 2018-04-10
 * @author Cay Horstmann
 */
public class ShuffleTest
{
   public static void main(String[] args)
   {
      var numbers = new ArrayList<Integer>();
      for (int i = 1; i <= 49; i++)
         numbers.add(i);
      Collections.shuffle(numbers);
      List<Integer> winningCombination = numbers.subList(0, 6);
      Collections.sort(winningCombination);
      System.out.println(winningCombination);
   }
}
```

java.util.Collections 1.2

- static <T extends Comparable<? super T>> void sort(List<T> elements)

  sorts the elements in the list, using a stable sort algorithm. The algorithm is guaranteed to run in O(n log n) time, where n is the length of the list.

- static void shuffle(List<?> elements)

- `static void shuffle(List<?> elements, Random r)`

  randomly shuffles the elements in the list. This algorithm runs in O(n $a(n)$) time, where n is the length of the list and $a(n)$ is the average time to access an element.

java.util.List<E> 1.2

- `default void sort(Comparator<? super T> comparator)` 8

  sorts this list, using the given comparator.

java.util.Comparator<T> 1.2

- `static <T extends Comparable<? super T>> Comparator<T> reverseOrder()` 8

  yields a comparator that reverses the ordering provided by the `Comparable` interface.

- `default Comparator<T> reversed()` 8

  yields a comparator that reverses the ordering provided by this comparator.

9.6.3 Binary Search

To find an object in an array, you normally visit all elements until you find a match. However, if the array is sorted, you can look at the middle element and check whether it is larger than the element that you are trying to find. If so, keep looking in the first half of the array; otherwise, look in the second half. That cuts the problem in half, and you keep going in the same way. For example, if the array has 1024 elements, you will locate the match (or confirm that there is none) after 10 steps, whereas a linear search would have taken you an average of 512 steps if the element is present, and 1024 steps to confirm that it is not.

The `binarySearch` of the `Collections` class implements this algorithm. Note that the collection must already be sorted, or the algorithm will return the wrong answer. To find an element, supply the collection (which must implement the `List` interface—more on that in the note below) and the element to be located. If the collection is not sorted by the `compareTo` element of the `Comparable` interface, supply a comparator object as well.

```
i = Collections.binarySearch(c, element);
i = Collections.binarySearch(c, element, comparator);
```

A non-negative return value from the `binarySearch` method denotes the index of the matching object. That is, `c.get(i)` is equal to `element` under the comparison order. If the value is negative, then there is no matching element. However, you can use the return value to compute the location where you *should* insert `element` into the collection to keep it sorted. The insertion location is

```
insertionPoint = -i - 1;
```

It isn't simply `-i` because then the value of `0` would be ambiguous. In other words, the operation

```
if (i < 0)
   c.add(-i - 1, element);
```

adds the element in the correct place.

To be worthwhile, binary search requires random access. If you have to iterate one by one through half of a linked list to find the middle element, you have lost all advantage of the binary search. Therefore, the `binarySearch` algorithm reverts to a linear search if you give it a linked list.

java.util.Collections 1.2

- static <T extends Comparable<? super T>> int binarySearch(List<T> elements, T key)
- static <T> int binarySearch(List<T> elements, T key, Comparator<? super T> c)

  searches for a key in a sorted list, using a binary search if the element type implements the `RandomAccess` interface, and a linear search in all other cases. The methods are guaranteed to run in O(a(n) log n) time, where n is the length of the list and a(n) is the average time to access an element. The methods return either the index of the key in the list, or a negative value `i` if the key is not present in the list. In that case, the key should be inserted at index `-i - 1` for the list to stay sorted.

9.6.4 Simple Algorithms

The `Collections` class contains several simple but useful algorithms. Among them is the example from the beginning of this section—finding the maximum value of a collection. Others include copying elements from one list to another, filling a container with a constant value, and reversing a list.

Why supply such simple algorithms in the standard library? Surely most programmers could easily implement them with simple loops. I like the algorithms because they make life easier for the programmer *reading* the code. When you read a loop that was implemented by someone else, you have to decipher the original programmer's intentions. For example, look at this loop:

```
for (int i = 0; i < words.size(); i++)
   if (words.get(i).equals("C++")) words.set(i, "Java");
```

Now compare the loop with the call

```
Collections.replaceAll(words, "C++", "Java");
```

When you see the method call, you know right away what the code does.

The API notes at the end of this section describe the simple algorithms in the Collections class.

The default methods Collection.removeIf and List.replaceAll that are just a bit more complex. You provide a lambda expression to test or transform elements. For example, here we remove all short words and change the remaining ones to lowercase:

```
words.removeIf(w -> w.length() <= 3);
words.replaceAll(String::toLowerCase);
```

java.util.Collections 1.2

- static <T extends Comparable<? super T>> T min(Collection<T> elements)
- static <T extends Comparable<? super T>> T max(Collection<T> elements)
- static <T> min(Collection<T> elements, Comparator<? super T> c)
- static <T> max(Collection<T> elements, Comparator<? super T> c)

  returns the smallest or largest element in the collection. (The parameter bounds are simplified for clarity.)

- static <T> void copy(List<? super T> to, List<T> from)

  copies all elements from a source list to the same positions in the target list. The target list must be at least as long as the source list.

- static <T> void fill(List<? super T> l, T value)

  sets all positions of a list to the same value.

- static <T> boolean addAll(Collection<? super T> c, T... values) 5

  adds all values to the given collection and returns true if the collection changed as a result.

- static <T> boolean replaceAll(List<T> l, T oldValue, T newValue) 1.4

  replaces all elements equal to oldValue with newValue.

- static int indexOfSubList(List<?> l, List<?> s) 1.4
- static int lastIndexOfSubList(List<?> l, List<?> s) 1.4

  returns the index of the first or last sublist of l equaling s, or -1 if no sublist of l equals s. For example, if l is [s, t, a, r] and s is [t, a, r], then both methods return the index 1.

- static void swap(List<?> l, int i, int j) 1.4

  swaps the elements at the given offsets.

- static void reverse(List<?> l)

  reverses the order of the elements in a list. For example, reversing the list [t, a, r] yields the list [r, a, t]. This method runs in O(*n*) time, where *n* is the length of the list.

- static void rotate(List<?> l, int d) 1.4

  rotates the elements in the list, moving the entry with index i to position (i + d) % l.size(). For example, rotating the list [t, a, r] by 2 yields the list [a, r, t]. This method runs in O(*n*) time, where *n* is the length of the list.

- static int frequency(Collection<?> c, Object o) 5

  returns the count of elements in c that equal the object o.

- boolean disjoint(Collection<?> c1, Collection<?> c2) 5

  returns true if the collections have no elements in common.

java.util.Collection<T> 1.2

- `default boolean removeIf(Predicate<? super E> filter)` 8

  removes all matching elements.

java.util.List<E> 1.2

- `default void replaceAll(UnaryOperator<E> op)` 8

  applies the operation to all elements of this list.

9.6.5 Bulk Operations

There are several operations that copy or remove elements "in bulk." The call

```
coll1.removeAll(coll2);
```

removes all elements from `coll1` that are present in `coll2`. Conversely,

```
coll1.retainAll(coll2);
```

removes all elements from `coll1` that are *not* present in `coll2`. Here is a typical application.

Suppose you want to find the *intersection* of two sets—the elements that two sets have in common. First, make a new set to hold the result.

```
var result = new HashSet<String>(firstSet);
```

Here, we use the fact that every collection has a constructor whose parameter is another collection that holds the initialization values.

Now, use the `retainAll` method:

```
result.retainAll(secondSet);
```

It retains all elements that occur in both sets. You have formed the intersection without programming a loop.

You can carry this idea further and apply a bulk operation to a *view*. For example, suppose you have a map that maps employee IDs to employee objects and you have a set of the IDs of all employees that are to be terminated.

```
Map<String, Employee> staffMap = . . .;
Set<String> terminatedIDs = . . .;
```

Simply form the key set and remove all IDs of terminated employees.

```
staffMap.keySet().removeAll(terminatedIDs);
```

Since the key set is a view into the map, the keys and associated employee names are automatically removed from the map.

By using a subrange view, you can restrict bulk operations to sublists and subsets. For example, suppose you want to add the first ten elements of a list to another container. Form a sublist to pick out the first ten:

```
relocated.addAll(staff.subList(0, 10));
```

The subrange can also be a target of a mutating operation.

```
staff.subList(0, 10).clear();
```

9.6.6 Converting between Collections and Arrays

Large portions of the Java platform API were designed before the collections framework was created. As a result, you will occasionally need to translate between traditional arrays and the more modern collections.

If you have an array that you need to turn into a collection, the `List.of` method serves this purpose. For example:

```
String[] names = . . .;
List<String> staff = List.of(names);
```

Obtaining an array from a collection is a bit trickier. You can use the `toArray` method:

```
Object[] names = staff.toArray();
```

But the result is an array of *objects*. Even if you know that your collection contained objects of a specific type, you cannot use a cast:

```
String[] names = (String[]) staff.toArray(); // ERROR
```

The array returned by the `toArray` method was created as an `Object[]` array, and you cannot change its type. Instead, pass an array constructor expression to the `toArray` method. The returned array is then created *as the correct array type*:

```
>String[] values = staff.toArray(String[]::new);
```

NOTE:

Prior to JDK 11, you had to use another form of the `toArray` method, passing an array of the correct type:

```
String[] values = staff.toArray(new String[0]);
```

This `toArray` method constructs another array of the same type. Or, if the array has sufficient length, it is reused:

```
staff.toArray(new String[staff.size()]);
```

In this case, no new array is created.

9.6.7 Writing Your Own Algorithms

If you write your own algorithm (or, in fact, any method that has a collection as a parameter), you should work with *interfaces*, not concrete implementations, whenever possible. For example, suppose you want to process items. Of course, you can implement a method like this:

```
public void processItems(ArrayList<Item> items)
{
   for (Item item : items)
do something with item
}
```

However, you now constrained the caller of your method—the caller must supply the items in an `ArrayList`. If the items happen to be in another collection, they first need to be repackaged. It is much better to accept a more general collection.

You should ask yourself this: What is the most general collection interface that can do the job? Do you care about the order? Then you should accept a `List`. But if the order doesn't matter, you can accept collections of any kind:

```
public void processItems(Collection<Item> items)
{
   for (Item item : items)
do something with item
}
```

Now, anyone can call this method with an `ArrayList` or a `LinkedList`, or even with an array wrapped in a call to the `List.of` method.

TIP:

In this case, you can do even better by accepting an Iterable<Item>. The Iterable interface has a single abstract method iterator which the enhanced for loop uses behind the scenes. The Collection interface extends Iterable.

Conversely, if your method returns multiple elements, you don't want to constrain yourself against future improvements. For example, consider

```
public ArrayList<Item> lookupItems(. . .)
{
   var result = new ArrayList<Item>();
   . . .
   return result;
}
```

This method promises to return an ArrayList, even though the caller almost certainly doesn't care what kind of lists it is. If instead you return a List, you can at any time add a branch that returns an empty or singleton list by calling

List.of.

NOTE:

If it is such a good idea to use collection interfaces as parameter and return type, why doesn't the Java library follow this rule consistently? For example, the JComboBox class has two constructors:

```
JComboBox(Object[] items)
JComboBox(Vector<?> items)
```

The reason is simply timing. The Swing library was created before the collections library.

9.7 Legacy Collections

A number of "legacy" container classes have been present since the first release of Java, before there was a collections framework.

They have been integrated into the collections framework—see Figure 9.12. I will briefly introduce them in the following sections.

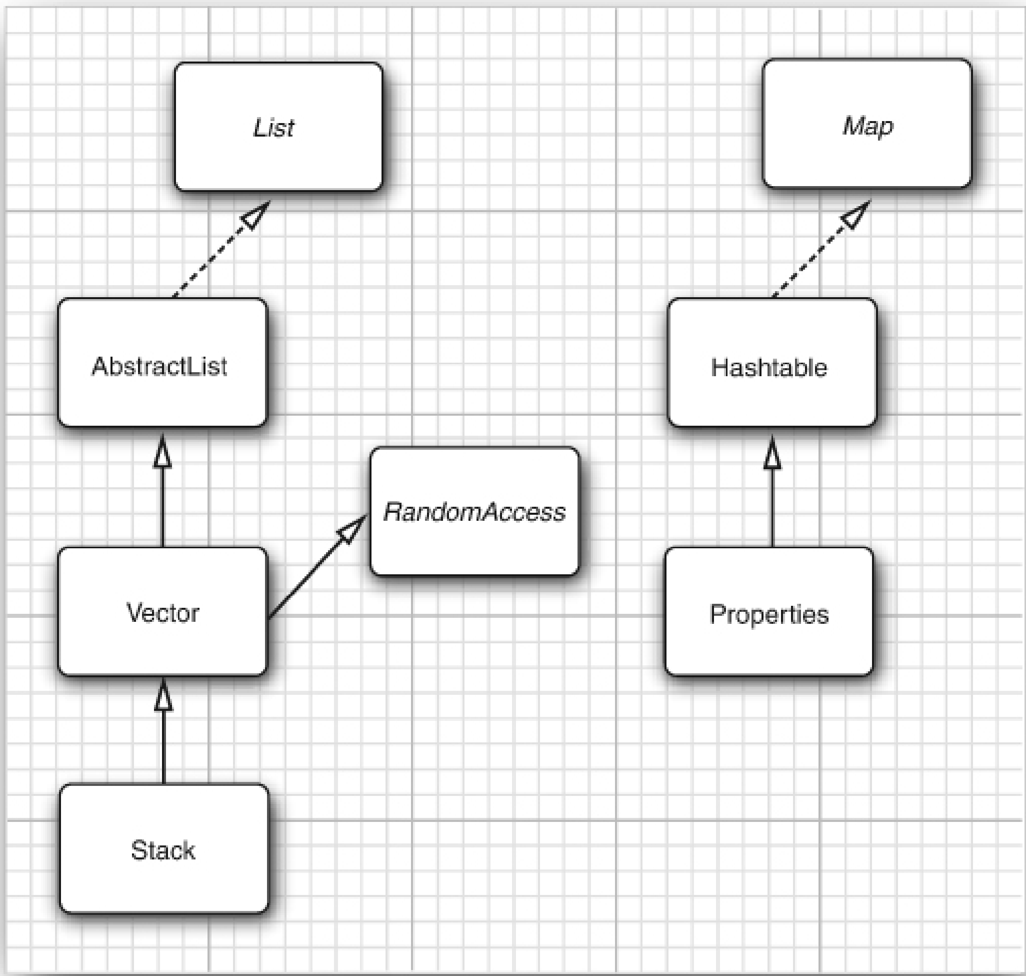


Figure 9.12 Legacy classes in the collections framework

9.7.1 The `Hashtable` Class

The classic `Hashtable` class serves the same purpose as the `HashMap` class and has essentially the same interface. Just like methods of the `Vector` class, the `Hashtable` methods are synchronized. If you do not require compatibility with legacy code, you should use a `HashMap` instead. If you need concurrent access, use a `ConcurrentHashMap`—see Chapter 12.

9.7.2 Enumerations

The legacy collections use the `Enumeration` interface for traversing sequences of elements. The `Enumeration` interface has two methods, `hasMoreElements` and `nextElement`. These are entirely analogous to the `hasNext` and `next` methods of the `Iterator` interface.

If you find this interface with legacy classes, you can use `Collections.list` to collect the elements in an `ArrayList`. For example, the `LogManager` class is only willing to reveal logger names as an `Enumeration`. Here is how you can get them all:

```
ArrayList<String> loggerNames =
Collections.list(LogManager.getLoggerNames());
```

Alternatively, as of Java 9, you can turn an enumeration into an iterator:

```
LogManager.getLoggerNames().asIterator().forEachRemaining(n ->
{ . . . });
```

You will occasionally encounter a legacy method that expects an enumeration parameter. The static method `Collections.enumeration` yields an enumeration object that enumerates the elements in the collection. For example:

```
List<InputStream> streams = . . .;
var in = new
SequenceInputStream(Collections.enumeration(streams));
   // the SequenceInputStream constructor expects an
enumeration
```

NOTE:

In C++, it is quite common to use iterators as parameters. Fortunately, on the Java platform, very few programmers use this idiom. It is much smarter to pass around the collection than to pass an iterator. The collection object is more useful. The recipients can always obtain the iterator from the collection when they need to do so, plus they have all the collection methods at their disposal. However, you will find enumerations in some legacy code because they were the only available mechanism for generic collections until the collections framework appeared in Java 1.2.

---

java.util.Enumeration<E> 1.0

- boolean hasMoreElements()

  returns true if there are more elements yet to be inspected.

- E nextElement()

  returns the next element to be inspected. Do not call this method if hasMoreElements() returned false.

- default Iterator<E> asIterator() 9

  yields an iterator that iterates over the enumerated elements.

java.util.Collections 1.2

- static <T> Enumeration<T> enumeration(Collection<T> c)

  returns an enumeration that enumerates the elements of c.

- public static <T> ArrayList<T> list(Enumeration<T> e)

  returns an array list containing the elements enumerated by e.

9.7.3 Property Maps

A *property map* is a map structure of a special type. It has three particular characteristics:

- The keys and values are strings.
- The map can easily be saved to a file and loaded from a file.
- There is a secondary table for default values.

The Java platform class that implements a property map is called `Properties`. Property maps are useful in specifying configuration options for programs. For example:

```
var settings = new Properties();
settings.setProperty("width", "600.0");
settings.setProperty("filename",
"/home/cay/books/cj12/code/v1ch09/raven.html");
```

Use the `store` method to save map list of properties to a file. Here, we just save the property map in the file `program.properties`. The second argument is a comment that is included in the file.

```
var out = new FileWriter("program.properties",
StandardCharsets.UTF_8);
settings.store(out, "Program Properties");
```

The sample set gives the following output:

```
#Program Properties
#Sun Dec 31 12:54:19 PST 2017
top=227.0
left=1286.0
width=423.0
height=547.0
filename=/home/cay/books/cj12/code/v1ch09/raven.html
```

To load the properties from a file, use

```
var in = new FileReader("program.properties",
StandardCharsets.UTF_8);
settings.load(in);
```

CAUTION:

If you use the `load` and `store` methods with input/output streams, then the archaic jISO 8859–1 character encoding is used, and characters > U+00FF are saved as Unicode escapes. For UTF-8, use readers/writers, as in the code snippets above.

The `System.getProperties` method yields a `Properties` object to describe system information. For example, the home directory has the key `"user.home"`. You can read it with the `getProperties` method that yields the key as a string:

```
String userDir = System.getProperty("user.home");
```

CAUTION:

For historical reasons, the `Properties` class implements Map<Object, Object>. Therefore, you can use the `get` and `put` methods of the `Map` interface. But the `get` method returns the type `Object`, and the `put` method allows you to insert any object. It is best to stick with the `getProperty` and `setProperty` methods that work with strings, not objects.

To get the Java version of the virtual machine, look up the `"java.version"` property. You get a string such as `"17.0.1"` (but `"1.8.0"` up to Java 8.)

TIP:

As you can see, the version numbering changed in Java 9. This seemingly small change broke a good number of tools that had relied on the old format. If you parse the version string, be sure to read JEP 322 at http://openjdk.java.net/jeps/322 to see how version strings will be formatted in the future—or at least, until the numbering scheme changes again.

The `Properties` class has two mechanisms for providing defaults. First, whenever you look up the value of a string, you can specify a default that should be used automatically when the key is not present.

```
String filename = settings.getProperty("filename", "");
```

If there is a `"filename"` property in the property map, `filename` is set to that string. Otherwise, `filename` is set to the empty string.

If you find it too tedious to specify the default in every call to `getProperty`, you can pack all the defaults into a secondary property map and supply that map in the constructor of your primary property map.

```
var defaultSettings = new Properties();
defaultSettings.setProperty("width", "600");
defaultSettings.setProperty("height", "400");
defaultSettings.setProperty("filename", "");
. . .
var settings = new Properties(defaultSettings);
```

Yes, you can even specify defaults to defaults if you give another property map parameter to the `defaultSettings` constructor, but it is not something one would normally do.

The companion code has a sample program that shows how you can use properties for storing and loading program state. The program uses the `ImageViewer` program from Chapter 2 and remembers the frame position, size, and last loaded file. Run the program, load a file, and move and resize the window. Then close the program and reopen it to see that it remembers your file and your favorite window placement. You can also manually edit the file `.corejava/ImageViewer.properties` in your home directory.

Properties are simple tables without a hierarchical structure. It is common to introduce a fake hierarchy with key names such as `window.main.color`, `window.main.title`, and so on. But the `Properties` class has no methods that help organize such a hierarchy. If you store complex configuration information, you should use the `Preferences` class instead—see Chapter 10.

`java.util.Properties` 1.0

- `Properties()`

  creates an empty property map.

- `Properties(Properties defaults)`

  creates an empty property map with a map of defaults.

- `String getProperty(String key)`

  gets a property. Returns the string associated with the key, or the string associated with the key in the default table if it wasn't present in the table, or `null` if the key wasn't present in the default table either.

- `String getProperty(String key, String defaultValue)`

  gets a property with a default value if the key is not found. Returns the string associated with the key, or the default string if it wasn't present in the table.

- `Object setProperty(String key, String value)`

  sets a property. Returns the previously set value of the given key.

- `Set<String> stringPropertyNames()` 6

returns a set of all keys, including the keys from the default map.

- `void load(Reader in) throws IOException` 6

  loads a property map from a reader.

- `void store(Writer out, String header)` 6

  saves a property map to a writer. The header is in the first line of the stored file.

`java.lang.System` 1.0

- `Properties getProperties()`

  retrieves all system properties. The application must have permission to retrieve all properties, or a security exception is thrown.

- `String getProperty(String key)`

  retrieves the system property with the given key name. The application must have permission to retrieve the property, or a security exception is thrown. The following properties can always be retrieved:

```
java.version
java.vendor
java.vendor.url
java.home
java.class.path
java.library.path
java.class.version
os.name
os.version
os.arch
file.separator
path.separator
line.separator
java.io.tempdir
user.name
```

```
user.home
user.dir
java.compiler
java.specification.version
java.specification.vendor
java.specification.name
java.vm.specification.version
java.vm.specification.vendor
java.vm.specification.name
java.vm.version
java.vm.vendor
java.vm.name
```

9.7.4 Stacks

Since version 1.0, the standard library had a `Stack` class with the familiar `push` and `pop` methods. However, the `Stack` class extends the `Vector` class, which is not satisfactory from a theoretical perspective—you can apply such un-stack-like operations as `insert` and `remove` to insert and remove values anywhere, not just at the top of the stack.

`java.util.Stack<E>` 1.0

- `E push(E item)`

  pushes `item` onto the stack and returns `item`.

- `E pop()`

  pops and returns the top item of the stack. Don't call this method if the stack is empty.

- `E peek()`

  returns the top of the stack without popping it. Don't call this method if the stack is empty.

9.7.5 Bit Sets

The Java platform's `BitSet` class stores a sequence of bits. (It is not a *set* in the mathematical sense—bit *vector* or bit *array* would have been more appropriate terms.) Use a bit set if you need to store a sequence of bits (for example, flags) efficiently. A bit set packs the bits into bytes, so it is far more efficient to use a bit set than an `ArrayList` of `Boolean` objects.

The `BitSet` class gives you a convenient interface for reading, setting, and resetting individual bits. Using this interface avoids the masking and other bitfiddling operations that are necessary if you store bits in `int` or `long` variables.

For example, for a `BitSet` named `bucketOfBits`,

```
bucketOfBits.get(i)
```

returns `true` if the `i`th bit is on, and `false` otherwise. Similarly,

```
bucketOfBits.set(i)
```

turns the `i`th bit on. Finally,

```
bucketOfBits.clear(i)
```

turns the `i`th bit off.

C++ NOTE:

The C++ `bitset` template has the same functionality as the Java platform `BitSet`.

`java.util.BitSet` 1.0

- `BitSet(int initialCapacity)`

  constructs a bit set.

- `int cardinality()` 1.4

  returns the number of bits that are set, or, when considered as a set of integers, the number of elements.

- `int length()` 1.2

  returns the "logical length" (1 plus the index of the highest set bit). This is useful for iterating over the elements.

- `int size()`

  returns the number of bits currently available in the internal data structure, *not* the number of set elements.

- `boolean get(int bit)`

  gets a bit.

- `void set(int bit)`

  sets a bit.

- `void clear(int bit)`

  clears a bit.

- `void and(BitSet set)`

  logically ANDs this bit set with another.

- `void or(BitSet set)`

  logically ORs this bit set with another.

- `void xor(BitSet set)`

  logically XORs this bit set with another.

- `void andNot(BitSet set)`

  clears all bits in this bit set that are set in the other bit set.

- `IntStream stream()` 8

  yields a stream of the index values of the bits that are set, or, when considered as a set of integers, a stream of the elements.

As an example of using bit sets, I want to show you an implementation of the “sieve of Eratosthenes” algorithm for finding prime numbers. (A prime number is a number like 2, 3, or 5 that is divisible only by itself and 1, and the sieve of Eratosthenes was one of the first methods discovered to enumerate these fundamental building blocks.) This isn’t a terribly good algorithm for finding the primes, but for some reason it has become a popular benchmark for compiler performance. (It isn’t a good benchmark either, because it mainly tests bit operations.)

Oh well, I bow to tradition and present an implementation. This program counts all prime numbers between 2 and 2,000,000. (There are 148,933 primes in this interval, so you probably don’t want to print them all out.)

Without going into too many details of this program, the idea is to march through a bit set with 2 million bits. First, we turn on all the bits. After that, we turn off the bits that are multiples of numbers known to be prime. The positions of the bits that remain after this process are themselves prime numbers. Listing 9.8 lists this program in the Java programming language, and Listing 9.9 is the C++ code.

NOTE:

Even though the sieve isn’t a good benchmark, I couldn’t resist timing the two implementations of the algorithm. Here are the timing results with an Intel i5–8265U processor and 16 GB of RAM, running Ubuntu 20.04:

- C++ (g++ 9.3.0): 115 milliseconds
- Java (Java 17): 31 milliseconds

I have run this test for eleven editions of *Core Java*, and in the last seven editions, Java easily beat C++. In all fairness, if one cranks up the optimization level in the C++ compiler, it beats Java with a time of 14 milliseconds. Java could only match that if the program ran long enough to trigger the Hotspot just-in-time compiler.

Listing 9.8 `sieve/Sieve.java`

```
package sieve;

import java.util.*;

/**
 * This program runs the Sieve of Erathostenes benchmark. It computes all primes
 * up to 2,000,000.
 * @version 1.22 2021-06-17
 * @author Cay Horstmann
 */
public class Sieve
{
   public static void main(String[] s)
   {
      int n = 2000000;
      long start = System.currentTimeMillis();
      var bitSet = new BitSet(n + 1);
      int i;
      for (i = 2; i <= n; i++)
         bitSet.set(i);
      i = 2;
      while (i * i <= n)
      {
         if (bitSet.get(i))
         {
            int k = i * i;
            while (k <= n)
            {
               bitSet.clear(k);
               k += i;
            }
```

```
        }
        i++;
      }
      long end = System.currentTimeMillis();
      System.out.println(bitSet.cardinality() + " primes");
      System.out.println((end - start) + " milliseconds");
   }
}
```

Listing 9.9 `sieve/sieve.cpp`

```
/**
 * @version 1.22 2021-06-17
 * @author Cay Horstmann
 */

#include <bitset>
#include <iostream>
#include <ctime>

using namespace std;

int main()
{
   const int N = 2000000;
   clock_t cstart = clock();

   bitset<N + 1> b;
   int i;
   for (i = 2; i <= N; i++)
      b.set(i);
   i = 2;
   while (i * i <= N)
   {
      if (b.test(i))
      {
         int k = i * i;
         while (k <= N)
```

```
         {
            b.reset(k);
            k += i;
         }
      }
      i++;
   }

   clock_t cend = clock();
   double millis = 1000.0 * (cend - cstart) / CLOCKS_PER_SEC;

   cout << b.count() << " primes\n" << millis << " milliseconds\n";

   return 0;
}
```

This completes our tour through the Java collections framework. As you have seen, the Java library offers a wide variety of collection classes for your programming needs. In the next chapter, you will learn how to write graphical user interfaces.

Chapter 10. Graphical User Interface Programming

In this chapter

Java was born at a time when most computer users interacted with desktop applications that have a graphical user interface (GUI). Nowadays, browser-based and mobile applications are far more common, but there are still times when it is useful to provide a desktop application. Moreover, many teachers and students enjoy learning Java through GUI applications. In this and the following chapter, I discuss the basics of user interface programming with the Swing toolkit. If, on the other hand, you are not interested in writing GUI programs, you can safely skip these two chapters.

10.1 A History of Java User Interface Toolkits

When Java 1.0 was introduced, it contained a class library, called the Abstract Window Toolkit (AWT), for basic GUI programming. The basic AWT library deals with user interface elements by delegating their creation and behavior to the native GUI toolkit on each target platform (Windows, Linux, Macintosh, and so on). For example, if you used the original AWT to put a text box on a Java window, an underlying "peer" text box actually handled the text input. The resulting program could then, in theory, run on any of these platforms, with the "look-and-feel" of the target platform.

The peer-based approach worked well for simple applications, but it soon became apparent that it was fiendishly difficult to write a high-quality portable graphics library depending on native user interface elements. User interface elements such as menus, scrollbars, and text fields can have subtle differences in behavior on different platforms. It was hard, therefore, to give users a consistent and predictable experience with this approach. Moreover, some graphical environments (such as X11/Motif) do not have as rich a collection of user interface components as does Windows or the Macintosh. This further limits a portable library based on a "lowest common denominator" approach. As a result, GUI applications built with the AWT simply did not look as nice as native Windows or Macintosh applications, nor did they have the kind of functionality that users of those platforms had come to expect. More depress-ingly, there were *different* bugs in the AWT user interface library on the different platforms. Developers complained that they had to test their applications on each platform—a practice derisively called "write once, debug everywhere."

In 1996, Netscape created a GUI library they called the IFC (Internet Foundation Classes) that used an entirely different approach. User interface elements, such as buttons, menus, and so on, were *painted* onto blank windows. The only functionality required from the underlying windowing system was a way to put up a window and to paint on it. Thus, Netscape's IFC widgets looked and behaved the same no matter which platform the program ran on. Sun Microsystems worked with Netscape to perfect this approach, creating a user interface library with the code name "Swing." Swing was available as an extension to Java 1.1 and became a part of the standard library in Java 1.2.

Swing is now the official name for the non-peer-based GUI toolkit.

NOTE:

Swing is not a complete replacement for the AWT—it is built on top of the AWT architecture. Swing simply gives you more capable user interface components. Whenever you write a Swing program, you use the foundations of the AWT—in particular, event handling. From now on, I will say

“Swing” when I mean the “painted” user interface classes, and “AWT” when I refer to the underlying mechanisms of the windowing toolkit, such as event handling.

Swing has to work hard painting every pixel of the user interface. When Swing was first released, users complained that it was slow. (You can still get a feel for the problem if you run Swing applications on hardware such as a Raspberry Pi.) After a while, desktop computers got faster, and users complained that Swing was ugly—indeed, it had fallen behind the native widgets that had been spruced up with animations and fancy effects. More ominously, Adobe Flash was increasingly used to create user interfaces with even flashier effects that didn’t use the native controls at all.

In 2007, Sun Microsystems introduced an entirely different user interface toolkit, called JavaFX, as a competitor to Flash. It ran on the Java VM but had its own programming language, called JavaFX Script. The language was optimized for programming animations and fancy effects. Programmers complained about the need to learn a new language, and they stayed away in droves. In 2011, Oracle released a new version, JavaFX 2.0, that had a Java API and no longer needed a separate programming language. Starting with Java 7 update 6, JavaFX has been bundled with the JDK and JRE. However, as this book is being written, Oracle has declared that JavaFX will no longer be bundled with Java, starting with version 11.

Since this is a book about the core Java language and APIs, I will focus on Swing for user interface programming.

10.2 Displaying Frames

A top-level window (that is, a window that is not contained inside another window) is called a *frame* in Java. The AWT library has a class, called `Frame`, for this top level. The Swing version of this class is called `JFrame` and extends the `Frame` class. The `JFrame` is one of the few Swing components that is not painted on a canvas. Thus, the decorations (buttons, title bar, icons, and so on) are drawn by the user’s windowing system, not by Swing.

CAUTION:

Most Swing component classes start with a "J": `JButton`, `JFrame`, and so on. There are classes such as `Button` and `Frame`, but they are AWT components. If you accidentally omit a "J", your program may still compile and run, but the mixture of Swing and AWT components can lead to visual and behavioral inconsistencies.

10.2.1 Creating a Frame

In this section, we will go over the most common methods for working with a Swing `JFrame`. Listing 10.1 lists a simple program that displays an empty frame on the screen, as illustrated in Figure 10.1.

Figure 10.1 The simplest visible frame

Listing 10.1 `simpleFrame/SimpleFrameTest.java`

```
package simpleFrame;

import java.awt.*;
import javax.swing.*;

/**
```

```
 * @version 1.34 2018-04-10
 * @author Cay Horstmann
 */
public class SimpleFrameTest
{
   public static void main(String[] args)
   {
      EventQueue.invokeLater(() ->
         {
            var frame = new SimpleFrame();
            frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
            frame.setVisible(true);
         });
   }
}

class SimpleFrame extends JFrame
{
   private static final int DEFAULT_WIDTH = 300;
   private static final int DEFAULT_HEIGHT = 200;

   public SimpleFrame()
   {
      setSize(DEFAULT_WIDTH, DEFAULT_HEIGHT);
   }
}
```

Let’s work through this program, line by line.

The Swing classes are placed in the `javax.swing` package. The package name `java`*x* indicates a Java extension package, not a core package. For historical reasons, Swing is considered an extension. However, it is present in every Java implementation since version 1.2.

By default, a frame has a rather useless size of 0 × 0 pixels. We define a subclass `SimpleFrame` whose constructor sets the size to 300 × 200 pixels. This is the only difference between a `SimpleFrame` and a `JFrame`.

In the `main` method of the `SimpleFrameTest` class, we construct a `SimpleFrame` object and make it visible.

There are two technical issues that we need to address in every Swing program.

First, all Swing components must be configured from the *event dispatch thread*, the thread of control that passes events such as mouse clicks and keystrokes to the user interface components. The following code fragment is used to execute statements in the event dispatch thread:

```
EventQueue.invokeLater(() ->
{
   statements
});
```

NOTE:

You will see many Swing programs that do not initialize the user interface in the event dispatch thread. It used to be perfectly acceptable to carry out the initialization in the main thread. Sadly, as Swing components got more complex, the developers of the JDK were no longer able to guarantee the safety of that approach. The probability of an error is extremely low, but you would not want to be one of the unlucky few who encounter an intermittent problem. It is better to do the right thing, even if the code looks rather mysterious.

Next, we define what should happen when the user closes the application's frame. For this particular program, we want the program to exit. To select this behavior, we use the statement

```
frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
```

In other programs with multiple frames, you would not want the program to exit just because the user closed one of the frames. By default, a frame is hidden when the user closes it, but the program does not terminate. (It might have been nice if the program terminated once the *last* frame becomes invisible, but that is not how Swing works.)

Simply constructing a frame does not automatically display it. Frames start their life invisible. That gives the programmer the chance to add components into the frame before showing it for the first time. To show the frame, the `main` method calls the `setVisible` method of the frame.

After scheduling the initialization statements, the `main` method exits. Note that exiting `main` does not terminate the program—just the main thread. The event dispatch thread keeps the program alive until it is terminated, either by closing the frame or by calling the `System.exit` method.

The running program is shown in Figure 10.1—it is a truly boring top-level window. As you can see in the figure, the title bar and the surrounding decorations, such as resize corners, are drawn by the operating system and not the Swing library. The Swing library draws everything inside the frame. In this program, it just fills the frame with a default background color.

10.2.2 Frame Properties

The `JFrame` class itself has only a few methods for changing how frames look. Of course, through the magic of inheritance, most of the methods for working with the size and position of a frame come from the various superclasses of `JFrame`. Here are some of the most important methods:

- The `setLocation` and `setBounds` methods for setting the position of the frame
- The `setIconImage` method, which tells the windowing system which icon to display in the title bar, task switcher window, and so on
- The `setTitle` method for changing the text in the title bar
- The `setResizable` method, which takes a `boolean` to determine if a frame will be resizeable by the user

Figure 10.2 illustrates the inheritance hierarchy for the `JFrame` class.

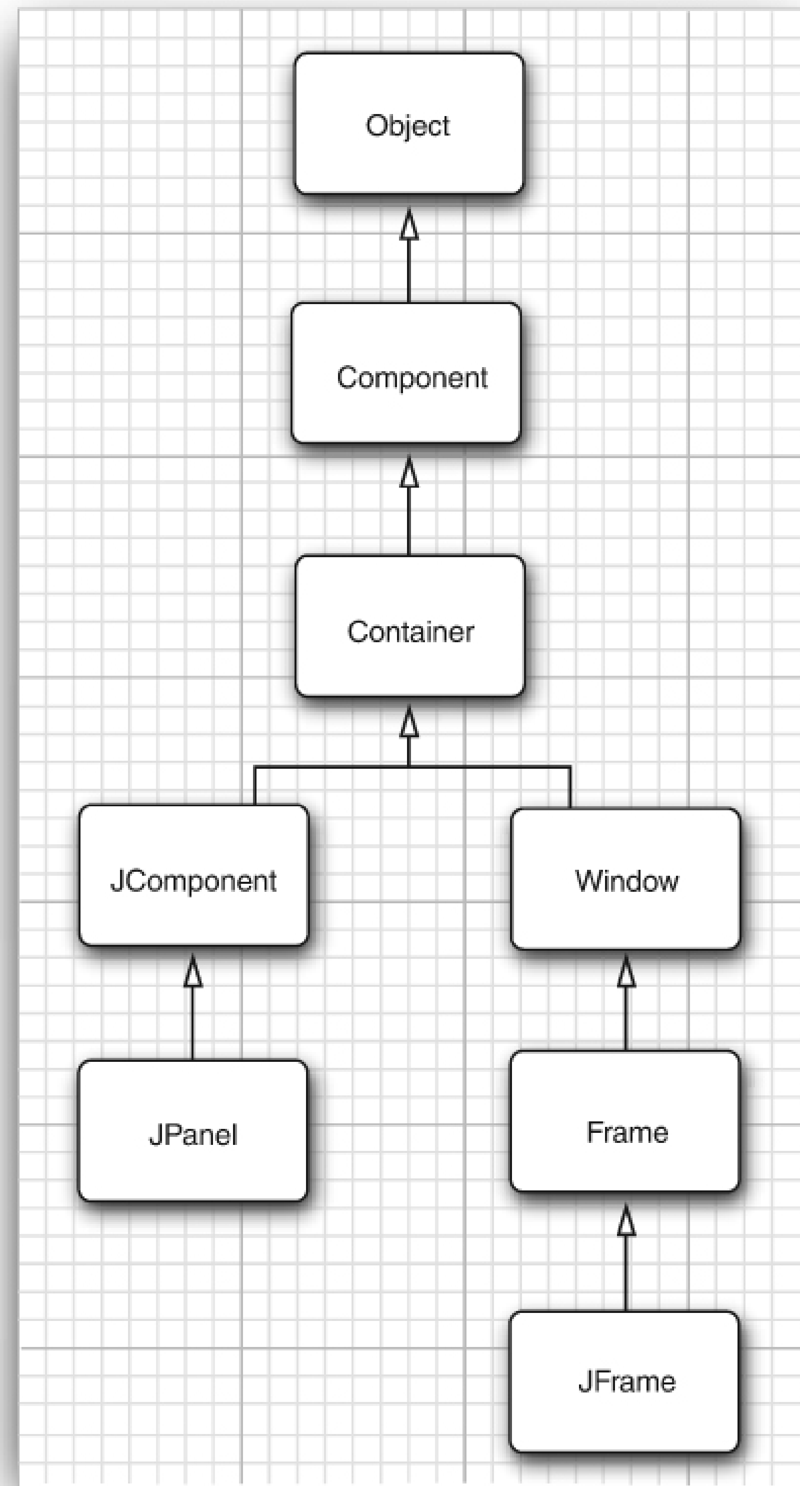


Figure 10.2 Inheritance hierarchy for the frame and component classes in AWT and Swing

As the API notes indicate, the `Component` class (which is the ancestor of all GUI objects) and the `Window` class (which is the superclass of the `Frame` class) are where you need to look for the methods to resize and reshape frames. For example, the `setLocation` method in the `Component` class is one way to reposition a component. If you make the call

```
setLocation(x, y)
```

the top left corner is located `x` pixels across and `y` pixels down, where (0, 0) is the top left corner of the screen. Similarly, the `setBounds` method in `Component` lets you resize and relocate a component (in particular, a `JFrame`) in one step, as

```
setBounds(x, y, width, height)
```

Many methods of component classes come in getter/setter pairs, such as the following methods of the `Frame` class:

```
public String getTitle()
public void setTitle(String title)
```

Such a getter/setter pair is called a *property*. A property has a name and a type. The name is obtained by changing the first letter after the `get` or `set` to lowercase. For example, the `Frame` class has a property with name `title` and type `String`.

Conceptually, `title` is a property of the frame. When we set the property, we expect the title to change on the user's screen. When we get the property, we expect to get back the value that we have set.

There is one exception to the `get/set` convention: For properties of type `boolean`, the getter starts with `is`. For example, the following two methods define the `resizable` property:

```
public boolean isResizable()
public void setResizable(boolean resizable)
```

To determine an appropriate size for a frame, first find out the screen size. Call the static `getDefaultToolkit` method of the `Toolkit` class to get the `Toolkit` object. (The `Toolkit` class is a dumping ground for a variety of methods interfacing with the native windowing system.) Then call the `getScreenSize` method, which returns the screen size as a `Dimension` object. A `Dimension` object simultaneously stores a width and a height, in public (!) instance variables `width` and `height`. Then you can use a suitable percentage of the screen size to size the frame. Here is the code:

```
Toolkit kit = Toolkit.getDefaultToolkit();
Dimension screenSize = kit.getScreenSize();
int screenWidth = screenSize.width;
int screenHeight = screenSize.height;
setSize(screenWidth / 2, screenHeight / 2);
```

You can also supply frame icon:

```
Image img = new ImageIcon("icon.gif").getImage();
setIconImage(img);
```

java.awt.Component 1.0

- `boolean isVisible()`
- `void setVisible(boolean b)`

  gets or sets the `visible` property. Components are initially visible, with the exception of top-level components such as `JFrame`.

- `void setSize(int width, int height)` 1.1

  resizes the component to the specified width and height.

- `void setLocation(int x, int y)` 1.1

moves the component to a new location. The `x` and `y` coordinates use the coordinates of the container if the component is not a top-level component, or the coordinates of the screen if the component is top level (for example, a `JFrame`).

- `void setBounds(int x, int y, int width, int height)` 1.1

  moves and resizes this component.

- `Dimension getSize()` 1.1
- `void setSize(Dimension d)` 1.1

  gets or sets the `size` property of this component.

`java.awt.Window` 1.0

- `void setLocationByPlatform(boolean b)` 5

  gets or sets the `locationByPlatform` property. When the property is set before this window is displayed, the platform picks a suitable location.

`java.awt.Frame` 1.0

- `boolean isResizable()`
- `void setResizable(boolean b)`

  gets or sets the `resizable` property. When the property is set, the user can resize the frame.

- `String getTitle()`
- `void setTitle(String s)`

  gets or sets the `title` property that determines the text in the title bar for the frame.

- `Image getIconImage()`

• `void setIconImage(Image image)`

gets or sets the `iconImage` property that determines the icon for the frame. The windowing system may display the icon as part of the frame decoration or in other locations.

`java.awt.Toolkit` 1.0

• `static Toolkit getDefaultToolkit()`

returns the default toolkit.

• `Dimension getScreenSize()`

gets the size of the user's screen.

`javax.swing.ImageIcon` 1.2

• `ImageIcon(String filename)`

constructs an icon whose image is stored in a file.

• `Image getImage()`

gets the image of this icon.

10.3 Displaying Information in a Component

In this section, I will show you how to display information inside a frame (Figure 10.3).

You could draw the message string directly onto a frame, but that is not considered good programming practice. In Java, frames are really designed to be containers for components, such as a menu bar and other user interface elements. You normally draw on another component which you add to the frame.

Figure 10.3 A frame that displays information

The structure of a `JFrame` is surprisingly complex. Look at Figure 10.4 which shows the makeup of a `JFrame`. As you can see, four panes are layered in a `JFrame`. The root pane, layered pane, and glass pane are of no interest to us; they are required to organize the menu bar and content pane and to implement the look-and-feel. The part that most concerns Swing programmers is the *content pane*. Any components that you add to a frame are automatically placed into the content pane:

```
Component c = . . .;
frame.add(c); // added to the content pane
```

In our case, we want to add a single component to the frame onto which we will draw our message. To draw on a component, you define a class that extends `JComponent` and override the `paintComponent` method in that class.

The `paintComponent` method takes one parameter of type `Graphics`. A `Graphics` object remembers a collection of settings for drawing images and text, such as the font you set or the current color. All drawing in Java must go through a `Graphics` object. It has methods that draw patterns, images, and text.

Here’s how to make a component onto which you can draw:

```
class MyComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      code for drawing
   }
}
```

Each time a window needs to be redrawn, no matter what the reason, the event handler notifies the component. This causes the `paintComponent` methods of all components to be executed.

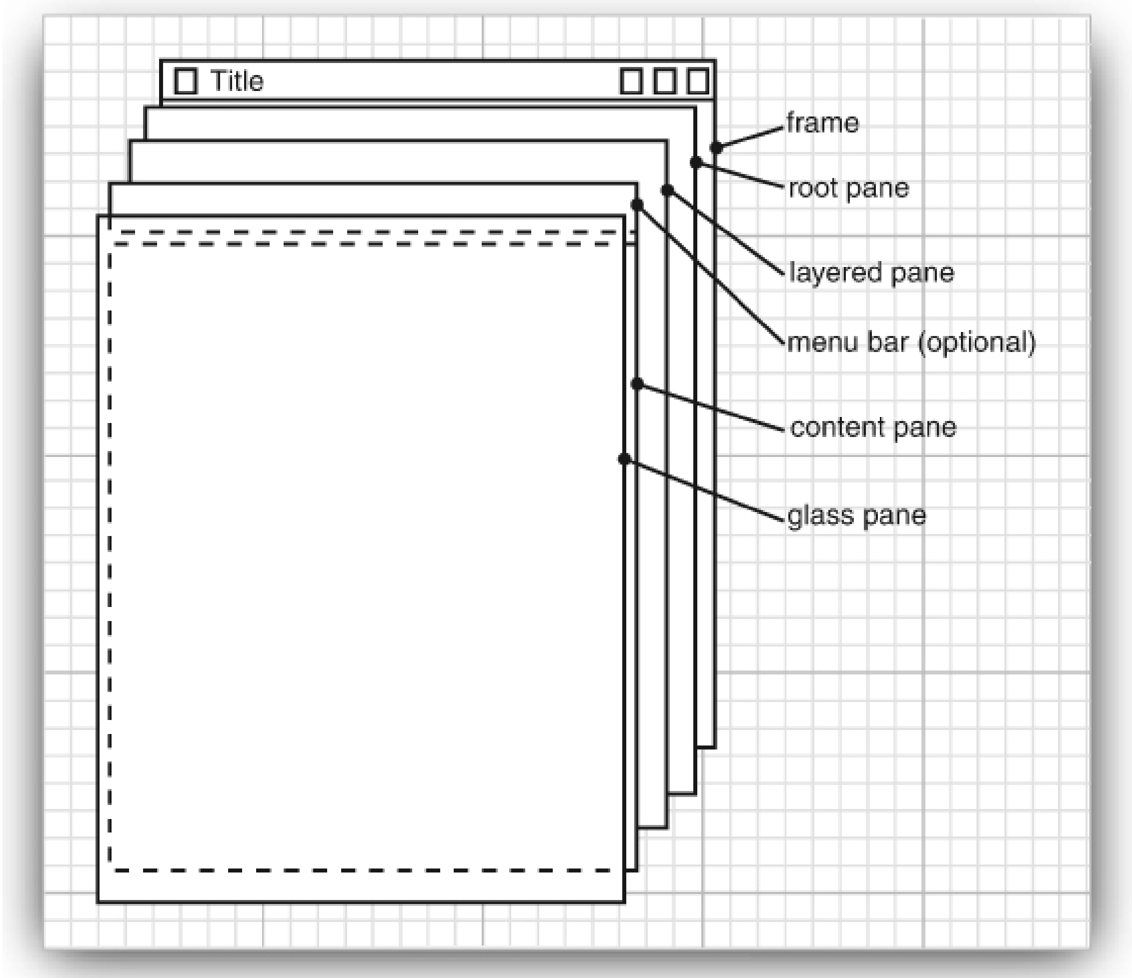


Figure 10.4 Internal structure of a JFrame

Never call the `paintComponent` method yourself. It is called automatically whenever a part of your application needs to be redrawn, and you should not interfere with this automatic process.

What sorts of actions trigger this automatic response? For example, painting occurs when the user increases the size of the window, or minimizes and then restores the window. If the user popped up another window that covered an existing window and then made the overlaid window disappear, the window that was covered is now corrupted and will need to be repainted. (The graphics system does not save the pixels underneath.) And, of course, when the window is displayed for the first time, it needs to process the code that specifies how and where it should draw the initial elements.

TIP:

If you need to force repainting of the screen, call the `repaint` method instead of `paintComponent`. The `repaint` method will cause `paintComponent` to be called for all components, with a properly configured `Graphics` object.

As you saw in the code fragment above, the `paintComponent` method takes a single parameter of type `Graphics`. Measurement on a `Graphics` object for screen display is done in pixels. The (0, 0) coordinate denotes the top left corner of the component on whose surface you are drawing.

The `Graphics` class has various drawing methods, and displaying text is considered a special kind of drawing. Our `paintComponent` method looks like this:

```
public class NotHelloWorldComponent extends JComponent
{
   public static final int MESSAGE_X = 75;
   public static final int MESSAGE_Y = 100;
   public void paintComponent(Graphics g)
   {
      g.drawString("Not a Hello, World program", MESSAGE_X,
```

```
MESSAGE_Y);
   }
   . . .
}
```

Finally, a component should tell its users how big it would like to be. Override the `getPreferredSize` method and return an object of the `Dimension` class with the preferred width and height:

```
public class NotHelloWorldComponent extends JComponent
{
   private static final int DEFAULT_WIDTH = 300;
   private static final int DEFAULT_HEIGHT = 200;
   . . .
   public Dimension getPreferredSize()
   {
      return new Dimension(DEFAULT_WIDTH, DEFAULT_HEIGHT);
   }
}
```

When you fill a frame with one or more components, and you simply want to use their preferred size, call the `pack` method instead of the `setSize` method:

```
class NotHelloWorldFrame extends JFrame
{
   public NotHelloWorldFrame()
   {
      add(new NotHelloWorldComponent());
      pack();
   }
}
```

Listing 10.2 shows the complete code.

Listing 10.2 `notHelloWorld/NotHelloWorld.java`

```java
package notHelloWorld;

import javax.swing.*;
import java.awt.*;

/**
 * @version 1.34 2018-04-10
 * @author Cay Horstmann
 */
public class NotHelloWorld
{
  public static void main(String[] args)
  {
     EventQueue.invokeLater(() ->
        {
           var frame = new NotHelloWorldFrame();
           frame.setTitle("NotHelloWorld");
           frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
           frame.setVisible(true);
        });
  }
}

/**
 * A frame that contains a message panel.
 */
class NotHelloWorldFrame extends JFrame
{
   public NotHelloWorldFrame()
   {
      add(new NotHelloWorldComponent());
      pack();
   }
}

/**
 * A component that displays a message.
 */
```

```
class NotHelloWorldComponent extends JComponent
{
   public static final int MESSAGE_X = 75;
   public static final int MESSAGE_Y = 100;

   private static final int DEFAULT_WIDTH = 300;
   private static final int DEFAULT_HEIGHT = 200;

   public void paintComponent(Graphics g)
   {
       g.drawString("Not a Hello, World program", MESSAGE_X, MESSAGE_Y);
   }

   public Dimension getPreferredSize()
   {
       return new Dimension(DEFAULT_WIDTH, DEFAULT_HEIGHT);
   }
}
```

`javax.swing.JFrame` 1.2

- `Component add(Component c)`

  adds and returns the given component to the content pane of this frame.

`java.awt.Component` 1.0

- `void repaint()`

  causes a repaint of the component "as soon as possible."

- `Dimension getPreferredSize()`

  is the method to override to return the preferred size of this component.

javax.swing.JComponent 1.2

- `void paintComponent(Graphics g)`

  is the method to override to describe how your component needs to be painted.

java.awt.Window 1.0

- `void pack()`

  resizes this window, taking into account the preferred sizes of its components.

10.3.1 Working with 2D Shapes

Starting with Java 1.0, the `Graphics` class has methods to draw lines, rectangles, ellipses, and so on. But those drawing operations are very limited. We will instead use the shape classes from the *Java 2D* library.

To use this library, you need to obtain an object of the `Graphics2D` class. This class is a subclass of the `Graphics` class. Ever since Java 1.2, methods such as `paintComponent` automatically receive an object of the `Graphics2D` class. Simply use a cast, as follows:

```
public void paintComponent(Graphics g)
{
   Graphics2D g2 = (Graphics2D) g;
   . . .
}
```

The Java 2D library organizes geometric shapes in an object-oriented fashion. In particular, there are classes to represent lines, rectangles, and ellipses:

```
Line2D
Rectangle2D
Ellipse2D
```

These classes all implement the `Shape` interface. The Java 2D library supports more complex shapes—arcs, quadratic and cubic curves, and general paths—that we do not discuss in this chapter.

To draw a shape, you first create an object of a class that implements the `Shape` interface and then call the `draw` method of the `Graphics2D` class. For example:

```
Rectangle2D rect = . . .;
g2.draw(rect);
```

The Java 2D library uses floating-point coordinates, not integers, for pixels. Internal calculations are carried out with single-precision `float` quantities. Single precision is sufficient—after all, the ultimate purpose of the geometric computations is to set pixels on the screen or printer. As long as any roundoff errors stay within one pixel, the visual outcome is not affected.

However, manipulating `float` values is sometimes inconvenient for the programmer because Java is adamant about requiring casts when converting `double` values into `float` values. For example, consider the following statement:

```
float f = 1.2; // ERROR--possible loss of precision
```

This statement does not compile because the constant `1.2` has type `double`, and the compiler is nervous about loss of precision. The remedy is to add an `F` suffix to the floating-point constant:

```
float f = 1.2F; // OK
```

Now consider this statement:

```
float f = r.getWidth(); // ERROR
```

This statement does not compile either, for the same reason. The `getWidth` method returns a `double`. This time, the remedy is to provide a cast:

```
float f = (float) r.getWidth(); // OK
```

These suffixes and casts are a bit of a pain, so the designers of the 2D library decided to supply *two versions* of each shape class: one with `float` coordinates for frugal programmers, and one with `double` coordinates for the lazy ones. (In this book, we fall into the second camp and use `double` coordinates whenever we can.)

The library designers chose a curious mechanism for packaging these choices. Consider the `Rectangle2D` class. This is an abstract class with two concrete subclasses, which are also static inner classes:

```
Rectangle2D.Float
Rectangle2D.Double
```

Figure 10.5 shows the inheritance diagram.

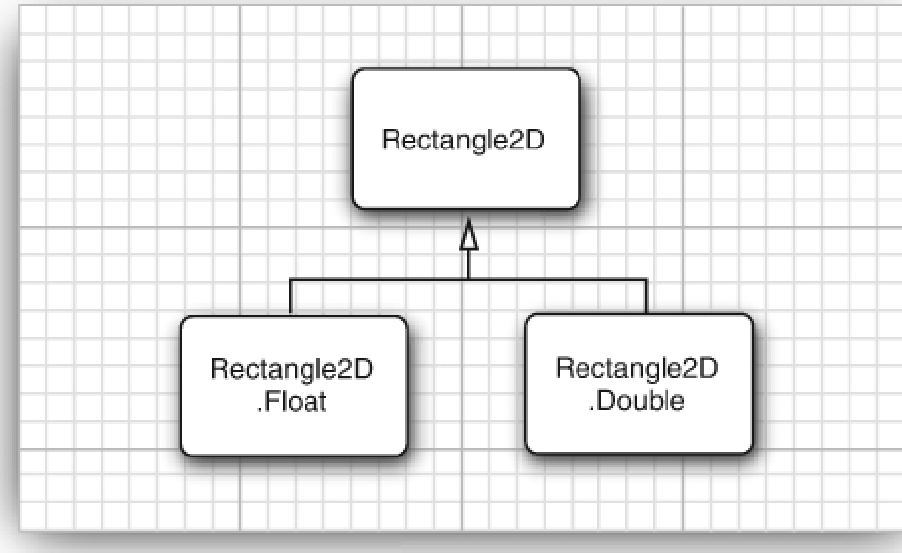


Figure 10.5 2D rectangle classes

It is best to ignore the fact that the two concrete classes are static inner classes—that is just a gimmick to avoid names such as `FloatRectangle2D` and `DoubleRectangle2D`.

When you construct a `Rectangle2D.Float` object, you supply the coordinates as `float` numbers. For a `Rectangle2D.Double` object, you supply them as `double` numbers.

```
var floatRect = new Rectangle2D.Float(10.0F, 25.0F, 22.5F,
20.0F);
var doubleRect = new Rectangle2D.Double(10.0, 25.0, 22.5,
20.0);
```

The construction parameters denote the top left corner, width, and height of the rectangle.

The `Rectangle2D` methods use `double` parameters and return values. For example, the `getWidth` method returns a `double` value, even if the width is stored as a `float` in a `Rectangle2D.Float` object.

TIP:

Simply use the `Double` shape classes to avoid dealing with `float` values altogether. However, if you are constructing thousands of shape objects, consider using the `Float` classes to conserve memory.

What we just discussed for the `Rectangle2D` classes holds for the other shape classes as well. Furthermore, there is a `Point2D` class with subclasses `Point2D.Float` and `Point2D.Double`. Here is how to make a point object:

```
var p = new Point2D.Double(10, 20);
```

The classes `Rectangle2D` and `Ellipse2D` both inherit from the common superclass `RectangularShape`. Admittedly, ellipses are not rectangular, but they have a *bounding rectangle* (see Figure 10.6).

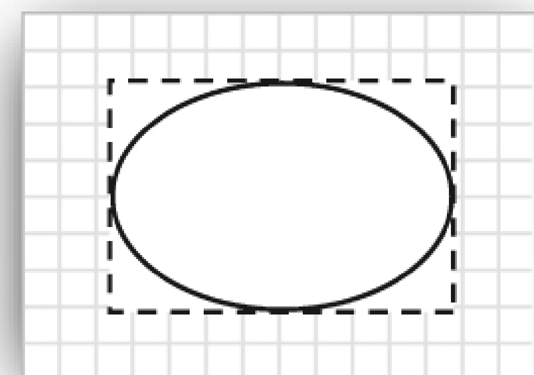


Figure 10.6 The bounding rectangle of an ellipse

The `RectangularShape` class defines over 20 methods that are common to these shapes, among them such useful methods as `getWidth`, `getHeight`, `getCenterX`, and `getCenterY` (but, sadly, at the time of this writing, not a `getCenter` method that would return the center as a `Point2D` object).

Finally, a couple of legacy classes from Java 1.0 have been fitted into the shape class hierarchy. The `Rectangle` and `Point` classes, which store a rectangle and a point with integer coordinates, extend the `Rectangle2D` and `Point2D` classes.

Figure 10.7 shows the relationships between the shape classes. However, the `Double` and `Float` subclasses are omitted. Legacy classes are marked with a gray fill.

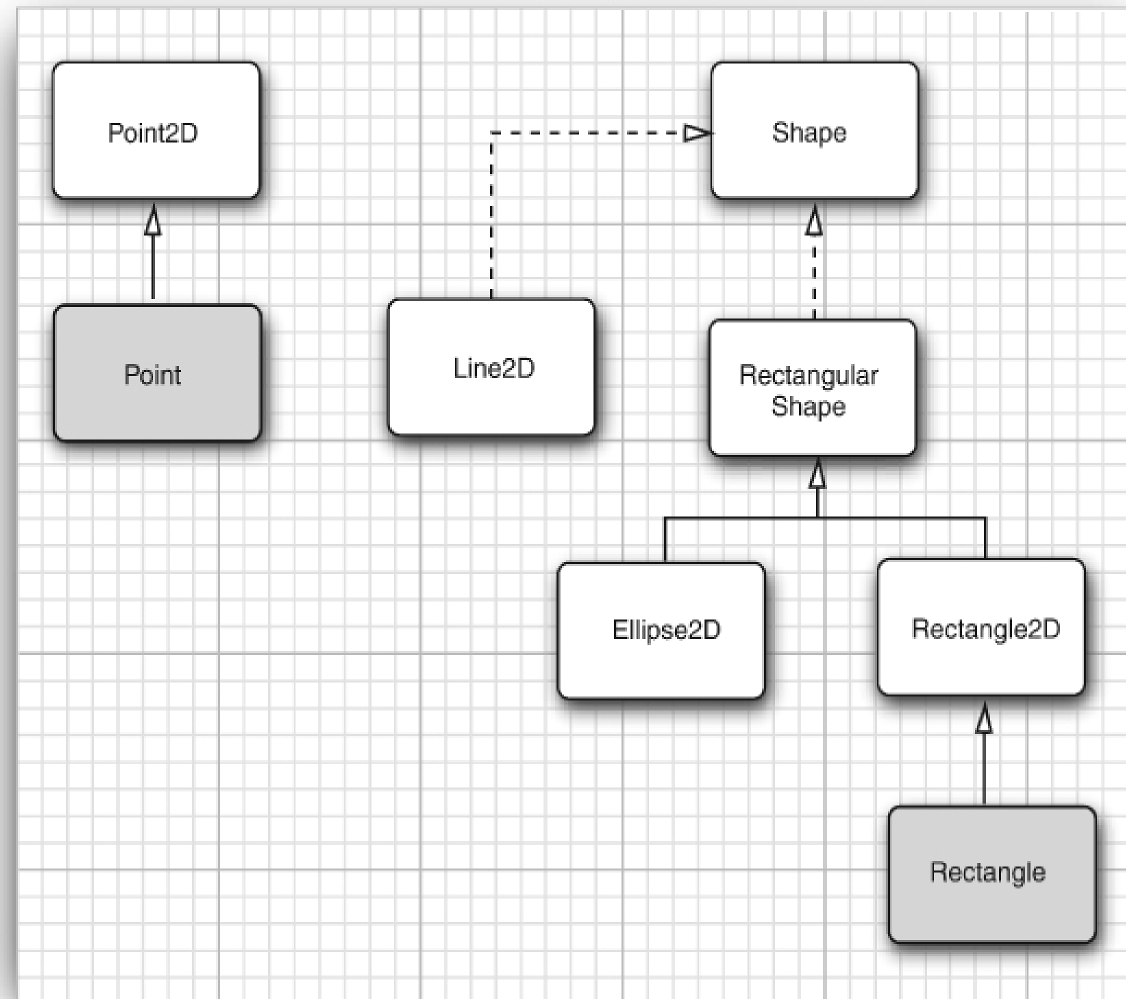


Figure 10.7 Relationships between the shape classes

`Rectangle2D` and `Ellipse2D` objects are simple to construct. You need to specify

- The *x* and *y* coordinates of the top left corner; and
- The width and height.

For ellipses, these refer to the bounding rectangle. For example,

```
var e = new Ellipse2D.Double(150, 200, 100, 50);
```

constructs an ellipse that is bounded by a rectangle with the top left corner at (150, 200), width of 100, and height of 50.

When constructing an ellipse, you usually know the center, width, and height, but not the corner points of the bounding rectangle (which don't even lie on the ellipse). The `setFrameFromCenter` method uses the center point, but it still requires one of the four corner points. Thus, you will usually end up constructing an ellipse as follows:

```
var ellipse
   = new Ellipse2D.Double(centerX - width / 2, centerY - height
/ 2, width, height);
```

To construct a line, you supply the start and end points, either as `Point2D` objects or as pairs of numbers:

```
var line = new Line2D.Double(start, end);
```

or

```
var line = new Line2D.Double(startX, startY, endX, endY);
```

The program in Listing 10.3 draws a rectangle, the ellipse that is enclosed in the rectangle, a diagonal of the rectangle, and a circle that has the same center as the rectangle. Figure 10.8 shows the result.

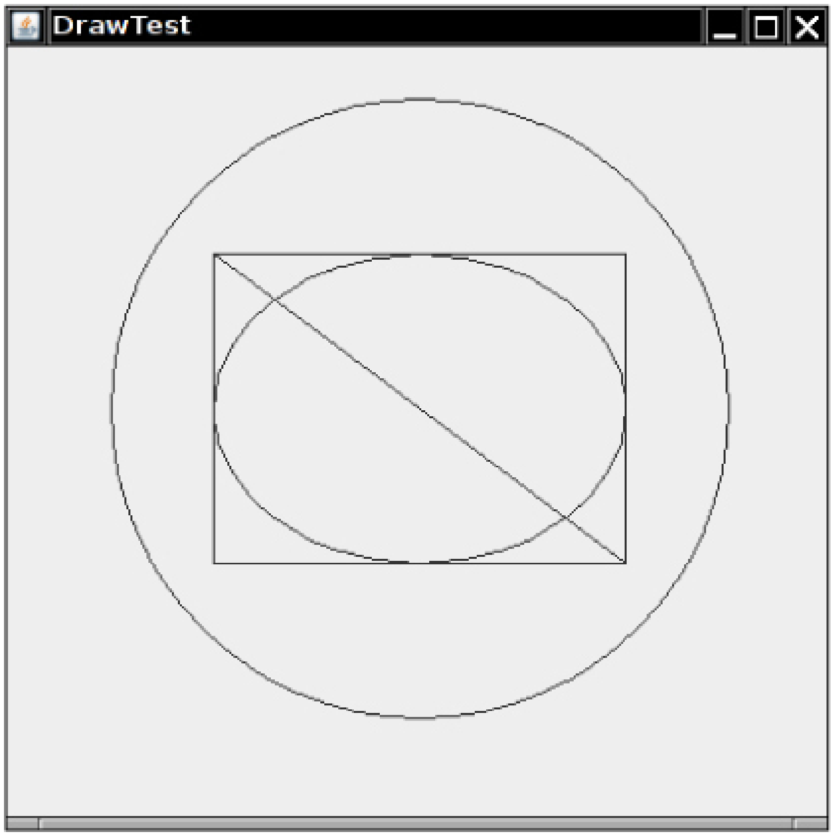


Figure 10.8 Drawing geometric shapes

Listing 10.3 `draw/DrawTest.java`

```
package draw;

import java.awt.*;
import java.awt.geom.*;
import javax.swing.*;

/**
 * @version 1.34 2018-04-10
 * @author Cay Horstmann
 */
public class DrawTest
{
   public static void main(String[] args)
   {
      EventQueue.invokeLater(() ->
```

```
          {
            var frame = new DrawFrame();
            frame.setTitle("DrawTest");
            frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
            frame.setVisible(true);
          });
   }
}

/**
 * A frame that contains a panel with drawings.
 */
class DrawFrame extends JFrame
{
   public DrawFrame()
   {
      add(new DrawComponent());
      pack();
   }
}

/**
 * A component that displays rectangles and ellipses.
 */
class DrawComponent extends JComponent
{
   private static final int DEFAULT_WIDTH = 400;
   private static final int DEFAULT_HEIGHT = 400;

   public void paintComponent(Graphics g)
   {
       var g2 = (Graphics2D) g;

       // draw a rectangle

       double leftX = 100;
       double topY = 100;
       double width = 200;
```

```java
        double height = 150;

        var rect = new Rectangle2D.Double(leftX, topY, width, height);
        g2.draw(rect);

        // draw the enclosed ellipse

        var ellipse = new Ellipse2D.Double();
        ellipse.setFrame(rect);
        g2.draw(ellipse);

        // draw a diagonal line

        g2.draw(new Line2D.Double(leftX, topY, leftX + width, topY + height));

        // draw a circle with the same center

        double centerX = rect.getCenterX();
        double centerY = rect.getCenterY();
        double radius = 150;

        var circle = new Ellipse2D.Double();
        circle.setFrameFromCenter(centerX, centerY, centerX + radius, centerY + radius);
        g2.draw(circle);
    }

    public Dimension getPreferredSize()
    {
        return new Dimension(DEFAULT_WIDTH, DEFAULT_HEIGHT);
    }
}
```

java.awt.geom.RectangularShape 1.2

- `double getCenterX()`

- `double getCenterY()`
- `double getMinX()`
- `double getMinY()`
- `double getMaxX()`
- `double getMaxY()`

  returns the center, minimum, or maximum *x* or *y* value of the enclosing rectangle.

- `double getWidth()`
- `double getHeight()`

  returns the width or height of the enclosing rectangle.

- `double getX()`
- `double getY()`

  returns the *x* or *y* coordinate of the top left corner of the enclosing rectangle.

`java.awt.geom.Rectangle2D.Double` 1.2

- `Rectangle2D.Double(double x, double y, double w, double h)`

  constructs a rectangle with the given top left corner, width, and height.

`java.awt.geom.Ellipse2D.Double` 1.2

- `Ellipse2D.Double(double x, double y, double w, double h)`

  constructs an ellipse whose bounding rectangle has the given top left corner, width, and height.

java.awt.geom.Point2D.Double 1.2

- `Point2D.Double(double x, double y)`

  constructs a point with the given coordinates.

java.awt.geom.Line2D.Double 1.2

- `Line2D.Double(Point2D start, Point2D end)`
- `Line2D.Double(double startX, double startY, double endX, double endY)`

  constructs a line with the given start and end points.

10.3.2 Using Color

The `setPaint` method of the `Graphics2D` class lets you select a color that is used for all subsequent drawing operations on the graphics context. For example:

```
g2.setPaint(Color.RED);
g2.drawString("Warning!", 100, 100);
```

You can fill the interiors of closed shapes (such as rectangles or ellipses) with a color. Simply call `fill` instead of `draw`:

```
Rectangle2D rect = . . .;
g2.setPaint(Color.RED);
g2.fill(rect); // fills rect with red
```

To draw in multiple colors, select a color, draw or fill, then select another color, and draw or fill again.

NOTE:

The `fill` method paints one fewer pixel to the right and the bottom. For example, if you draw a `new Rectangle2D.Double(0, 0, 10, 20)`, then the drawing includes the pixels with $x = 10$ and $y = 20$. If you fill the same rectangle, those pixels are not painted.

Define colors with the `Color` class. The `java.awt.Color` class offers predefined constants for the following 13 standard colors:

```
BLACK, BLUE, CYAN, DARK_GRAY, GRAY, GREEN, LIGHT_GRAY,
MAGENTA, ORANGE, PINK, RED, WHITE, YELLOW
```

You can specify a custom color by creating a `Color` object by its red, green, and blue components, each a value between `0` and `255`:

```
g2.setPaint(new Color(0, 128, 128)); // a dull blue-green
g2.drawString("Welcome!", 75, 125);
```

NOTE:

In addition to solid colors, you can call `setPaint` with instances of classes that implement the `Paint` interface. This enables drawing with gradients and textures.

To set the *background color*, use the `setBackground` method of the `Component` class, an ancestor of `JComponent`.

```
var component = new MyComponent();
component.setBackground(Color.PINK);
```

There is also a `setForeground` method. It specifies the default color that is used for drawing on the component.

`java.awt.Color` 1.0

- `Color(int r, int g, int b)`

  creates a color object with the given red, green, and blue components between `0` and `255`.

`java.awt.Graphics2D` 1.2

- `Paint getPaint()`
- `void setPaint(Paint p)`

  gets or sets the paint property of this graphics context. The `Color` class implements the `Paint` interface. Therefore, you can use this method to set the paint attribute to a solid color.

- `void fill(Shape s)`

  fills the shape with the current paint.

`java.awt.Component` 1.0

- `Color getForeground()`
- `Color getBackground()`
- `void setForeground(Color c)`
- `void setBackground(Color c)`

  gets or sets the foreground or background color.

10.3.3 Using Fonts

The "Not a Hello World" program at the beginning of this chapter displayed a string in the default font. Sometimes, you will want to show your text in a different font. You can specify a font by its *font face name*. A font face name is composed of a *font family name*, such as "Helvetica", and an optional suffix such as "Bold". For example, the font faces "Helvetica" and "Helvetica Bold" are both considered to be part of the family named "Helvetica."

To find out which fonts are available on a particular computer, call the `getAvailableFontFamilyNames` method of the `GraphicsEnvironment` class. The method returns an array of strings containing the names of all available fonts. To obtain an instance of the `GraphicsEnvironment` class that describes the graphics environment of the user's system, use the static `getLocalGraphicsEnvironment` method. The following program prints the names of all fonts on your system:

```
import java.awt.*;
public class ListFonts
{
   public static void main(String[] args)
   {
      String[] fontNames = GraphicsEnvironment
         .getLocalGraphicsEnvironment()
         .getAvailableFontFamilyNames();
      for (String fontName : fontNames)
         System.out.println(fontName);
   }
}
```

The AWT defines five *logical* font names:

```
SansSerif
Serif
Monospaced
Dialog
DialogInput
```

These names are always mapped to some fonts that actually exist on the client machine. For example, on a Windows system, `SansSerif` is mapped to Arial.

In addition, the Oracle JDK always includes three font families named "Lucida Sans," "Lucida Bright," and "Lucida Sans Typewriter."

To draw characters in a font, you must first create an object of the class `Font`. Specify the font face name, the font style, and the point size. Here is an example of how you construct a `Font` object:

```
var sansbold14 = new Font("SansSerif", Font.BOLD, 14);
```

The third argument is the point size. Points are commonly used in typography to indicate the size of a font. There are 72 points per inch.

You can use a logical font name in place of the font face name in the `Font` constructor. Specify the style (plain, **bold**, *italic*, or ***bold italic***) by setting the second `Font` constructor argument to one of the following values:

```
Font.PLAIN
Font.BOLD
Font.ITALIC
Font.BOLD + Font.ITALIC
```

The font is plain with a font size of 1 point. Use the `deriveFont` method to get a font of the desired size:

```
Font f = f1.deriveFont(14.0F);
```

CAUTION:

There are two overloaded versions of the `deriveFont` method. One of them (with a `float` parameter) sets the font size, the other (with an `int` parameter) sets the font style. Thus, `f1.deriveFont(14)` sets the style and not the size!

(The result is an italic font because it happens that the binary representation of `14` has the `ITALIC` bit but not the `BOLD` bit set.)

Here's the code that displays the string "Hello, World!" in the standard sans serif font on your system, using 14-point bold type:

```
var sansbold14 = new Font("SansSerif", Font.BOLD, 14);
g2.setFont(sansbold14);
var message = "Hello, World!";
g2.drawString(message, 75, 100);
```

Next, let's *center* the string in its component instead of drawing it at an arbitrary position. We need to know the width and height of the string in pixels. These dimensions depend on three factors:

- The font used (in our case, sans serif, bold, 14 point);
- The string (in our case, "Hello, World!"); and
- The device on which the font is drawn (in our case, the user's screen).

To obtain an object that represents the font characteristics of the screen device, call the `getFontRenderContext` method of the `Graphics2D` class. It returns an object of the `FontRenderContext` class. Simply pass that object to the `getStringBounds` method of the `Font` class:

```
FontRenderContext context = g2.getFontRenderContext();
Rectangle2D bounds = sansbold14.getStringBounds(message,
context);
```

The `getStringBounds` method returns a rectangle that encloses the string.

To interpret the dimensions of that rectangle, you should know some basic typesetting terms (see Figure 10.9). The *baseline* is the imaginary line where, for example, the bottom of a character like 'e' rests. The *ascent* is the distance from the baseline to the top of an *ascender*, which is the upper part of a letter like 'b' or 'k', or an uppercase character. The *descent* is the distance from the baseline to a *descender,* which is the lower portion of a letter like ‘p’ or ‘g’.

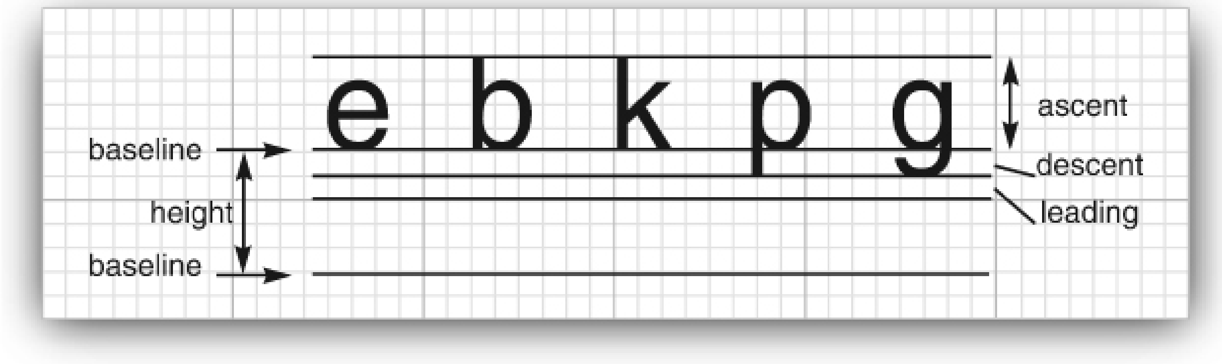


Figure 10.9 Typesetting terms illustrated

Leading is the space between the descent of one line and the ascent of the next line. (The term has its origin from the strips of lead that typesetters used to separate lines.) The *height* of a font is the distance between successive baselines, which is the same as descent + leading + ascent.

The width of the rectangle that the `getStringBounds` method returns is the horizontal extent of the string. The height of the rectangle is the sum of ascent, descent, and leading. The rectangle has its origin at the baseline of the string. The top *y* coordinate of the rectangle is negative. Thus, you can obtain string width, height, and ascent as follows:

```
double stringWidth = bounds.getWidth();
double stringHeight = bounds.getHeight();
double ascent = -bounds.getY();
```

If you need to know the descent or leading, use the `getLineMetrics` method of the `Font` class. That method returns an object of the `LineMetrics` class, which has methods to obtain the descent and leading:

```
LineMetrics metrics = f.getLineMetrics(message, context);
float descent = metrics.getDescent();
float leading = metrics.getLeading();
```

NOTE:

When you need to compute layout dimensions outside the `paintComponent` method, you can't obtain the font render context from the `Graphics2D` object. Instead, call the `getFontMetrics` method of the `JComponent` class and then call `getFontRenderContext`.

```
FontRenderContext context = getFontMetrics(f).getFontRenderContext();
```

To show that the positioning is accurate, the sample program in Listing 10.4 centers the string in the frame and draws the baseline and the bounding rectangle. Figure 10.10 shows the screen display.

Figure 10.10 Drawing the baseline and string bounds

Listing 10.4 `font/FontTest.java`

```
package font;

import java.awt.*;
import java.awt.font.*;
import java.awt.geom.*;
```

```java
import javax.swing.*;

/**
 * @version 1.35 2018-04-10
 * @author Cay Horstmann
 */
public class FontTest
{
   public static void main(String[] args)
   {
      EventQueue.invokeLater(() ->
         {
            var frame = new FontFrame();
            frame.setTitle("FontTest");
            frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
            frame.setVisible(true);
         });
   }
}

/**
 * A frame with a text message component.
 */
class FontFrame extends JFrame
{
   public FontFrame()
   {
      add(new FontComponent());
      pack();
   }
}

/**
 * A component that shows a centered message in a box.
 */
class FontComponent extends JComponent
{
    private static final int DEFAULT_WIDTH = 300;
```

```
     private static final int DEFAULT_HEIGHT = 200;

   public void paintComponent(Graphics g)
   {
      var g2 = (Graphics2D) g;

      String message = "Hello, World!";

      var f = new Font("Serif", Font.BOLD, 36);
      g2.setFont(f);

      // measure the size of the message

      FontRenderContext context = g2.getFontRenderContext();
      Rectangle2D bounds = f.getStringBounds(message, context);

      // set (x,y) = top left corner of text

      double x = (getWidth() - bounds.getWidth()) / 2;
      double y = (getHeight() - bounds.getHeight()) / 2;

      // add ascent to y to reach the baseline

      double ascent = -bounds.getY();
      double baseY = y + ascent;

      // draw the message

      g2.drawString(message, (int) x, (int) baseY);

      g2.setPaint(Color.LIGHT_GRAY);

      // draw the baseline

      g2.draw(new Line2D.Double(x, baseY, x +
bounds.getWidth(), baseY));

      // draw the enclosing rectangle

```

```
      var rect = new Rectangle2D.Double(x, y, bounds.getWidth(), bounds.getHeight());
      g2.draw(rect);
   }

   public Dimension getPreferredSize()
   {
      return new Dimension(DEFAULT_WIDTH, DEFAULT_HEIGHT);
   }
}
```

`java.awt.Font` 1.0

- `Font(String name, int style, int size)`

  creates a new font object. The font name is either a font face name (such as `"Helvetica Bold"`) or a logical font name (such as `"Serif"`, `"SansSerif"`). The style is one of `Font.PLAIN`, `Font.BOLD`, `Font.ITALIC`, or `Font.BOLD + Font.ITALIC`.

- `String getFontName()`

  gets the font face name (such as `"Helvetica Bold"`).

- `String getFamily()`

  gets the font family name (such as `"Helvetica"`).

- `String getName()`

  gets the logical name (such as `"SansSerif"`) if the font was created with a logical font name; otherwise, gets the font face name.

- `Rectangle2D getStringBounds(String s, FontRenderContext context)` 1.2

  returns a rectangle that encloses the string. The origin of the rectangle falls on the baseline. The top *y* coordinate of the rectangle equals the negative of the ascent. The height of the rectangle equals the sum of ascent, descent, and leading. The width equals the string width.

- `LineMetrics getLineMetrics(String s, FontRenderContext context)` 1.2

  returns a line metrics object to determine the extent of the string.

- `Font deriveFont(int style)` 1.2
- `Font deriveFont(float size)` 1.2
- `Font deriveFont(int style, float size)` 1.2

  returns a new font that is equal to this font, except that it has the given size and style.

java.awt.font.LineMetrics 1.2

- `float getAscent()`

  gets the font ascent—the distance from the baseline to the tops of uppercase characters.

- `float getDescent()`

  gets the font descent—the distance from the baseline to the bottoms of descenders.

- `float getLeading()`

  gets the font leading—the space between the bottom of one line of text and the top of the next line.

- `float getHeight()`

  gets the total height of the font—the distance between the two baselines of text (descent + leading + ascent).

java.awt.Graphics2D 1.2

- `FontRenderContext getFontRenderContext()`

gets a font render context that specifies font characteristics in this graphics context.

- `void drawString(String str, float x, float y)`

  draws a string in the current font and color.

`javax.swing.JComponent` 1.2

- `FontMetrics getFontMetrics(Font f)` 5

  gets the font metrics for the given font. The `FontMetrics` class is a precursor to the `LineMetrics` class.

`java.awt.FontMetrics` 1.0

- `FontRenderContext getFontRenderContext()` 1.2

  gets a font render context for the font.

10.3.4 Displaying Images

You can use the `ImageIcon` class to read an image from a file:

```
Image image = new ImageIcon(filename).getImage();
```

Now the variable `image` contains a reference to an object that encapsulates the image data. Display the image with the `drawImage` method of the `Graphics` class.

```
public void paintComponent(Graphics g)
{
  . . .
```

```
    g.drawImage(image, x, y, null);
  }
```

We can take this a little bit further and tile the window with the graphics image. The result looks like the screen shown in Figure 10.11. We do the tiling in the `paintComponent` method. We first draw one copy of the image in the top left corner and then use the `copyArea` call to copy it into the entire window:

```
for (int i = 0; i * imageWidth <= getWidth(); i++)
   for (int j = 0; j * imageHeight <= getHeight(); j++)
      if (i + j > 0)
         g.copyArea(0, 0, imageWidth, imageHeight, i *
imageWidth, j * imageHeight);
```

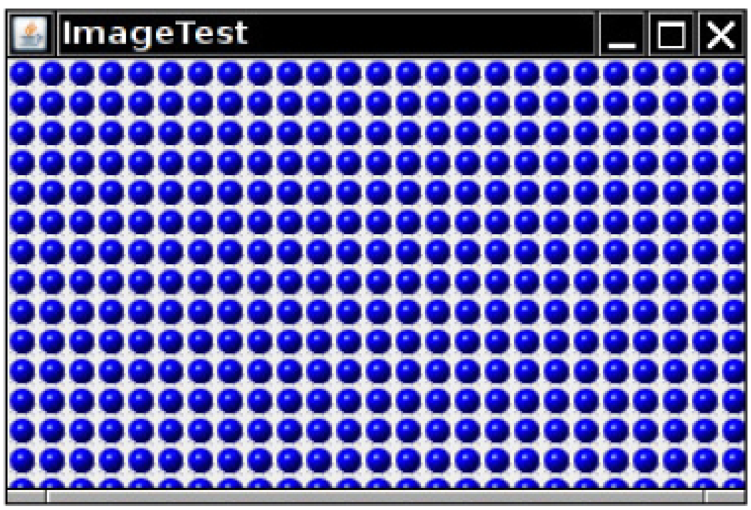


Figure 10.11 Window with tiled graphics image

`java.awt.Graphics` 1.0

- `boolean drawImage(Image img, int x, int y, ImageObserver observer)`
- `boolean drawImage(Image img, int x, int y, int width, int height, ImageObserver observer)`

draws an unscaled or scaled image. Note: This call may return before the image is drawn. The `imageObserver` object is notified of the rendering progress. This was a useful feature in the distant past. Nowadays, just pass a `null` observer.

- `void copyArea(int x, int y, int width, int height, int dx, int dy)`

  copies an area of the screen. The `dx` and `dy` parameters are the distance from the source area to the target area.

10.4 Event Handling

Any operating environment that supports GUIs constantly monitors events such as keystrokes or mouse clicks. These events are then reported to the programs that are running. Each program then decides what, if anything, to do in response to these events.

10.4.1 Basic Event Handling Concepts

In the Java AWT, *event sources* (such as buttons or scrollbars) have methods that allow you to register *event listeners*—objects that carry out the desired response to the event.

When an event listener is notified about an event, information about the event is encapsulated in an *event object*. In Java, all event objects ultimately derive from the class `java.util.EventObject`. Of course, there are subclasses for each event type, such as `ActionEvent` and `WindowEvent`.

Different event sources can produce different kinds of events. For example, a button can send `ActionEvent` objects, whereas a window can send `WindowEvent` objects.

To sum up, here's an overview of how event handling in the AWT works:

- An event listener is an instance of a class that implements a *listener interface*.

- An event source is an object that can register listener objects and send them event objects.
- The event source sends out event objects to all registered listeners when that event occurs.
- The listener objects then uses the information in the event object to determine their reaction to the event.

Figure 10.12 shows the relationship between the event handling classes and interfaces.

Here is an example for specifying a listener:

```
ActionListener listener = . . .;
var button = new JButton("OK");
button.addActionListener(listener);
```

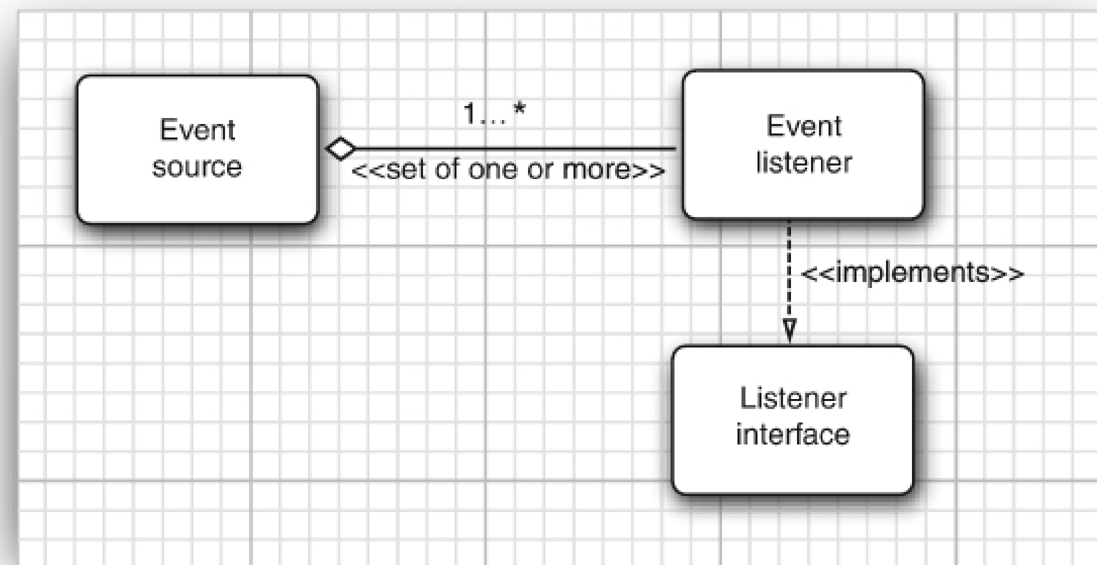


Figure 10.12 Relationship between event sources and listeners

Now the `listener` object is notified whenever an “action event” occurs in the button. For buttons, as you might expect, an action event is a button click.

To implement the `ActionListener` interface, the listener class must have a method called `actionPerformed` that receives an `ActionEvent` object as a parameter.

```
class MyListener implements ActionListener
{
   . . .
   public void actionPerformed(ActionEvent event)
   {
      // reaction to button click goes here
      . . .
   }
}
```

Whenever the user clicks the button, the `JButton` object creates an `ActionEvent` object and calls `listener.actionPerformed(event)`, passing that event object. An event source such as a button can have multiple listeners. In that case, the button calls the `actionPerformed` methods of all listeners whenever the user clicks the button.

Figure 10.13 shows the interaction between the event source, event listener, and event object.

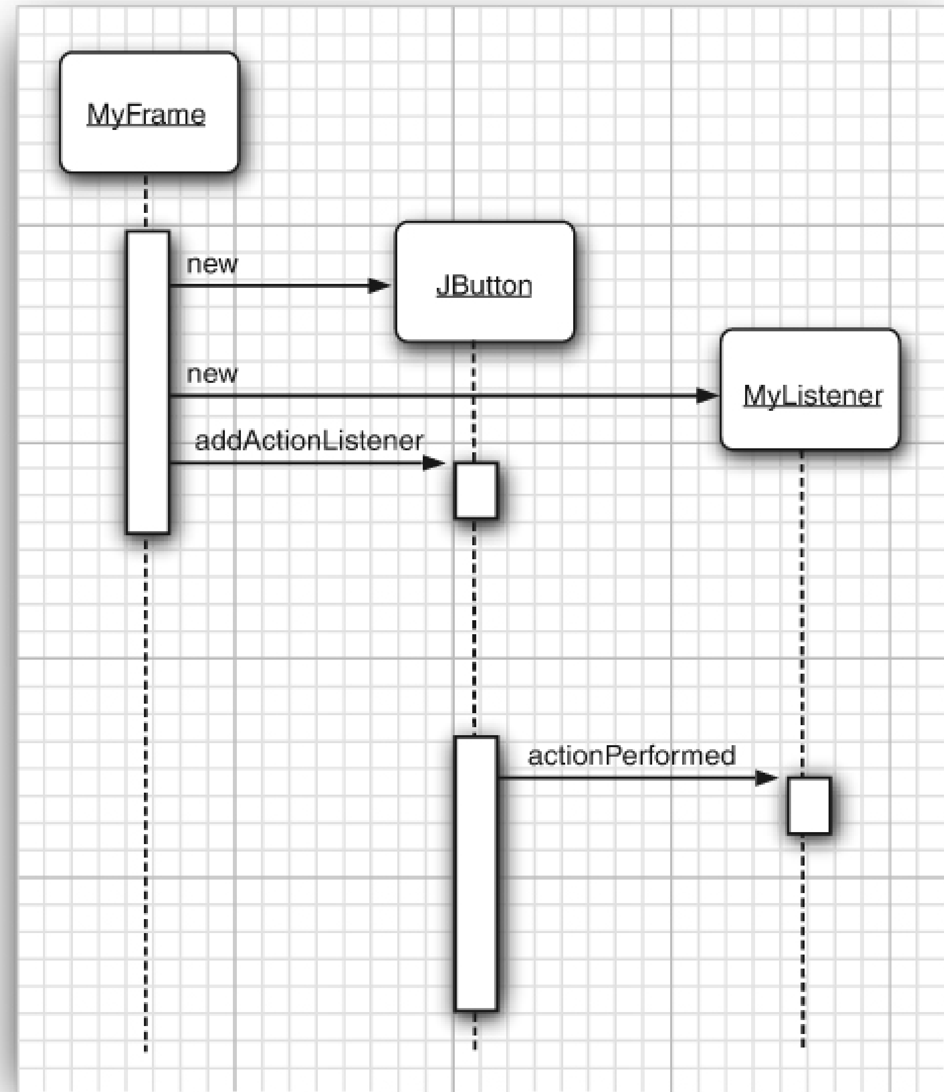


Figure 10.13 Event notification

10.4.2 Example: Handling a Button Click

As a way of getting comfortable with the event delegation model, let's work through all the details needed for the simple example of responding to a button click. For this example, we will show a panel populated with three buttons. Three listener objects are added as action listeners to the buttons.

With this scenario, each time a user clicks on any of the buttons on the panel, the associated listener object receives an `ActionEvent` that indicates a button click. In our sample program, the listener object will then change the background color of the panel.

Before I can show you the program that listens to button clicks, I need to explain how to create buttons and how to add them to a panel.

To create a button, specify a label string, an icon, or both in the button constructor. Here are two examples:

```
var yellowButton = new JButton("Yellow");
var blueButton = new JButton(new ImageIcon("blue-ball.gif"));
```

Call the `add` method to add the buttons to a panel:

```
var yellowButton = new JButton("Yellow");
var blueButton = new JButton("Blue");
var redButton = new JButton("Red");

buttonPanel.add(yellowButton);
buttonPanel.add(blueButton);
buttonPanel.add(redButton);
```

Figure 10.14 shows the result.

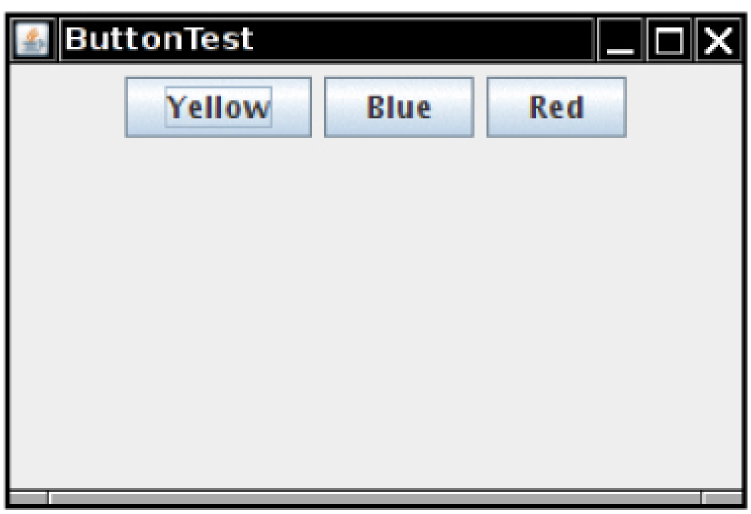


Figure 10.14 A panel filled with buttons

Next, we need to add code that listens to these buttons. This requires classes that implement the `ActionListener` interface, which, as I just mentioned, has one method: `actionPerformed`, whose signature looks like this:

```
public void actionPerformed(ActionEvent event)
```

The way to use the `ActionListener` interface is the same in all situations: The `actionPerformed` method (which is the only method in `ActionListener`) takes an object of type `ActionEvent` as a parameter. This event object gives you information about the event that happened.

When a button is clicked, we want the background color of the panel to change to a particular color. We store the desired color in our listener class.

```
class ColorAction implements ActionListener
{
   private Color backgroundColor;
   public ColorAction(Color c)
   {
      backgroundColor = c;
   }
   public void actionPerformed(ActionEvent event)
   {
      // set panel background color
      . . .
   }
}
```

We then construct one object for each color and set the objects as the button listeners.

```
var yellowAction = new ColorAction(Color.YELLOW);
var blueAction = new ColorAction(Color.BLUE);
var redAction = new ColorAction(Color.RED);
```

```
yellowButton.addActionListener(yellowAction);
blueButton.addActionListener(blueAction);
redButton.addActionListener(redAction);
```

For example, if a user clicks on the button marked “Yellow”, the `actionPerformed` method of the `yellowAction` object is called. Its `backgroundColor` instance field is set to `Color.YELLOW`, and it can now proceed to set the panel’s background color.

Just one issue remains. The `ColorAction` object doesn’t have access to the `buttonPanel` variable. You can solve this problem in two ways. You can store the panel in the `ColorAction` object and set it in the `ColorAction` constructor. Or, more conveniently, you can make `ColorAction` into an inner class of the `ButtonFrame` class. Its methods can then access the outer panel automatically.

Listing 10.5 contains the complete frame class. Whenever you click one of the buttons, the appropriate action listener changes the background color of the panel.

Listing 10.5 `button/ButtonFrame.java`

```
package button;

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

/**
 * A frame with a button panel.
 */
public class ButtonFrame extends JFrame
{
  private JPanel buttonPanel;
  private static final int DEFAULT_WIDTH = 300;
  private static final int DEFAULT_HEIGHT = 200;

  public ButtonFrame()
  {
```

```
      setSize(DEFAULT_WIDTH, DEFAULT_HEIGHT);

      // create buttons
      var yellowButton = new JButton("Yellow");
      var blueButton = new JButton("Blue");
      var redButton = new JButton("Red");

      buttonPanel = new JPanel();

      // add buttons to panel
      buttonPanel.add(yellowButton);
      buttonPanel.add(blueButton);
      buttonPanel.add(redButton);

      // add panel to frame
      add(buttonPanel);

      // create button actions
      var yellowAction = new ColorAction(Color.YELLOW);
      var blueAction = new ColorAction(Color.BLUE);
      var redAction = new ColorAction(Color.RED);

      // associate actions with buttons
      yellowButton.addActionListener(yellowAction);
      blueButton.addActionListener(blueAction);
      redButton.addActionListener(redAction);
   }

   /**
    * An action listener that sets the panel's background color.
    */
   private class ColorAction implements ActionListener
   {
      private Color backgroundColor;

      public ColorAction(Color c)
      {
         backgroundColor = c;
```

```
        }

        public void actionPerformed(ActionEvent event)
        {
            buttonPanel.setBackground(backgroundColor);
        }
    }
}
```

---

javax.swing.JButton 1.2

- `JButton(String label)`
- `JButton(Icon icon)`
- `JButton(String label, Icon icon)`

  constructs a button. The label string can be plain text or HTML; for example, "<html>Ok</html>".

java.awt.Container 1.0

- `Component add(Component c)`

  adds the component `c` to this container.

10.4.3 Specifying Listeners Concisely

In the preceding section, we defined a class for the event listener and constructed three objects of that class. It is not all that common to have multiple instances of a listener class. Most commonly, each listener carries out a separate action. In that case, there is no need to make a separate class. Simply use a lambda expression:

```
exitButton.addActionListener(event -> System.exit(0));
```

Now consider the case in which we have multiple related actions, such as the color buttons of the preceding section. In such a case, implement a helper method:

```
public void makeButton(String name, Color backgroundColor)
{
   var button = new JButton(name);
   buttonPanel.add(button);
   button.addActionListener(event ->
      buttonPanel.setBackground(backgroundColor));
}
```

Note that the lambda expression refers to the parameter variable `backgroundColor`.

Then we simply call

```
makeButton("yellow", Color.YELLOW);
makeButton("blue", Color.BLUE);
makeButton("red", Color.RED);
```

Here, we construct three listener objects, one for each color, without explicitly defining a class. Each time the helper method is called, it makes an instance of a class that implements the `ActionListener` interface. Its `actionPerformed` action references the `backGroundColor` value that is, in fact, stored with the listener object. However, all this happens without you having to explicitly define listener classes, instance variables, or constructors that set them.

NOTE:

In older code, you will often see the use of anonymous classes:

```
exitButton.addActionListener(new ActionListener()
   {
      public void actionPerformed(new ActionEvent)
```

```
        {
           System.exit(0);
        }
     });
```

Of course, this rather verbose code is no longer necessary. Using a lambda expression is simpler and clearer.

10.4.4 Adapter Classes

Not all events are as simple to handle as button clicks. Suppose you want to monitor when the user tries to close the main frame in order to put up a dialog and exit the program only when the user agrees.

When the user tries to close a window, the `JFrame` object is the source of a `WindowEvent`. If you want to catch that event, you must have an appropriate listener object and add it to the frame's list of window listeners.

```
WindowListener listener = . . .;
frame.addWindowListener(listener);
```

The window listener must be an object of a class that implements the `WindowListener` interface. There are actually seven methods in the `WindowListener` interface. The frame calls them as the responses to seven distinct events that could happen to a window. The names are self-explanatory, except that "iconified" is usually called "minimized" under Windows. Here is the complete `WindowListener` interface:

```
public interface WindowListener
{
   void windowOpened(WindowEvent e);
   void windowClosing(WindowEvent e);
   void windowClosed(WindowEvent e);
   void windowIconified(WindowEvent e);
   void windowDeiconified(WindowEvent e);
```

```
      void windowActivated(WindowEvent e);
      void windowDeactivated(WindowEvent e);
   }
```

Of course, we can define a class that implements the interface, add a call to `System.exit(0)` in the `windowClosing` method, and write do-nothing functions for the other six methods. However, typing code for six methods that don't do anything is the kind of tedious busywork that nobody likes. To simplify this task, each of the AWT listener interfaces that have more than one method comes with a companion *adapter* class that implements all the methods in the interface but does nothing with them. For example, the `WindowAdapter` class has seven do-nothing methods. You extend the adapter class to specify the desired reactions to some, but not all, of the event types in the interface. (An interface such as `ActionListener` that has only a single method does not need an adapter class.)

Here is how we can define a window listener that overrides the `windowClosing` method:

```
class Terminator extends WindowAdapter
{
   public void windowClosing(WindowEvent e)
   {
      if (user agrees)
         System.exit(0);
   }
}
```

Now you can register an object of type `Terminator` as the event listener:

```
var listener = new Terminator();
frame.addWindowListener(listener);
```

NOTE:

Nowadays, one would implement do-nothing methods of the `WindowListener` interface as default methods. However, Swing was invented many years before there were default methods.

---

java.awt.event.WindowListener 1.1

- `void windowOpened(WindowEvent e)`

  is called after the window has been opened.

- `void windowClosing(WindowEvent e)`

  is called when the user has issued a window manager command to close the window. Note that the window will close only if its `hide` or `dispose` method is called.

- `void windowClosed(WindowEvent e)`

  is called after the window has closed.

- `void windowIconified(WindowEvent e)`

  is called after the window has been iconified.

- `void windowDeiconified(WindowEvent e)`

  is called after the window has been deiconified.

- `void windowActivated(WindowEvent e)`

  is called after the window has become active. Only a frame or dialog can be active. Typically, the window manager decorates the active window—for example, by highlighting the title bar.

- `void windowDeactivated(WindowEvent e)`

  is called after the window has become deactivated.

java.awt.event.WindowStateListener 1.4

- `void windowStateChanged(WindowEvent event)` is called after the window has been maximized, iconified, or restored to normal size.

10.4.5 Actions

It is common to have multiple ways to activate the same command. The user can choose a certain function through a menu, a keystroke, or a button on a toolbar. This is easy to achieve in the AWT event model: link all events to the same listener. For example, suppose `blueAction` is an action listener whose `actionPerformed` method changes the background color to blue. You can attach the same object as a listener to several event sources:

- A toolbar button labeled "Blue"
- A menu item labeled "Blue"
- A keystroke Ctrl+B

The color change command will now be handled in a uniform way, no matter whether it was caused by a button click, a menu selection, or a key press.

The Swing package provides a very useful mechanism to encapsulate commands and to attach them to multiple event sources: the `Action` interface. An *action* is an object that encapsulates

- A description of the command (as a text string and an optional icon); and
- Parameters that are necessary to carry out the command (such as the requested color in our example).

The `Action` interface has the following methods:

```
void actionPerformed(ActionEvent event)
void setEnabled(boolean b)
boolean isEnabled()
void putValue(String key, Object value)
Object getValue(String key)
void addPropertyChangeListener(PropertyChangeListener listener)
```

```
void removePropertyChangeListener(PropertyChangeListener
listener)
```

The first method is the familiar method in the `ActionListener` interface; in fact, the `Action` interface extends the `ActionListener` interface. Therefore, you can use an `Action` object whenever an `ActionListener` object is expected.

The next two methods let you enable or disable the action and check whether the action is currently enabled. When an action is attached to a menu or toolbar and the action is disabled, the option is grayed out.

The `putValue` and `getValue` methods let you store and retrieve arbitrary name/value pairs in the action object. A couple of important predefined strings, namely `Action.NAME` and `Action.SMALL_ICON`, store action names and icons into an action object:

```
action.putValue(Action.NAME, "Blue");
action.putValue(Action.SMALL_ICON, new ImageIcon("blue-
ball.gif"));
```

Table 10.1 shows all predefined action table names.

If the action object is added to a menu or toolbar, the name and icon are automatically retrieved and displayed in the menu item or toolbar button. The `SHORT_DESCRIPTION` value turns into a tooltip.

The final two methods of the `Action` interface allow other objects, in particular menus or toolbars that trigger the action, to be notified when the properties of the action object change. For example, if a menu is added as a property change listener of an action object and the action object is subsequently disabled, the menu is called and can gray out the action name.

Note that `Action` is an *interface*, not a class. Any class implementing this interface must implement the seven methods we just discussed. Fortunately, a friendly soul has provided a class `AbstractAction` that implements all methods except for `actionPerformed`. That class takes care of storing all name/value pairs and managing the property change listeners. You simply extend `AbstractAction` and supply an `actionPerformed` method.

Table 10.1 Predefined Action Table Names

Name	Value
NAME	The name of the action, displayed on buttons and menu items.
SMALL_ICON	A place to store a small icon for display in a button, menu item, or toolbar.
SHORT_DESCRIPTION	A short description of the icon for display in a tooltip.
LONG_DESCRIPTION	A long description of the icon for potential use in online help. No Swing component uses this value.
MNEMONIC_KEY	A mnemonic abbreviation for display in menu items.
ACCELERATOR_KEY	A place to store an accelerator keystroke. No Swing component uses this value.
ACTION_COMMAND_KEY	Historically, used in the now-obsolete `registerKeyboardAction` method.
DEFAULT	Potentially useful catch-all property. No Swing component uses this value.

Let's build an action object that can execute color change commands. We store the name of the command, an icon, and the desired color. We store the color in the table of name/value pairs that the `AbstractAction` class provides. Here is the code for the `ColorAction` class. The constructor sets the name/value pairs, and the `actionPerformed` method carries out the color change action.

```
public class ColorAction extends AbstractAction
{
   public ColorAction(String name, Icon icon, Color c)
   {
      putValue(Action.NAME, name);
```

```
        putValue(Action.SMALL_ICON, icon);
        putValue("color", c);
        putValue(Action.SHORT_DESCRIPTION, "Set panel color to "
+ name.toLowerCase());
    }
    public void actionPerformed(ActionEvent event)
    {
        Color c = (Color) getValue("color");
        buttonPanel.setBackground(c);
    }
}
```

Our test program creates three objects of this class, such as

```
var blueAction = new ColorAction("Blue", new ImageIcon("blue-
ball.gif"), Color.BLUE);
```

Next, let's associate this action with a button. That is easy because we can use a `JButton` constructor that takes an `Action` object.

```
var blueButton = new JButton(blueAction);
```

That constructor reads the name and icon from the action, sets the short description as the tooltip, and sets the action as the listener. You can see the icons and a tooltip in Figure 10.15.

As demonstrated in the next chapter, it is just as easy to add the same action to a menu.

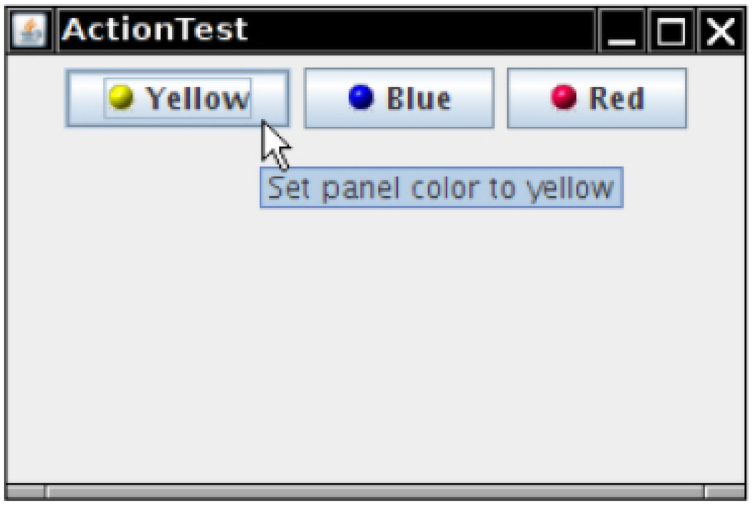


Figure 10.15 Buttons display the icons from the action objects.

Finally, we want to add the action objects to keystrokes so that an action is carried out when the user types a keyboard command. To associate actions with keystrokes, you first need to generate objects of the `KeyStroke` class. This convenience class encapsulates the description of a key. To generate a `KeyStroke` object, don't call a constructor but instead use the static `getKeyStroke` method of the `KeyStroke` class.

```
KeyStroke ctrlBKey = KeyStroke.getKeyStroke("ctrl B");
```

To understand the next step, you need to understand the concept of *keyboard focus*. A user interface can have many buttons, menus, scrollbars, and other components. When you hit a key, it is sent to the component that has focus. That component is usually (but not always) visually distinguished. For example, in the Java look-and-feel, a button with focus has a thin rectangular border around the button text. You can use the Tab key to move the focus between components. When you press the space bar, the button with focus is clicked. Other keys carry out different actions; for example, the arrow keys can move a scrollbar.

However, in our case, we do not want to send the keystroke to the component that has focus. Otherwise, each of the buttons would need to know how to handle the Ctrl+Y, Ctrl+B, and Ctrl+R keys.

This is a common problem, and the Swing designers came up with a convenient solution. Every `JComponent` has three *input maps*, each mapping `KeyStroke` objects to associated actions. The three input maps correspond to three different conditions (see Table 10.2).

Table 10.2 Input Map Conditions

Flag	Invoke Action
WHEN_FOCUSED	When this component has keyboard focus
WHEN_ANCESTOR_OF_FOCUSED_COMPONENT	When this component contains the component that has keyboard focus
WHEN_IN_FOCUSED_WINDOW	When this component is contained in the same window as the component that has keyboard focus

Keystroke processing checks these maps in the following order:

1. Check the `WHEN_FOCUSED` map of the component with input focus. If the keystroke exists and its corresponding action is enabled, execute the action and stop processing.
2. Starting from the component with input focus, check the `WHEN_ANCESTOR_OF_FOCUSED_COMPONENT` maps of its parent components. As soon as a map with the keystroke and a corresponding enabled action is found, execute the action and stop processing.
3. Look at all *visible* and *enabled* components, in the window with input focus, that have this keystroke registered in a `WHEN_IN_FOCUSED_WINDOW` map. Give these components (in the order of their keystroke registration) a chance to execute the corresponding action. As soon as the first enabled action is executed, stop processing.

To obtain an input map from the component, use the `getInputMap` method. Here is an example:

```
InputMap imap = panel.getInputMap(JComponent.WHEN_FOCUSED);
```

The WHEN_FOCUSED condition means that this map is consulted when the current component has the keyboard focus. In our situation, that isn't the map we want. One of the buttons, not the panel, has the input focus. Either of the other two map choices works fine for inserting the color change keystrokes. We use WHEN_ANCESTOR_OF_FOCUSED_COMPONENT in our example program.

The InputMap doesn't directly map KeyStroke objects to Action objects. Instead, it maps to arbitrary objects, and a second map, implemented by the ActionMap class, maps objects to actions. That makes it easier to share the same actions among keystrokes that come from different input maps.

Thus, each component has three input maps and one action map. To tie them together, you need to come up with names for the actions. Here is how you can tie a key to an action:

```
imap.put(KeyStroke.getKeyStroke("ctrl Y"), "panel.yellow");
ActionMap amap = panel.getActionMap();
amap.put("panel.yellow", yellowAction);
```

It is customary to use the string "none" for a do-nothing action. That makes it easy to deactivate a key:

```
imap.put(KeyStroke.getKeyStroke("ctrl C"), "none");
```

CAUTION:

The JDK documentation suggests using the action name as the action's key. I don't think that is a good idea. The action name is displayed on buttons and menu items; thus, it can change at the whim of the UI designer and may be translated into multiple languages. Such unstable strings are poor choices for lookup keys, so I recommend that you come up with action names that are independent of the displayed names.

To summarize, here is what you do to carry out the same action in response to a button, a menu item, or a keystroke:

1. Implement a class that extends the `AbstractAction` class. You may be able to use the same class for multiple related actions.
2. Construct an object of the action class.
3. Construct a button or menu item from the action object. The constructor will read the label text and icon from the action object.
4. For actions that can be triggered by keystrokes, you have to carry out additional steps. First, locate the top-level component of the window, such as a panel that contains all other components.
5. Then, get the `WHEN_ANCESTOR_OF_FOCUSED_COMPONENT` input map of the top-level component. Make a `KeyStroke` object for the desired keystroke. Make an action key object, such as a string that describes your action. Add the pair (keystroke, action key) into the input map.
6. Finally, get the action map of the top-level component. Add the pair (action key, action object) into the map.

javax.swing.Action 1.2

- `boolean isEnabled()`
- `void setEnabled(boolean b)`

  gets or sets the `enabled` property of this action.

- `void putValue(String key, Object value)`

  places a key/value pair inside the action object. The key can be any string, but several names have predefined meanings—see Table 10.1.

- `Object getValue(String key)`

  returns the value of a stored name/value pair.

javax.swing.KeyStroke 1.2

- `static KeyStroke getKeyStroke(String description)`

  constructs a keystroke from a human-readable description (a sequence of whitespace-delimited strings). The description starts with zero or more modifiers (`shift`, `control`, `ctrl`, `meta`, `alt`, `altGraph`) and ends with either the string `typed`, followed by a one-character string (for example, `"typed a"`), or an optional event specifier (`pressed` or `released`, with `pressed` being the default), followed by a key code. The key code, when prefixed with `VK_`, should correspond to a `KeyEvent` constant; for example, `"INSERT"` corresponds to `KeyEvent.VK_INSERT`.

`javax.swing.JComponent` 1.2

- `ActionMap getActionMap()` 1.3

  returns the map that associates action map keys (which can be arbitrary objects) with `Action` objects.

- `InputMap getInputMap(int flag)` 1.3

  gets the input map that maps key strokes to action map keys. The flag is one of the values in Table 10.2.

10.4.6 Mouse Events

You do not need to handle mouse events explicitly if you just want the user to be able to click on a button or menu. These mouse operations are handled internally by the various components in the user interface. However, if you want to enable the user to draw with the mouse, you will need to trap the mouse move, click, and drag events.

In this section, I will show you a simple graphics editor application that allows the user to place, move, and erase squares on a canvas (see Figure 10.16).

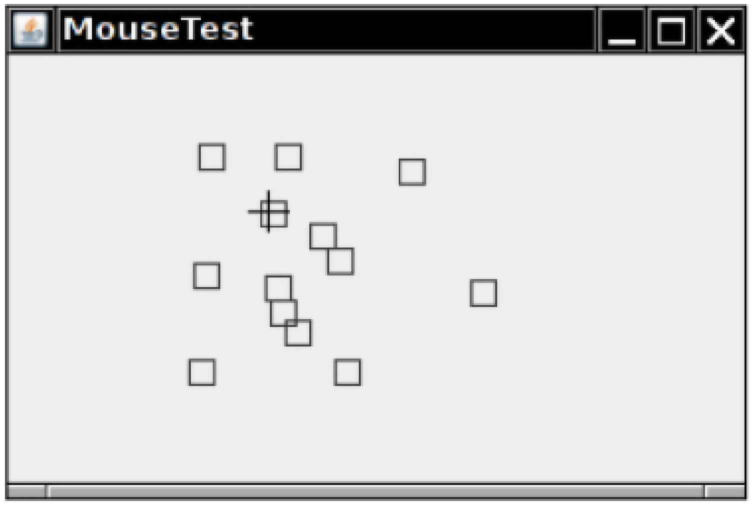


Figure 10.16 A mouse test program

When the user clicks a mouse button, three listener methods are called: `mousePressed` when the mouse is first pressed, `mouseReleased` when the mouse is released, and, finally, `mouseClicked`. If you are only interested in complete clicks, you can ignore the first two methods. By using the `getX` and `getY` methods on the `MouseEvent` argument, you can obtain the *x* and *y* coordinates of the mouse pointer when the mouse was clicked. To distinguish between single, double, and triple (!) clicks, use the `getClickCount` method.

In our sample program, we supply both a `mousePressed` and a `mouseClicked` methods. When you click on a pixel that is not inside any of the squares that have been drawn, a new square is added. We implemented this in the `mousePressed` method so that the user receives immediate feedback and does not have to wait until the mouse button is released. When a user double-clicks inside an existing square, it is erased. We implemented this in the `mouseClicked` method because we need the click count.

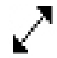
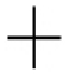
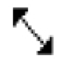
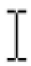
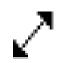
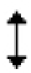
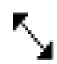
```
public void mousePressed(MouseEvent event)
{
   current = find(event.getPoint());
   if (current == null) // not inside a square
      add(event.getPoint());
}
public void mouseClicked(MouseEvent event)
```

```
{
   current = find(event.getPoint());
   if (current != null && event.getClickCount() >= 2)
      remove(current);
}
```

As the mouse moves over a window, the window receives a steady stream of mouse movement events. Note that there are separate `MouseListener` and `MouseMotionListener` interfaces. This is done for efficiency—there are a lot of mouse events as the user moves the mouse around, and a listener that just cares about mouse *clicks* will not be bothered with unwanted mouse *moves*.

Our test application traps mouse motion events to change the cursor to a different shape (a cross hair) when it is over a square. This is done with the `getPredefinedCursor` method of the `Cursor` class. Table 10.3 lists the constants to use with this method along with what the cursors look like under Windows.

Table 10.3 Sample Cursor Shapes

Icon	Constant	Icon	Constant
	DEFAULT_CURSOR		NE_RESIZE_CURSOR
	CROSSHAIR_CURSOR		E_RESIZE_CURSOR
	HAND_CURSOR		SE_RESIZE_CURSOR
	MOVE_CURSOR		S_RESIZE_CURSOR
	TEXT_CURSOR		SW_RESIZE_CURSOR
	WAIT_CURSOR		W_RESIZE_CURSOR
	N_RESIZE_CURSOR		NW_RESIZE_CURSOR

Here is the `mouseMoved` method of the `MouseMotionListener` in our example program:

```
public void mouseMoved(MouseEvent event)
{
   if (find(event.getPoint()) == null)
      setCursor(Cursor.getDefaultCursor());
   else
      setCursor(Cursor.getPredefinedCursor(Cursor.CROSSHAIR_CUR
SOR));
}
```

If the user presses a mouse button while the mouse is in motion, `mouseDragged` calls are generated instead of `mouseMoved` calls. Our test application lets a user drag the square under the cursor. We simply update the currently dragged rectangle to be centered under the mouse position. Then, we repaint the canvas to show the new mouse position.

```
public void mouseDragged(MouseEvent event)
{
   if (current != null)
   {
      int x = event.getX();
      int y = event.getY();
      current.setFrame(x - SIDELENGTH / 2, y - SIDELENGTH / 2,
SIDELENGTH, SIDELENGTH);
      repaint();
   }
}
```

NOTE:

The `mouseMoved` method is only called as long as the mouse stays inside the component. However, the `mouseDragged` method keeps getting called even when the mouse is being dragged outside the component.

There are two other mouse event methods: `mouseEntered` and `mouseExited`. These methods are called when the mouse enters or exits a component.

Finally, let's see how to listen to mouse events. Mouse clicks are reported through the `mouseClicked` method, which is part of the `MouseListener` interface. Many applications are only interested in mouse clicks and not in mouse moves; with the mouse move events occurring so frequently, the mouse move and drag events are defined in a separate interface called `MouseMotionListener`.

In our program we are interested in both types of mouse events. We define two inner classes: `MouseHandler` and `MouseMotionHandler`. The `MouseHandler` class extends the `MouseAdapter` class because it defines only two of the five `MouseListener` methods. (The `MouseAdapter` class defines all of them as do-nothing methods.) The `MouseMotionHandler` implements the `MouseMotionListener` and defines both methods of that interface. Listing 10.6 is the program listing.

Listing 10.6 `mouse/MouseComponent.java`

```java
package mouse;

import java.awt.*;
import java.awt.event.*;
import java.awt.geom.*;
import java.util.*;
import javax.swing.*;

/**
 * A component with mouse operations for adding and removing squares.
 */
public class MouseComponent extends JComponent
{
   private static final int DEFAULT_WIDTH = 300;
   private static final int DEFAULT_HEIGHT = 200;

   private static final int SIDELENGTH = 10;
   private ArrayList<Rectangle2D> squares;
   private Rectangle2D current; // the square containing the mouse cursor

   public MouseComponent()
   {
      squares = new ArrayList<>();
      current = null;

      addMouseListener(new MouseHandler());
      addMouseMotionListener(new MouseMotionHandler());
   }

   public Dimension getPreferredSize()
   {
      return new Dimension(DEFAULT_WIDTH, DEFAULT_HEIGHT);
   }

   public void paintComponent(Graphics g)
```

```
      {
         var g2 = (Graphics2D) g;

         // draw all squares
         for (Rectangle2D r : squares)
            g2.draw(r);
      }

   /**
    * Finds the first square containing a point.
    * @param p a point
    * @return the first square that contains p
    */
   public Rectangle2D find(Point2D p)
   {
      for (Rectangle2D r : squares)
      {
         if (r.contains(p)) return r;
      }
       return null;
   }

   /**
    * Adds a square to the collection.
    * @param p the center of the square
    */
   public void add(Point2D p)
   {
      double x = p.getX();
      double y = p.getY();

      current = new Rectangle2D.Double(x - SIDELENGTH / 2, y - SIDELENGTH / 2,
         SIDELENGTH, SIDELENGTH);
      squares.add(current);
      repaint();
   }

   /**
```

```
 * Removes a square from the collection.
 * @param s the square to remove
 */
public void remove(Rectangle2D s)
{
   if (s == null) return;
   if (s == current) current = null;
   squares.remove(s);
   repaint();
}

private class MouseHandler extends MouseAdapter
{
   public void mousePressed(MouseEvent event)
   {
      // add a new square if the cursor isn't inside a square
      current = find(event.getPoint());
      if (current == null) add(event.getPoint());
   }

   public void mouseClicked(MouseEvent event)
   {
       // remove the current square if double clicked
       current = find(event.getPoint());
       if (current != null && event.getClickCount() >= 2) remove(current);
   }
}

   private class MouseMotionHandler implements MouseMotionListener
   {
      public void mouseMoved(MouseEvent event)
      {
         // set the mouse cursor to cross hairs if it is inside a rectangle

         if (find(event.getPoint()) == null) setCursor(Cursor.getDefaultCursor());
```

```
         else setCursor(Cursor.getPredefinedCursor(Cursor.CROSSHAIR_CURSOR));
      }

      public void mouseDragged(MouseEvent event)
      {
         if (current != null)
         {
            int x = event.getX();
            int y = event.getY();

            // drag the current rectangle to center it at (x, y)
            current.setFrame(x - SIDELENGTH / 2, y - SIDELENGTH / 2, SIDELENGTH, SIDELENGTH);
            repaint();
         }
      }
   }
}
```

`java.awt.event.MouseEvent` 1.1

- `int getX()`
- `int getY()`
- `Point getPoint()`

  returns the *x* (horizontal) and *y* (vertical) coordinates of the point where the event happened, measured from the top left corner of the component that is the event source.

- `int getClickCount()`

  returns the number of consecutive mouse clicks associated with this event. (The time interval for what constitutes “consecutive” is system-dependent.)

java.awt.Component 1.0

- `public void setCursor(Cursor cursor)` 1.1

  sets the cursor image to the specified cursor.

10.4.7 The AWT Event Hierarchy

The `EventObject` class has a subclass `AWTEvent`, which is the parent of all AWT event classes. Figure 10.17 shows the inheritance diagram of the AWT events.

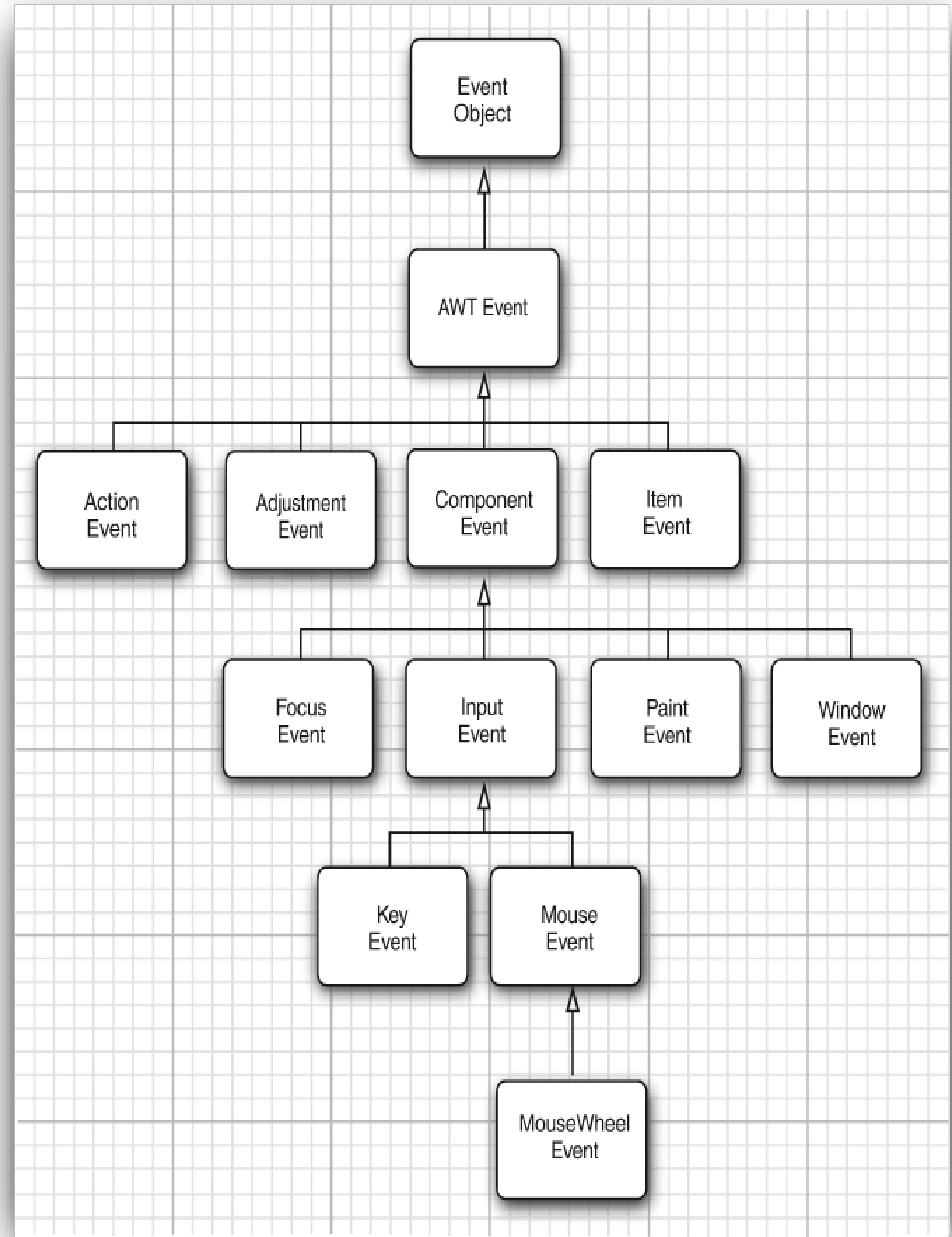


Figure 10.17 Inheritance diagram of AWT event classes

Some of the Swing components generate event objects of yet more event types; these directly extend `EventObject`, not `AWTEvent`.

The event objects encapsulate information about the event that the event source communicates to its listeners. When necessary, you can then analyze the event objects that were passed to the listener object, as we did in the button example with the `getSource` and `getActionCommand` methods.

Some of the AWT event classes are of no practical use for the Java programmer. For example, the AWT inserts `PaintEvent` objects into the event queue, but these objects are not delivered to listeners. Java programmers don't listen to paint events; instead, they override the `paintComponent` method to control re-painting. The AWT also generates a number of events that are needed only by systems programmers, to provide input systems for ideographic languages, automated testing robots, and so on.

The AWT makes a useful distinction between *low-level* and *semantic* events. A semantic event is one that expresses what the user is doing, such as "clicking that button"; an `ActionEvent` is a semantic event. Low-level events are those events that make this possible. In the case of a button click, this is a mouse down, a series of mouse moves, and a mouse up (but only if the mouse up is inside the button area). Or it might be a keystroke, which happens if the user selects the button with the Tab key and then activates it with the space bar. Similarly, adjusting a scrollbar is a semantic event, but dragging the mouse is a low-level event.

Here are the most commonly used semantic event classes in the `java.awt.event` package:

- `ActionEvent` (for a button click, a menu selection, selecting a list item, or Enter typed in a text field)
- `AdjustmentEvent` (the user adjusted a scrollbar)
- `ItemEvent` (the user made a selection from a set of checkbox or list items)

Five low-level event classes are commonly used:

- `KeyEvent` (a key was pressed or released)

- `MouseEvent` (the mouse button was pressed, released, moved, or dragged)
- `MouseWheelEvent` (the mouse wheel was rotated)
- `FocusEvent` (a component got focus or lost focus)
- `WindowEvent` (the window state changed)

Table 10.4 shows the most important AWT listener interfaces, events, and event sources.

Table 10.4 Event Handling Summary

Interface	Methods	Parameter/Accessors	Events Generated By
ActionListener	actionPerformed	ActionEvent • getActionCommand • getModifiers	AbstractButton JComboBox JTextField Timer
AdjustmentListener	adjustmentValueChanged	AdjustmentEvent • getAdjustable • getAdjustmentType • getValue	JScrollbar
ItemListener	itemStateChanged	ItemEvent • getItem • getItemSelectable • getStateChange	AbstractButton JComboBox
FocusListener	focusGained focusLost	FocusEvent • isTemporary	Component
KeyListener	keyPressed keyReleased keyTyped	KeyEvent • getKeyChar • getKeyCode • getKeyModifiersText • getKeyText • isActionKey	Component
MouseListener	mousePressed mouseReleased mouseEntered mouseExited mouseClicked	MouseEvent • getClickCount • getX • getY • getPoint • translatePoint	Component
MouseMotionListener	mouseDragged mouseMoved	MouseEvent	Component
MouseWheelListener	mouseWheelMoved	MouseWheelEvent • getWheelRotation • getScrollAmount	Component
WindowListener	windowClosing windowOpened windowIconified windowDeiconified windowClosed windowActivated windowDeactivated	WindowEvent • getWindow	Window
WindowFocusListener	windowGainedFocus windowLostFocus	WindowEvent • getOppositeWindow	Window
WindowStateListener	windowStateChanged	WindowEvent • getOldState • getNewState	Window

10.5 The Preferences API

I end this chapter with a discussion of the `java.util.prefs` API. In a desktop program, you will often want to store user preferences, such as the last file that the user worked on, the last window location, and so on.

As you have seen in Chapter 9, the `Properties` class makes it simple to load and save configuration information of a program. However, using property files has these disadvantages:

- Some operating systems have no concept of a home directory, making it difficult to find a uniform location for configuration files.
- There is no standard convention for naming configuration files, increasing the likelihood of name clashes as users install multiple Java applications.

Some operating systems have a central repository for configuration information. The best-known example is the registry in Microsoft Windows. The `Preferences` class provides such a central repository in a platform-independent manner. In Windows, the `Preferences` class uses the registry for storage; on Linux, the information is stored in the local file system instead. Of course, the repository implementation is transparent to the programmer using the `Preferences` class.

The `Preferences` repository has a tree structure, with node path names such as `/com/mycompany/myapp`. As with package names, name clashes are avoided as long as programmers start the paths with reversed domain names. In fact, the designers of the API suggest that the configuration node paths match the package names in your program.

Each node in the repository has a separate table of key/value pairs that you can use to store numbers, strings, or byte arrays. No provision is made for storing serializable objects. The API designers felt that the serialization format is too fragile for long-term storage. Of course, if you disagree, you can save serialized objects in byte arrays.

For additional flexibility, there are multiple parallel trees. Each program user has one tree; an additional tree, called the system tree, is available for settings that are common to all users. The `Preferences` class uses the operating system's notion of the "current user" for accessing the appropriate user tree.

To access a node in the tree, start with the user or system root:

```
Preferences root = Preferences.userRoot();
```

or

```
Preferences root = Preferences.systemRoot();
```

Then access the node. You can simply provide a node path name:

```
Preferences node = root.node("/com/mycompany/myapp");
```

A convenient shortcut gets a node whose path name equals the package name of a class. Simply take an object of that class and call

```
Preferences node =
Preferences.userNodeForPackage(obj.getClass());
```

or

```
Preferences node =
Preferences.systemNodeForPackage(obj.getClass());
```

Typically, `obj` will be the `this` reference.

Once you have a node, you can access the key/value table with methods

```
String get(String key, String defval)
int getInt(String key, int defval)
long getLong(String key, long defval)
float getFloat(String key, float defval)
double getDouble(String key, double defval)
```

```
boolean getBoolean(String key, boolean defval)
byte[] getByteArray(String key, byte[] defval)
```

Note that you must specify a default value when reading the information, in case the repository data is not available. Defaults are required for several reasons. The data might be missing because the user never specified a preference. Certain resource-constrained platforms might not have a repository, and mobile devices might be temporarily disconnected from the repository.

Conversely, you can write data to the repository with `put` methods such as

```
put(String key, String value)
putInt(String key, int value)
```

and so on.

You can enumerate all keys stored in a node with the method

```
String[] keys()
```

There is currently no way to find out the type of the value of a particular key.

NOTE:

Node names and keys are limited to 80 characters, and string values to 8192 characters.

Central repositories such as the Windows registry traditionally suffer from two problems:

- They turn into a "dumping ground" filled with obsolete information.
- Configuration data gets entangled into the repository, making it difficult to move preferences to a new platform.

The `Preferences` class has a solution for the second problem. You can export the preferences of a subtree (or, less commonly, a single node) by calling the methods

```
void exportSubtree(OutputStream out)
void exportNode(OutputStream out)
```

The data are saved in XML format. You can import them into another repository by calling

```
void importPreferences(InputStream in)
```

Here is a sample file:

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE preferences SYSTEM
"http://java.sun.com/dtd/preferences.dtd">
<preferences EXTERNAL_XML_VERSION="1.0">
   <root type="user">
      <map/>
      <node name="com">
         <map/>
         <node name="horstmann">
            <map/>
            <node name="corejava">
               <map>
            <entry key="height" value="200.0"/>
            <entry key="left" value="1027.0"/>
            <entry key="filename"
value="/home/cay/books/cj11/code/v1ch11/raven.html"/>
            <entry key="top" value="380.0"/>
            <entry key="width" value="300.0"/>
               </map>
            </node>
         </node>
      </node>
```

```
    </root>
</preferences>
```

If your program uses preferences, you should give your users the opportunity of exporting and importing them, so they can easily migrate their settings from one computer to another. The program in Listing 10.7 demonstrates this technique. The program simply saves the window location and the last loaded filename. Try resizing the window, then export your preferences, move the window, exit, and restart the application. The window will be just like you left it when you exited. Import your preferences, and the window reverts to its prior location.

Listing 10.7 `preferences/ImageViewer.java`

```
package preferences;

import java.awt.EventQueue;
import java.awt.event.*;
import java.io.*;
import java.util.prefs.*;
import javax.swing.*;

/**
 * A program to test preference settings. The program remembers the
 * frame position, size, and last selected file.
 * @version 1.10 2018-04-10
 * @author Cay Horstmann
 */
public class ImageViewer
{
   public static void main(String[] args)
   {
      EventQueue.invokeLater(() ->
         {
            var frame = new ImageViewerFrame();
            frame.setTitle("ImageViewer");
            frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOS
```

```
E);
            frame.setVisible(true);
         });
   }
}

/**
 * An image viewer that restores position, size, and image from user
 * preferences and updates the preferences upon exit.
 */
class ImageViewerFrame extends JFrame
{
   private static final int DEFAULT_WIDTH = 300;
   private static final int DEFAULT_HEIGHT = 200;
   private String image;

   public ImageViewerFrame()
   {
      Preferences root = Preferences.userRoot();
      Preferences node = root.node("/com/horstmann/corejava/ImageViewer");
      // get position, size, title from properties
      int left = node.getInt("left", 0);
      int top = node.getInt("top", 0);
      int width = node.getInt("width", DEFAULT_WIDTH);
      int height = node.getInt("height", DEFAULT_HEIGHT);
      setBounds(left, top, width, height);
      image = node.get("image", null);
      var label = new JLabel();
      if (image != null) label.setIcon(new ImageIcon(image));

      addWindowListener(new WindowAdapter()
      {
         public void windowClosing(WindowEvent event)
         {
            node.putInt("left", getX());
            node.putInt("top", getY());
            node.putInt("width", getWidth());
```

```
            node.putInt("height", getHeight());
            if (image != null) node.put("image", image);
         }
      });

      // use a label to display the images
      add(label);

      // set up the file chooser
      var chooser = new JFileChooser();
      chooser.setCurrentDirectory(new File("."));

      // set up the menu bar
      var menuBar = new JMenuBar();
      setJMenuBar(menuBar);

      var menu = new JMenu("File");
      menuBar.add(menu);

      var openItem = new JMenuItem("Open");
      menu.add(openItem);
      openItem.addActionListener(event ->
         {
            // show file chooser dialog
            int result = chooser.showOpenDialog(null);

            // if file selected, set it as icon of the label
            if (result == JFileChooser.APPROVE_OPTION)
            {
               image = chooser.getSelectedFile().getPath();
               label.setIcon(new ImageIcon(image));
            }
         });

      var exitItem = new JMenuItem("Exit");
      menu.add(exitItem);
      exitItem.addActionListener(event -> System.exit(0));
   }
}
```

`java.util.prefs.Preferences` 1.4

- `Preferences userRoot()`

  returns the root preferences node of the user of the calling program.

- `Preferences systemRoot()`

  returns the systemwide root preferences node.

- `Preferences node(String path)`

  returns a node that can be reached from the current node by the given path. If `path` is absolute (that is, starts with a `/`), then the node is located starting from the root of the tree containing this preference node. If there isn't a node with the given path, it is created.

- `Preferences userNodeForPackage(Class cl)`
- `Preferences systemNodeForPackage(Class cl)`

  returns a node in the current user's tree or the system tree whose absolute node path corresponds to the package name of the class `cl`.

- `String[] keys()`

  returns all keys belonging to this node.

- `String get(String key, String defval)`
- `int getInt(String key, int defval)`
- `long getLong(String key, long defval)`
- `float getFloat(String key, float defval)`
- `double getDouble(String key, double defval)`
- `boolean getBoolean(String key, boolean defval)`
- `byte[] getByteArray(String key, byte[] defval)`

  returns the value associated with the given key or the supplied default value if no value is associated with the key, the associated value is not of the correct type, or the preferences store is unavailable.

- `void put(String key, String value)`
- `void putInt(String key, int value)`
- `void putLong(String key, long value)`
- `void putFloat(String key, float value)`
- `void putDouble(String key, double value)`
- `void putBoolean(String key, boolean value)`
- `void putByteArray(String key, byte[] value)`

  stores a key/value pair with this node.

- `void exportSubtree(OutputStream out)`

  writes the preferences of this node and its children to the specified stream.

- `void exportNode(OutputStream out)`

  writes the preferences of this node (but not its children) to the specified stream.

- `void importPreferences(InputStream in)`

  imports the preferences contained in the specified stream.

This concludes our introduction into graphical user interface programming. The next chapter shows you how to work with the most common Swing components.

Chapter. 11 User Interface Components with Swing

In this chapter

The previous chapter was written primarily to show you how to use the event model in Java. In the process, you took the first steps toward learning how to build a graphical user interface. This chapter shows you the most important tools you'll need to build more full-featured GUIs.

We start out with a tour of the architectural underpinnings of Swing. Knowing what goes on "under the hood" is important in understanding how to use some of the more advanced components effectively. I then show you the most common user interface components in Swing, such as text fields, radio buttons, and menus. Next, you will learn how to use layout managers to arrange these components. Finally, you'll see how to implement dialog boxes in Swing.

This chapter covers the basic Swing components such as text components, buttons, and sliders. These are the essential user interface components that you will need most frequently. We will cover advanced Swing components in Volume II.

11.1 Swing and the Model-View-Controller Design Pattern

Let's step back for a minute and think about the pieces that make up a user interface component such as a button, a checkbox, a text field, or a sophisticated tree control. Every component has three characteristics:

- Its *content*, such as the state of a button (pushed in or not), or the text in a text field
- Its *visual appearance* (color, size, and so on)
- Its *behavior* (reaction to events)

Even a seemingly simple component such as a button exhibits some moderately complex interaction among these characteristics. Obviously, the visual appearance of a button depends on the look-and-feel. A Metal button looks different from a Windows button or a Motif button. In addition, the appearance depends on the button state; when a button is pushed in, it needs to be redrawn to look different. The state depends on the events that the button receives. When the user depresses the mouse inside the button, the button is pushed in.

Of course, when you use a button in your programs, you simply consider it as a *button*; you don't think too much about the inner workings and characteristics. That, after all, is the job of the programmer who implemented the button. However, programmers who implement buttons and all other user interface components are motivated to think a little harder about them, so that they work well no matter what look-and-feel is in effect.

To do this, the Swing designers turned to a well-known design pattern: the *model-view-controller* (MVC) pattern. This design pattern tells us to provide three separate objects:

- The *model,* which stores the content
- The *view,* which displays the content
- The *controller,* which handles user input

The pattern specifies precisely how these three objects interact. The model stores the content and has *no user interface*. For a button, the content is pretty trivial—just a small set of flags that tells whether the button is currently pushed in or out, whether it is active or inactive, and so on. For a text field, the content is a bit more interesting. It is a string object that holds the current text. This is *not the same* as the view of the content—if the content is larger than the text field, the user sees only a portion of the text displayed (see Figure 11.1).

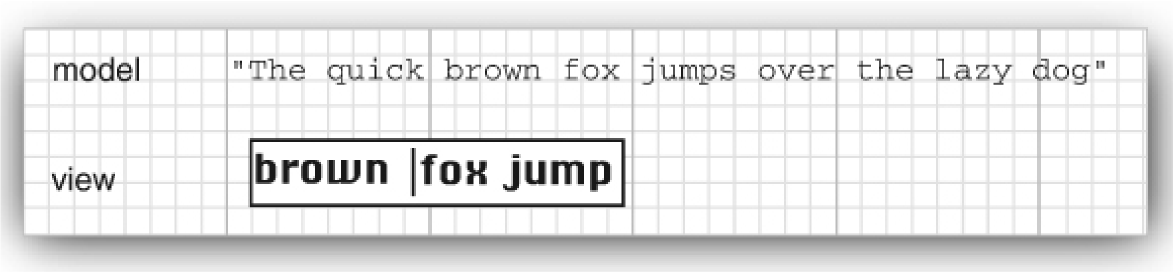


Figure 11.1 Model and view of a text field

The model must implement methods to change the content and to discover what the content is. For example, a text model has methods to add or remove characters in the current text and to return the current text as a string. Again, keep in mind that the model is completely nonvisual. It is the job of a view to draw the data stored in the model.

NOTE:

The term "model" is perhaps unfortunate because we often think of a model as a representation of an abstract concept. Car and airplane designers build models to simulate real cars and planes. But that analogy really leads you astray when thinking about the model-view-controller pattern. In this design pattern, the model stores the complete content, and the view gives a (complete or incomplete) visual representation of the content. A better analogy might be the model who poses for an artist. It is up to the artist to look at the model and create a view. Depending on the artist, that view might be a formal portrait, an impressionist painting, or a cubist drawing with strangely contorted limbs.

One of the advantages of the model-view-controller pattern is that a model can have multiple views, each showing a different part or aspect of the full content. For example, an HTML editor can offer two *simultaneous* views of the same content: a WYSIWYG view and a "raw tag" view (see Figure 11.2). When the model is updated through the controller of one of the views, it tells both attached views about the change. When the views are notified, they refresh themselves automatically. Of course, for a simple user interface component such as a button, you won't have multiple views of the same model.

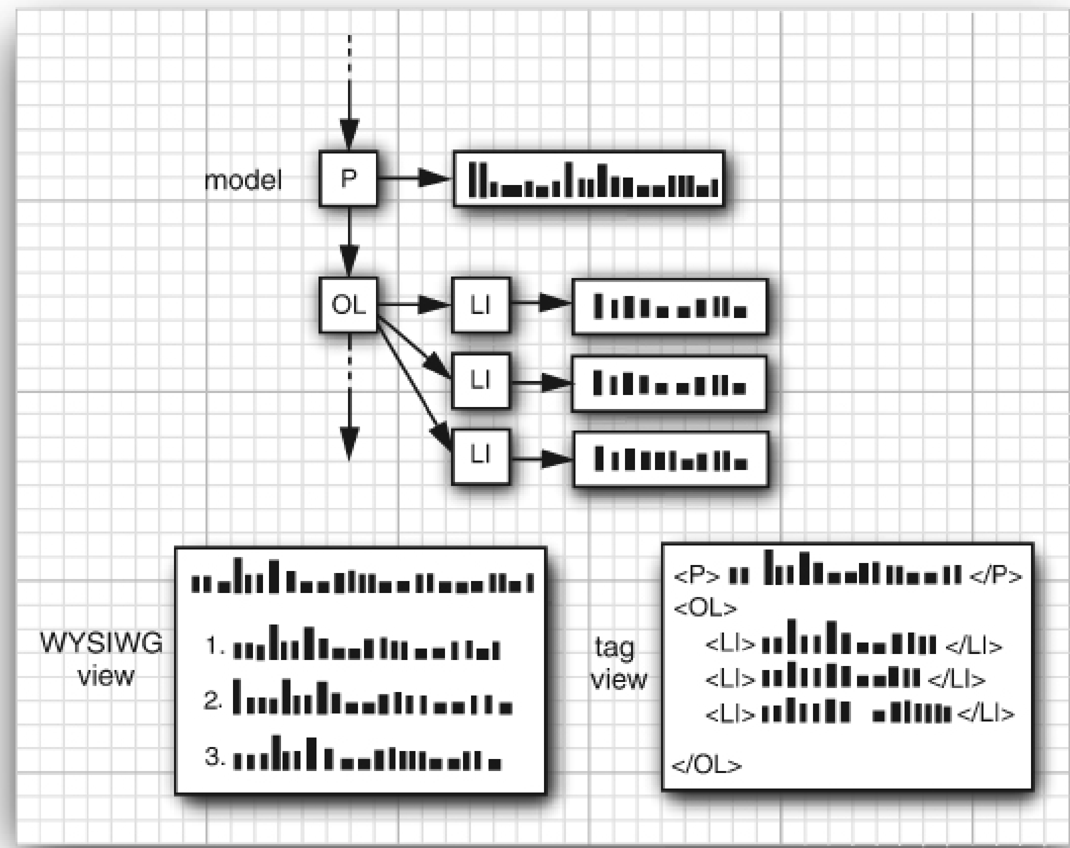


Figure 11.2 Two separate views of the same model

The controller handles the user-input events, such as mouse clicks and keystrokes. It then decides whether to translate these events into changes in the model or the view. For example, if the user presses a character key in a text box, the controller calls the "insert character" command of the model. The model then tells the view to update itself. The view never knows why the text changed. But if the user presses a cursor key, the controller may tell the view to scroll. Scrolling the view has no effect on the underlying text, so the model never knows that this event happened.

Figure 11.3 shows the interactions among model, view, and controller objects.

For most Swing components, the model class implements an interface whose name ends in `Model`; in this case, the interface is called `ButtonModel`. Classes implementing that interface can define the state of the various kinds of buttons. Actually, buttons aren't all that complicated, and the Swing library contains a single class, called `DefaultButtonModel`, that implements this interface.

You can get a sense of the sort of data maintained by a button model by looking at the properties of the `ButtonModel` interface—see Table 11.1.

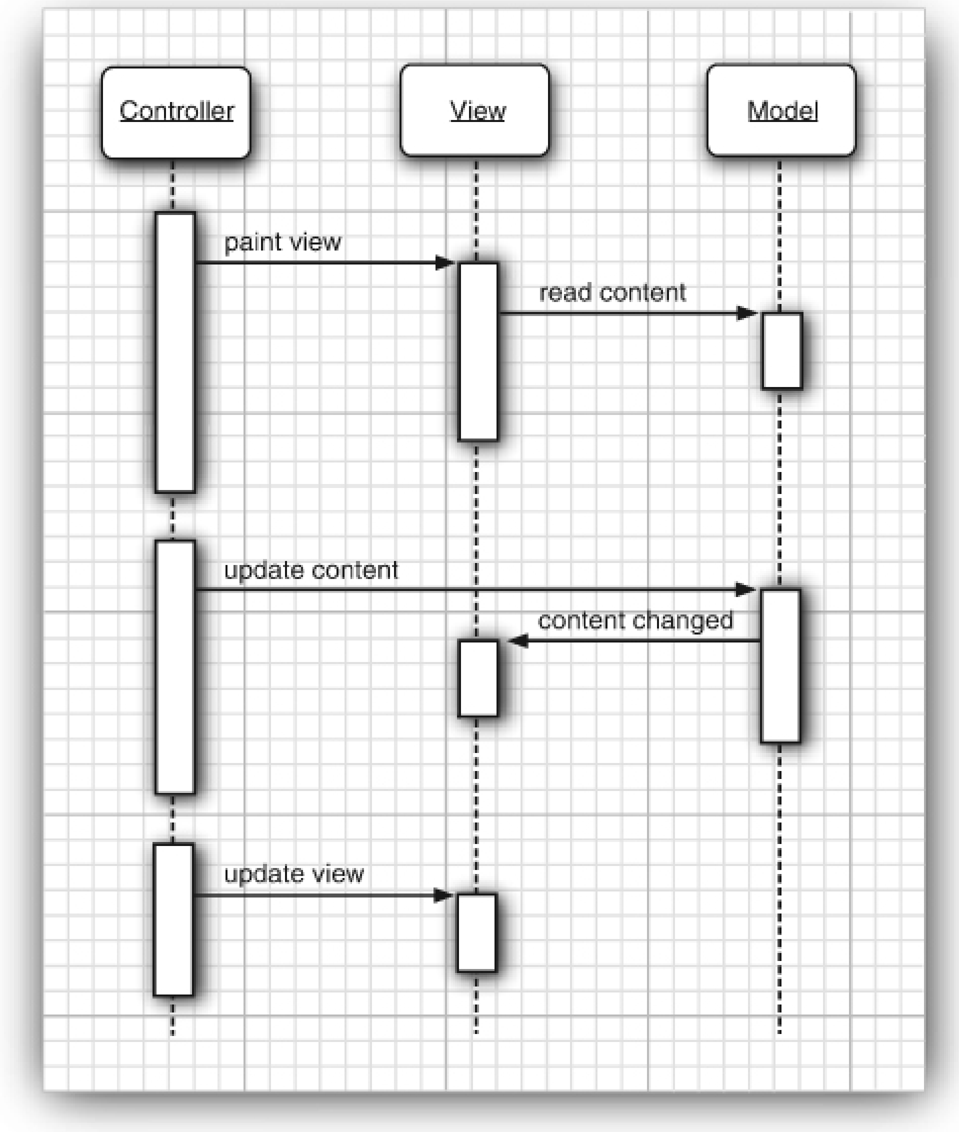


Figure 11.3 Interactions among model, view, and controller objects

Table 11.1 Properties of the `ButtonModel` Interface

Property Name	Value
actionCommand	The action command string associated with this button
mnemonic	The keyboard mnemonic for this button
armed	true if the button was pressed and the mouse is still over the button
enabled	true if the button is selectable
pressed	true if the button was pressed but the mouse button hasn't yet been released
rollover	true if the mouse is over the button
selected	true if the button has been toggled on (used for checkboxes and radio buttons)

Each `JButton` object stores a button model object which you can retrieve.

```
var button = new JButton("Blue");
ButtonModel model = button.getModel();
```

In practice, you won't care—the minutiae of the button state are only of interest to the view that draws it. All the important information—such as whether a button is enabled—is available from the `JButton` class. (Of course, the `JButton` then asks its model to retrieve that information.)

Have another look at the `ButtonModel` interface to see what *isn't* there. The model does *not* store the button label or icon. There is no way to find out what's on the face of a button just by looking at its model. (Actually, as you will see in Section 11.4.2, "Radio Buttons," on p. 670, this purity of design is the source of some grief for the programmer.)

It is also worth noting that the *same* model (namely, `DefaultButtonModel`) is used for push buttons, radio buttons, checkboxes, and even menu items. Of course, each of these button types has different views and controllers. When using the Metal look-and-feel, the `JButton` uses a class called `BasicButtonUI` for the view and a class called `ButtonUIListener` as controller. In general, each Swing component has an associated view object that ends in `UI`. But not all Swing components have dedicated controller objects.

So, having read this short introduction to what is going on under the hood in a `JButton`, you may be wondering: Just what is a `JButton` really? It is simply a wrapper class inheriting from `JComponent` that holds the `DefaultButtonModel` object, some view data (such as the button label and icons), and a `BasicButtonUI` object that is responsible for the button view.

11.2 Introduction to Layout Management

Before we go on to discussing individual Swing components, such as text fields and radio buttons, let's briefly cover how to arrange these components inside a frame.

Of course, Java development environments have drag-and-drop GUI builders. Nevertheless, it is important to know exactly what goes on "under the hood" because even the best of these tools will usually require hand-tweaking.

11.2.1 Layout Managers

Let's start by reviewing the program from Listing 10.4 that used buttons to change the background color of a frame.

The buttons are contained in a `JPanel` object and are managed by the *flow layout manager*, the default layout manager for a panel. Figure 11.4 shows what happens when you add more buttons to the panel. As you can see, a new row is started when there is no more room.

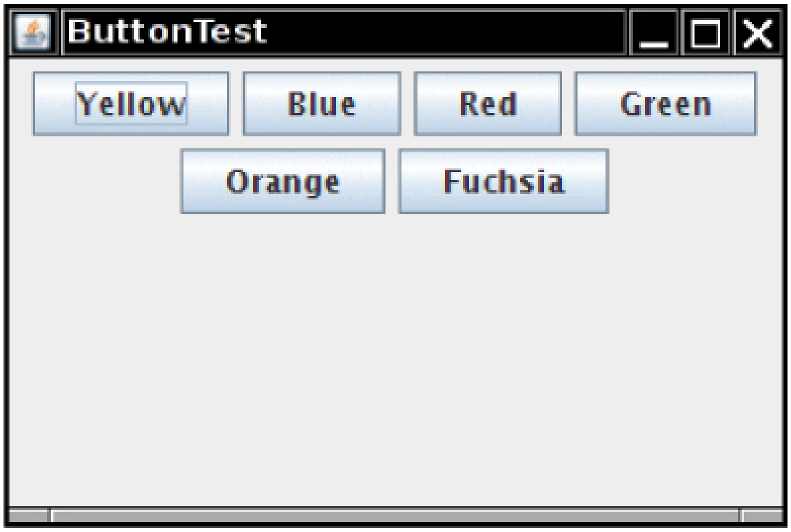


Figure 11.4 A panel with six buttons managed by a flow layout

Moreover, the buttons stay centered in the panel, even when the user resizes the frame (see Figure 11.5).

Figure 11.5 Changing the panel size rearranges the buttons automatically.

In general, *components* are placed inside *containers*, and a *layout manager* determines the positions and sizes of components in a container.

Buttons, text fields, and other user interface elements extend the class `Component`. Components can be placed inside containers, such as panels. Containers can themselves be put inside other containers, so the class

`Container` extends `Component`. Figure 11.6 shows the inheritance hierarchy for `Component`.

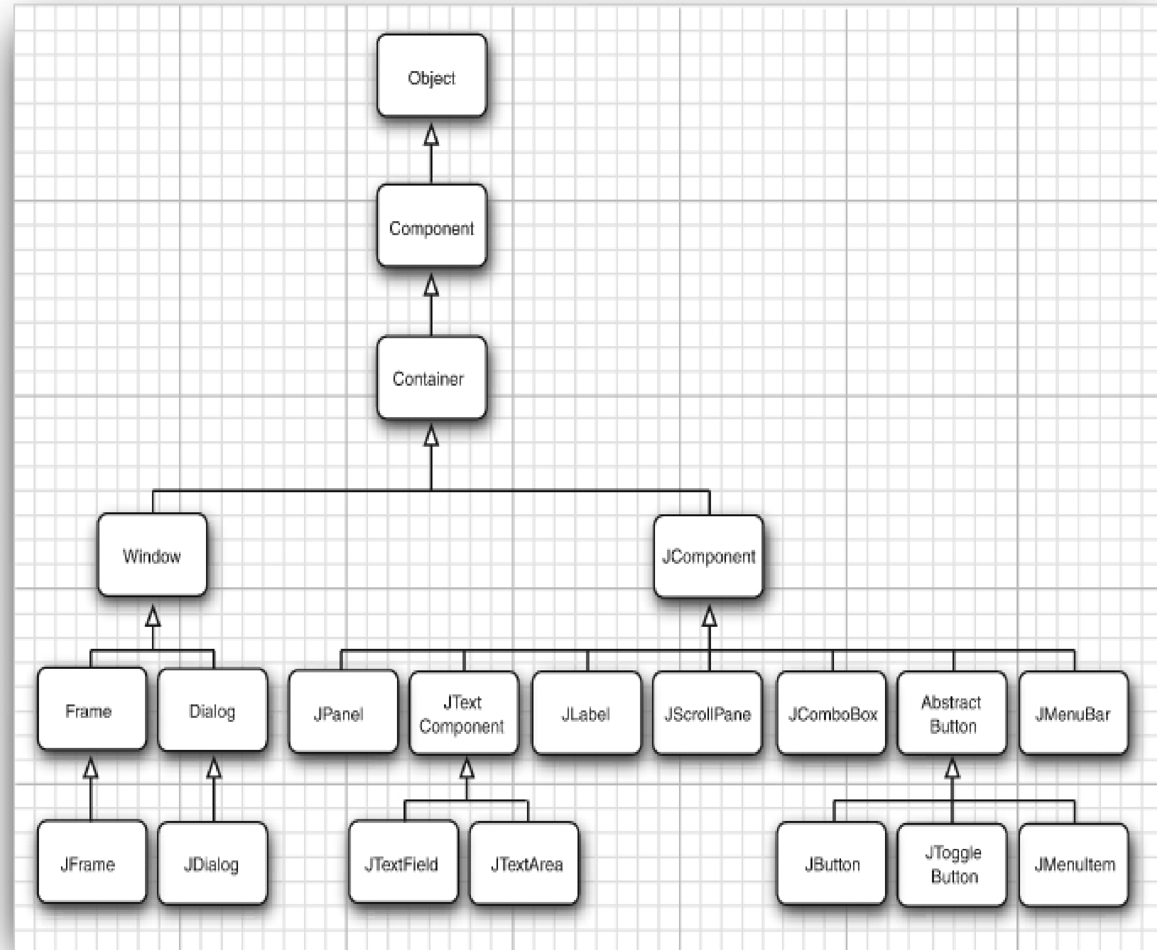


Figure 11.6 Inheritance hierarchy for the `Component` class

NOTE:

Unfortunately, the inheritance hierarchy is somewhat unclean in two respects. First, top-level windows, such as `JFrame`, are subclasses of `Container` and hence `Component`, but they cannot be placed inside other containers. Moreover, `JComponent` is a subclass of `Container`, not `Component`.

Therefore one can add other components into a `JButton`. (However, those components would not be displayed.)

Each container has a default layout manager, but you can always set your own. For example, the statement

```
panel.setLayout(new GridLayout(4, 4));
```

uses the `GridLayout` class to lay out the components in four rows and four columns. When you add components to the container, the `add` method of the container passes the component and any placement directions to the layout manager.

java.awt.Container 1.0

- `void setLayout(LayoutManager m)`

  sets the layout manager for this container.

- `Component add(Component c)`
- `Component add(Component c, Object constraints)` 1.1

  adds a component to this container and returns the component reference.

java.awt.FlowLayout 1.0

- `FlowLayout()`
- `FlowLayout(int align)`
- `FlowLayout(int align, int hgap, int vgap)`

  constructs a new `FlowLayout`. The `align` parameter is one of `LEFT`, `CENTER`, or `RIGHT`.

11.2.2 Border Layout

The *border layout manager* is the default layout manager of the content pane of every `JFrame`. Unlike the flow layout manager, which completely controls the position of each component, the border layout manager lets you choose where you want to place each component. You can choose to place the component in the center, north, south, east, or west of the content pane (see Figure 11.7).

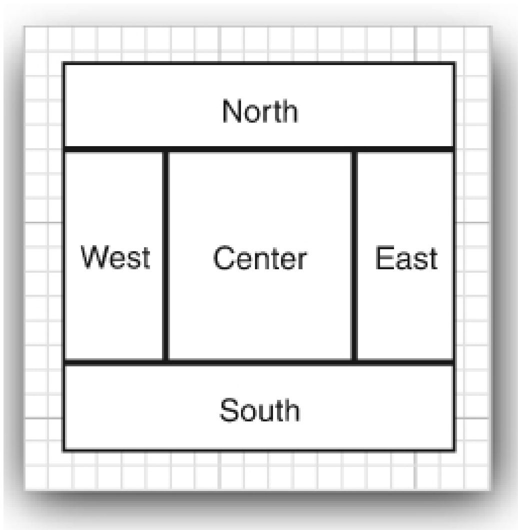


Figure 11.7 Border layout

For example:

```
frame.add(component, BorderLayout.SOUTH);
```

The edge components are laid out first, and the remaining available space is occupied by the center. When the container is resized, the dimensions of the edge components are unchanged, but the center component changes its size. Add components by specifying a constant `CENTER`, `NORTH`, `SOUTH`, `EAST`, or `WEST` of the `BorderLayout` class. Not all of the positions need to be occupied. If you don't supply any value, `CENTER` is assumed.

NOTE:

The `BorderLayout` constants are defined as strings. For example, `BorderLayout.SOUTH` is defined as the string `"South"`. This is safer than using strings. If you accidentally misspell a string, for example, `frame.add(component, "south")`, the compiler won't catch that error.

Unlike the flow layout, the border layout grows all components to fill the available space. (The flow layout leaves each component at its preferred size.) This is a problem when you add a button:

```
frame.add(yellowButton, BorderLayout.SOUTH); // don't
```

Figure 11.8 shows what happens when you use the preceding code fragment. The button has grown to fill the entire southern region of the frame. And, if you were to add another button to the southern region, it would just displace the first button.

Figure 11.8 A single button managed by a border layout

To solve this problem, use additional panels. For example, look at Figure 11.9. The three buttons at the bottom of the screen are all contained in a panel. The panel is put into the southern region of the content pane.

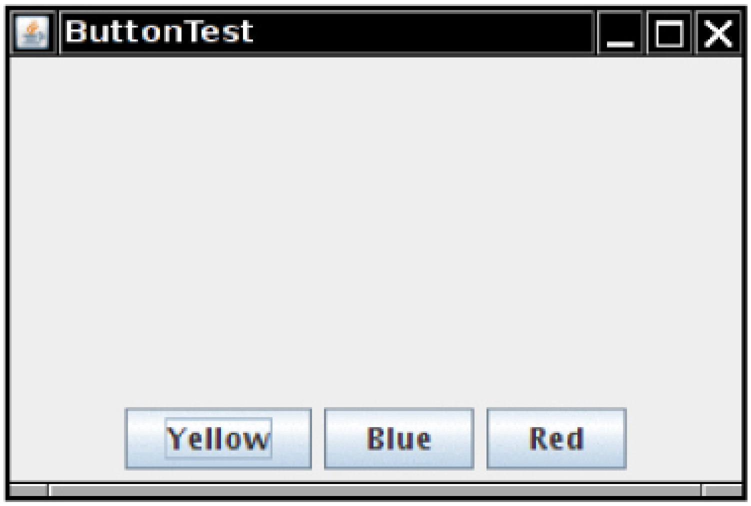


Figure 11.9 Panel placed at the southern region of the frame

To achieve this configuration, first create a new `JPanel` object, then add the individual buttons to the panel. The default layout manager for a panel is a `FlowLayout`, which is a good choice for this situation. Add the individual buttons to the panel, using the `add` method you have seen before. The position and size of the buttons is under the control of the `FlowLayout` manager. This means the buttons stay centered within the panel and do not expand to fill the entire panel area. Finally, add the panel to the content pane of the frame.

```
var panel = new JPanel();
panel.add(yellowButton);
panel.add(blueButton);
panel.add(redButton);
frame.add(panel, BorderLayout.SOUTH);
```

The border layout expands the size of the panel to fill the entire southern region.

java.awt.BorderLayout 1.0

- `BorderLayout()`

- `BorderLayout(int hgap, int vgap)`

  constructs a new `BorderLayout`.

11.2.3 Grid Layout

The grid layout arranges all components in rows and columns like a spreadsheet. All components are given the same size. The calculator program in Figure 11.10 uses a grid layout to arrange the calculator buttons. When you resize the window, the buttons grow and shrink, but all buttons have identical sizes.

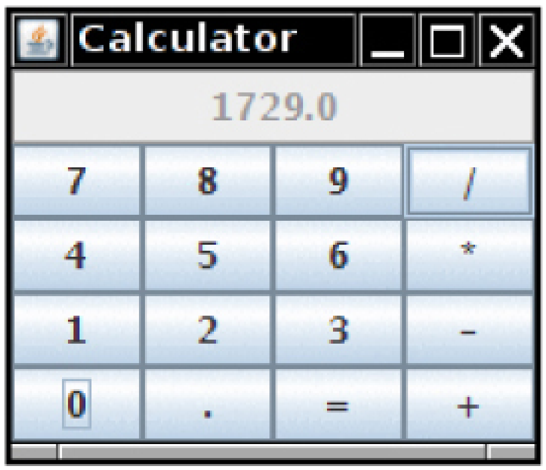


Figure 11.10 A calculator

In the constructor of the grid layout object, you specify how many rows and columns you need.

```
panel.setLayout(new GridLayout(4, 4));
```

Add the components, starting with the first entry in the first row, then the second entry in the first row, and so on.

```
panel.add(new JButton("1"));
panel.add(new JButton("2"));
```

Of course, few applications have as rigid a layout as the face of a calculator. In practice, small grids (usually with just one row or one column) can be useful to organize partial areas of a window. For example, if you want to have a row of buttons of identical sizes, you can put the buttons inside a panel that is governed by a grid layout with a single row.

java.awt.GridLayout 1.0

- `GridLayout(int rows, int columns)`
- `GridLayout(int rows, int columns, int hgap, int vgap)`

  constructs a new `GridLayout`. One of `rows` and `columns` (but not both) may be zero, denoting an arbitrary number of components per row or column.

11.3 Text Input

We are finally ready to start introducing the Swing user interface components. Let's begin with the components that let a user input and edit text. You can use the `JTextField` and `JTextArea` components for text input. A text field can accept only one line of text; a text area can accept multiple lines of text. A `JPasswordField` accepts one line of text without showing the contents.

All three of these classes inherit from a class called `JTextComponent`. You will not be able to construct a `JTextComponent` yourself because it is an abstract class. On the other hand, as is so often the case in Java, when you go searching through the API documentation, you may find that the methods you are looking for are actually in the parent class `JTextComponent` rather than the derived class. For example, the methods that get or set the text in a text field or text area are actually in `JTextComponent`.

javax.swing.text.JTextComponent 1.2

- `String getText()`
- `void setText(String text)`

  gets or sets the text of this text component.

- `boolean isEditable()`
- `void setEditable(boolean b)`

  gets or sets the `editable` property that determines whether the user can edit the content of this text component.

11.3.1 Text Fields

The usual way to add a text field to a window is to add it to a panel or other container—just as you would add a button:

```
var panel = new JPanel();
var textField = new JTextField("Default input", 20);
panel.add(textField);
```

This code adds a text field and initializes it by placing the string `"Default input"` inside it. The second parameter of this constructor sets the width. In this case, the width is 20 "columns." Unfortunately, a column is a rather imprecise measurement. One column is the expected width of one character in the font you are using for the text. The idea is that if you expect the inputs to be *n* characters or less, you are supposed to specify *n* as the column width. In practice, this measurement doesn't work out too well, and you should add 1 or 2 to the maximum input length to be on the safe side. Also, keep in mind that the number of columns is only a hint to the AWT that gives the *preferred* size. If the layout manager needs to grow or shrink the text field, it can adjust its size. The column width that you set in the `JTextField` constructor is not an upper limit on the number of characters the user can enter. The user can still type in longer strings, but the input scrolls when the text exceeds the length of the field. Users tend to find scrolling text fields irritating, so you should size the fields generously. If you need to reset the number of columns at runtime, you can do that with the `setColumns` method.

TIP:

After changing the size of a text box with the `setColumns` method, call the `revalidate` method of the surrounding container.

```
textField.setColumns(10);
panel.revalidate();
```

The `revalidate` method recomputes the size and layout of all components in a container. After you use the `revalidate` method, the layout manager resizes the container, and the changed size of the text field will be visible.

The `revalidate` method belongs to the `JComponent` class. It doesn't immediately resize the component but merely marks it for resizing. This approach avoids repetitive calculations if multiple components request to be resized. However, if you want to recompute all components inside a `JFrame`, you have to call the `validate` method—`JFrame` doesn't extend `JComponent`.

In general, users add text (or edit an existing text) in a text field. Quite often these text fields start out blank. To make a blank text field, just leave out the string as a parameter for the `JTextField` constructor:

```
var textField = new JTextField(20);
```

You can change the content of the text field at any time by using the `setText` method from the `JTextComponent` parent class mentioned in the previous section. For example:

```
textField.setText("Hello!");
```

And, as was mentioned in the previous section, you can find out what the user typed by calling the `getText` method. This method returns the exact text that the user has typed. To trim any extraneous leading and trailing spaces from the data in a text field, apply the `trim` method to the return value of `getText`:

```
String text = textField.getText().strip();
```

To change the font in which the user text appears, use the `setFont` method.

`javax.swing.JTextField` 1.2

- `JTextField(int cols)`

  constructs an empty `JTextField` with the specified number of columns.

- `JTextField(String text, int cols)`

  constructs a new `JTextField` with an initial string and the specified number of columns.

- `int getColumns()`
- `void setColumns(int cols)`

  gets or sets the number of columns that this text field should use.

`javax.swing.JComponent` 1.2

- `void revalidate()`

  causes the position and size of a component to be recomputed.

- `void setFont(Font f)`

  sets the font of this component.

`java.awt.Component` 1.0

- `void validate()`

recomputes the position and size of a component. If the component is a container, the positions and sizes of its components are recomputed.

- `Font getFont()`

  gets the font of this component.

11.3.2 Labels and Labeling Components

Labels are components that hold text. They have no decorations (for example, no boundaries). They also do not react to user input. You can use a label to identify components. For example, unlike buttons, text fields have no label to identify them. To label a component that does not itself come with an identifier:

1. Construct a `JLabel` component with the correct text.
2. Place it close enough to the component you want to identify so that the user can see that the label identifies the correct component.

The constructor for a `JLabel` lets you specify the initial text or icon and, optionally, the alignment of the content. Use constants from the `SwingConstants` interface to specify alignment. That interface defines a number of useful constants such as `LEFT`, `RIGHT`, `CENTER`, `NORTH`, `EAST`, and so on. The `JLabel` class is one of several Swing classes that implement this interface. Therefore, you can specify a right-aligned label either as

```
var label = new JLabel("User name: ", SwingConstants.RIGHT);
```

or

```
var label = new JLabel("User name: ", JLabel.RIGHT);
```

The `setText` and `setIcon` methods let you set the text and icon of the label at runtime.

TIP:

You can use both plain and HTML text in buttons, labels, and menu items. I don't recommend HTML in buttons—it interferes with the look-and-feel. But HTML in labels can be very effective. Simply surround the label string with `<html>. . .</html>`, like this:

```
label = new JLabel("<html><b>Required</b> entry:</html>");
```

Note that the first component with an HTML label may take some time to be displayed because the rather complex HTML rendering code must be loaded.

Labels can be positioned inside a container like any other component. This means you can use the techniques you have seen before to place your labels where you need them.

javax.swing.JLabel 1.2

- `JLabel(String text)`
- `JLabel(Icon icon)`
- `JLabel(String text, int align)`
- `JLabel(String text, Icon icon, int align)`

  constructs a label. The `align` parameter is one of the `SwingConstants` constants `LEFT` (default), `CENTER`, or `RIGHT`.

- `String getText()`
- `void setText(String text)`

  gets or sets the text of this label.

- `Icon getIcon()`
- `void setIcon(Icon icon)`

gets or sets the icon of this label.

11.3.3 Password Fields

Password fields are a special kind of text fields. To prevent nosy bystanders from seeing your password, the characters that the user enters are not actually displayed. Instead, each typed character is represented by an *echo character,* such as a bullet (•). Swing supplies a `JPasswordField` class that implements such a text field.

The password field is another example of the power of the model-view-controller architecture pattern. The password field uses the same model to store the data as a regular text field, but its view has been changed to display all characters as echo characters.

`javax.swing.JPasswordField` 1.2

- `JPasswordField(String text, int columns)`

  constructs a new password field.

- `void setEchoChar(char echo)`

  sets the echo character for this password field. This is advisory; a particular look-and-feel may insist on its own choice of echo character. A value of `0` resets the echo character to the default.

- `char[] getPassword()`

  returns the text contained in this password field. For stronger security, you should overwrite the content of the returned array after use. (The password is not returned as a `String` because a string would stay in the virtual machine until it is garbage-collected.)

11.3.4 Text Areas

Sometimes, you need to collect user input that is more than one line long. As mentioned earlier, you can use the `JTextArea` component for this. When you place a text area component in your program, a user can enter any number of lines of text, using the Enter key to separate them. Each line ends with a `'\n'`. Figure 11.11 shows a text area at work.

In the constructor for the `JTextArea` component, specify the number of rows and columns for the text area. For example,

```
textArea = new JTextArea(8, 40); // 8 lines of 40 columns each
```

where the `columns` parameter works as before—and you still need to add a few more columns for safety's sake. Also, as before, the user is not restricted to the number of rows and columns; the text simply scrolls when the user inputs too much. You can also use the `setColumns` method to change the number of columns and the `setRows` method to change the number of rows. These numbers only indicate the preferred size—the layout manager can still grow or shrink the text area.

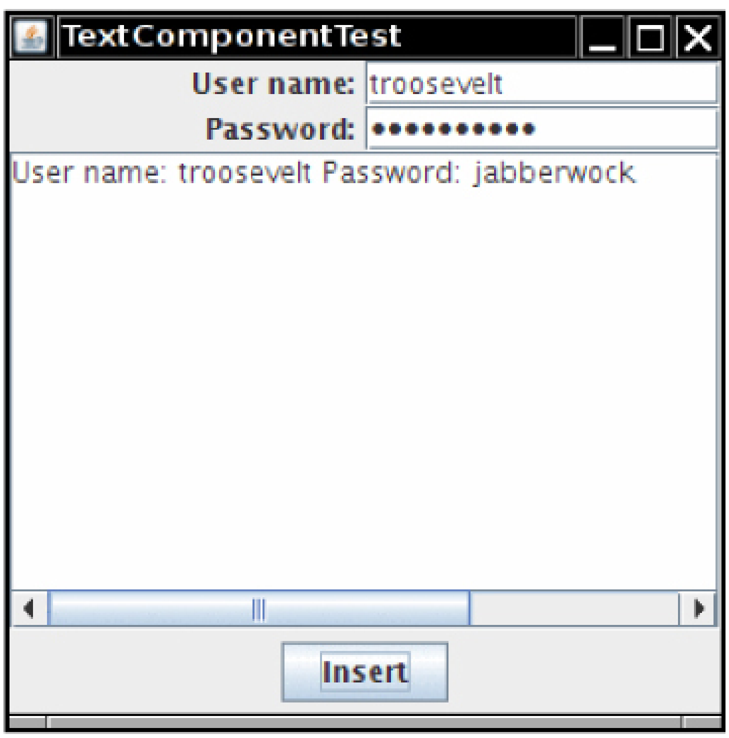


Figure 11.11 Text components

If there is more text than the text area can display, the remaining text is simply clipped. You can avoid clipping long lines by turning on line wrapping:

```
textArea.setLineWrap(true); // long lines are wrapped
```

This wrapping is a visual effect only; the text in the document is not changed—no automatic `'\n'` characters are inserted into the text.

11.3.5 Scroll Panes

In Swing, a text area does not have scrollbars. If you want scrollbars, you have to place the text area inside a *scroll pane*.

```
textArea = new JTextArea(8, 40);
var scrollPane = new JScrollPane(textArea);
```

The scroll pane now manages the view of the text area. Scrollbars automatically appear if there is more text than the text area can display, and they vanish again if text is deleted and the remaining text fits inside the area. The scrolling is handled internally by the scroll pane—your program does not need to process scroll events.

This is a general mechanism that works for any component, not just text areas. To add scrollbars to a component, put them inside a scroll pane.

Listing 11.1 demonstrates the various text components. This program shows a text field, a password field, and a text area with scrollbars. The text field and password field are labeled. Click on "Insert" to insert the field contents into the text area.

NOTE:

The `JTextArea` component displays plain text only, without special fonts or formatting. To display formatted text (such as HTML), you can use the

`JEditorPane` class that is discussed in Volume II.

Listing 11.1 `text/TextComponentFrame.java`

```
package text;

import java.awt.BorderLayout;
import java.awt.GridLayout;

import javax.swing.JButton;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JPanel;
import javax.swing.JPasswordField;
import javax.swing.JScrollPane;
import javax.swing.JTextArea;
import javax.swing.JTextField;
import javax.swing.SwingConstants;

/**
 * A frame with sample text components.
 */
public class TextComponentFrame extends JFrame
{
   public static final int TEXTAREA_ROWS = 8;
   public static final int TEXTAREA_COLUMNS = 20;

   public TextComponentFrame()
   {
      var textField = new JTextField();
      var passwordField = new JPasswordField();

      var northPanel = new JPanel();
      northPanel.setLayout(new GridLayout(2, 2));
      northPanel.add(new JLabel("User name: ",
SwingConstants.RIGHT));
      northPanel.add(textField);
```

```
        northPanel.add(new JLabel("Password: ", SwingConstants.RIGHT));
        northPanel.add(passwordField);

        add(northPanel, BorderLayout.NORTH);

        var textArea = new JTextArea(TEXTAREA_ROWS, TEXTAREA_COLUMNS);
        var scrollPane = new JScrollPane(textArea);

        add(scrollPane, BorderLayout.CENTER);

        // add button to append text into the text area

        var southPanel = new JPanel();

        var insertButton = new JButton("Insert");
        southPanel.add(insertButton);
        insertButton.addActionListener(event ->
          textArea.append("User name: " + textField.getText() + " Password: "
            + new String(passwordField.getPassword()) + "\n"));

        add(southPanel, BorderLayout.SOUTH);
        pack();
    }
}
```

`javax.swing.JTextArea` 1.2

- `JTextArea()`
- `JTextArea(int rows, int cols)`
- `JTextArea(String text, int rows, int cols)`

  constructs a new text area.
- `void setColumns(int cols)`

tells the text area the preferred number of columns it should use.

- `void setRows(int rows)`

  tells the text area the preferred number of rows it should use.

- `void append(String newText)`

  appends the given text to the end of the text already in the text area.

- `void setLineWrap(boolean wrap)`

  turns line wrapping on or off.

- `void setWrapStyleWord(boolean word)`

  If `word` is `true`, long lines are wrapped at word boundaries. If it is `false`, long lines are broken without taking word boundaries into account.

- `void setTabSize(int c)`

  sets tab stops every `c` columns. Note that the tabs aren't converted to spaces but cause alignment with the next tab stop.

`javax.swing.JScrollPane` 1.2

- `JScrollPane(Component c)`

creates a scroll pane that displays the content of the specified component. Scrollbars are supplied when the component is larger than the view.

11.4 Choice Components

You now know how to collect text input from users, but there are many occasions where you would rather give users a finite set of choices than have them enter the data in a text component. Using a set of buttons or a list of items tells your users what choices they have. (It also saves you the trouble of error checking.) In this section, you will learn how to program checkboxes, radio buttons, lists of choices, and sliders.

11.4.1 Checkboxes

If you want to collect just a “yes” or “no” input, use a checkbox component. Checkboxes automatically come with labels that identify them. The user can check the box by clicking inside it and turn off the checkmark by clicking inside the box again. Pressing the space bar when the focus is in the checkbox also toggles the checkmark.

Figure 11.12 shows a simple program with two checkboxes, one for turning the italic attribute of a font on or off, and the other for boldface. Note that the second checkbox has focus, as indicated by the rectangle around the label. Each time the user clicks one of the checkboxes, the screen is refreshed, using the new font attributes.

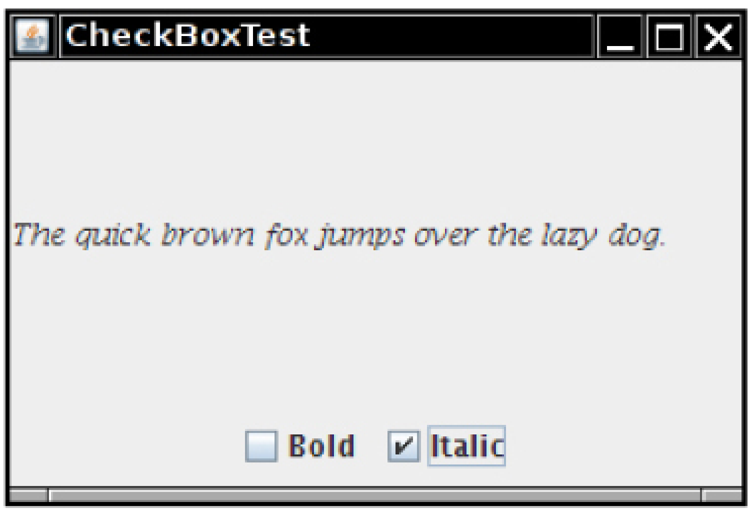


Figure 11.12 Checkboxes

Checkboxes need a label next to them to identify their purpose. Give the label text in the constructor:

```
bold = new JCheckBox("Bold");
```

Use the `setSelected` method to turn a checkbox on or off. For example:

```
bold.setSelected(true);
```

The `isSelected` method then retrieves the current state of each checkbox. It is `false` if unchecked, `true` if checked.

When the user clicks on a checkbox, this triggers an action event. As always, you attach an action listener to the checkbox. In our program, the two checkboxes share the same action listener.

```
ActionListener listener = . . .;
bold.addActionListener(listener);
italic.addActionListener(listener);
```

The listener queries the state of the `bold` and `italic` checkboxes and sets the font of the panel to plain, bold, italic, or both bold and italic.

```
ActionListener listener = event ->
 {
   int mode = 0;
   if (bold.isSelected()) mode += Font.BOLD;
   if (italic.isSelected()) mode += Font.ITALIC;
   label.setFont(new Font(Font.SERIF, mode, FONTSIZE));
 };
```

Listing 11.2 is the program listing for the checkbox example.

Listing 11.2 `checkBox/CheckBoxFrame.java`

```
package checkBox;

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

/**
 * A frame with a sample text label and check boxes for
```

```
selecting font
  * attributes.
  */
public class CheckBoxFrame extends JFrame
{
   private JLabel label;
   private JCheckBox bold;
   private JCheckBox italic;
   private static final int FONTSIZE = 24;

   public CheckBoxFrame()
   {
      // add the sample text label

      label = new JLabel("The quick brown fox jumps over the
lazy dog.");
      label.setFont(new Font("Serif", Font.BOLD, FONTSIZE));
      add(label, BorderLayout.CENTER);

      // this listener sets the font attribute of
      // the label to the check box state

      ActionListener listener = event ->
         {
           int mode = 0;
           if (bold.isSelected()) mode += Font.BOLD;
           if (italic.isSelected()) mode += Font.ITALIC;
           label.setFont(new Font("Serif", mode, FONTSIZE));
         };

   // add the check boxes
   var buttonPanel = new JPanel();

   bold = new JCheckBox("Bold");
   bold.addActionListener(listener);
   bold.setSelected(true);
   buttonPanel.add(bold);

   italic = new JCheckBox("Italic");
```

```
    italic.addActionListener(listener);
    buttonPanel.add(italic);

    add(buttonPanel, BorderLayout.SOUTH);
    pack();
  }
}
```

`javax.swing.JCheckBox` 1.2

- `JCheckBox(String label)`
- `JCheckBox(String label, Icon icon)`

  constructs a checkbox that is initially unselected.
- `JCheckBox(String label, boolean state)`

  constructs a checkbox with the given label and initial state.
- `boolean isSelected()`
- `void setSelected(boolean state)`

  gets or sets the selection state of the checkbox.

11.4.2 Radio Buttons

In the previous example, the user could check either, both, or neither of the two checkboxes. In many cases, we want the user to check only one of several boxes. When another box is checked, the previous box is automatically unchecked. Such a group of boxes is often called a *radio button group* because the buttons work like the station selector buttons on a radio. When you push in one button, the previously depressed button pops out. Figure 11.13 shows a typical example. We allow the user to select a font size from among the choices—Small, Medium, Large, or Extra large—but, of course, we will allow selecting only one size at a time.

Figure 11.13 A radio button group

Implementing radio button groups is easy in Swing. You construct one object of type `ButtonGroup` for every group of buttons. Then, you add objects of type `JRadioButton` to the button group. The button group object is responsible for turning off the previously set button when a new button is clicked.

```
var group = new ButtonGroup();

var smallButton = new JRadioButton("Small", false);
group.add(smallButton);

var mediumButton = new JRadioButton("Medium", true);
group.add(mediumButton);
. . .
```

The second argument of the constructor is `true` for the button that should be checked initially and `false` for all others. Note that the button group controls only the *behavior* of the buttons; if you want to group the buttons for layout purposes, you also need to add them to a container such as a `JPanel`.

If you look again at Figures 11.12 and 11.13, you will note that the appearance of the radio buttons is different from that of checkboxes. Checkboxes are square and contain a checkmark when selected. Radio buttons are round and contain a dot when selected.

The event notification mechanism for radio buttons is the same as for any other buttons. When the user checks a radio button, the button generates an action event. In our example program, we define an action listener that sets the font size to a particular value:

```
ActionListener listener = event ->
   label.setFont(new Font("Serif", Font.PLAIN, size));
```

Compare this listener setup to that of the checkbox example. Each radio button gets a different listener object. Each listener object knows exactly what it needs to do—set the font size to a particular value. With checkboxes, we used a different approach: Both checkboxes have the same action listener that calls a method looking at the current state of both checkboxes.

Could we follow the same approach here? We could have a single listener that computes the size as follows:

```
if (smallButton.isSelected()) size = 8;
else if (mediumButton.isSelected()) size = 12;
. . .
```

However, we prefer to use separate action listener objects because they tie the size values more closely to the buttons.

NOTE:

If you have a group of radio buttons, you know that only one of them is selected. It would be nice to be able to quickly find out which, without having to query all the buttons in the group. The `ButtonGroup` object controls all buttons, so it would be convenient if this object could give us a reference to the selected button. Indeed, the `ButtonGroup` class has a `getSelection` method, but that method doesn't return the radio button that is selected. Instead, it returns a `ButtonModel` reference to the model attached to the button. Unfortunately, none of the `ButtonModel` methods are very helpful. The `ButtonModel` interface inherits a method `getSelectedObjects` from the `ItemSelectable` interface that, rather uselessly, returns `null`. The `getActionCommand` method looks promising because the “action command” of a radio button is its text label. But the action command of its model is `null`. Only if you explicitly set the action commands of all radio buttons with the `setActionCommand` method do the action command values of the models also get set. Then you can retrieve the action command of the currently selected button with `buttonGroup.getSelection().getActionCommand()`.

Listing 11.3 is the complete program for font size selection that puts a set of radio buttons to work.

Listing 11.3 `radioButton/RadioButtonFrame.java`

```
package radioButton;

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

/**
 * A frame with a sample text label and radio buttons for selecting font sizes.
 */
public class RadioButtonFrame extends JFrame
{
   private JPanel buttonPanel;
   private ButtonGroup group;
   private JLabel label;
   private static final int DEFAULT_SIZE = 36;

   public RadioButtonFrame()
   {
      // add the sample text label

      label = new JLabel("The quick brown fox jumps over the lazy dog.");
```

```
      label.setFont(new Font("Serif", Font.PLAIN, DEFAULT_SIZE));
      add(label, BorderLayout.CENTER);

      // add the radio buttons

      buttonPanel = new JPanel();
      group = new ButtonGroup();

      addRadioButton("Small", 8);
      addRadioButton("Medium", 12);
      addRadioButton("Large", 18);
      addRadioButton("Extra large", 36);

      add(buttonPanel, BorderLayout.SOUTH);
      pack();
   }

   /**
   * Adds a radio button that sets the font size of the sample text.
   * @param name the string to appear on the button
   * @param size the font size that this button sets
   */
   public void addRadioButton(String name, int size)
   {
      boolean selected = size == DEFAULT_SIZE;
      var button = new JRadioButton(name, selected);
      group.add(button);
      buttonPanel.add(button);

      // this listener sets the label font size

      ActionListener listener = event -> label.setFont(new Font("Serif", Font.PLAIN, size));

      button.addActionListener(listener);
   }
}
```

`javax.swing.JRadioButton` 1.2

- `JRadioButton(String label, Icon icon)`

  constructs a radio button that is initially unselected.

- `JRadioButton(String label, boolean state)`

  constructs a radio button with the given label and initial state.

`javax.swing.ButtonGroup` 1.2

- `void add(AbstractButton b)`

  adds the button to the group.

- `ButtonModel getSelection()`

  returns the button model of the selected button.

`javax.swing.ButtonModel` 1.2

- `String getActionCommand()`

  returns the action command for this button model.

`javax.swing.AbstractButton` 1.2

- `void setActionCommand(String s)`

  sets the action command for this button and its model.

11.4.3 Borders

If you have multiple groups of radio buttons in a window, you will want to visually indicate which buttons are grouped. Swing provides a set of useful *borders* for this purpose. You can apply a border to any component that extends `JComponent`. The most common usage is to place a border around a panel and fill that panel with other user interface elements, such as radio buttons.

You can choose from quite a few borders, but you need to follow the same steps for all of them.

1. Call a static method of the `BorderFactory` to create a border. You can choose among the following styles (see Figure 11.14):
   - Lowered bevel
   - Raised bevel
   - Etched
   - Line
   - Matte
   - Empty (just to create some blank space around the component)

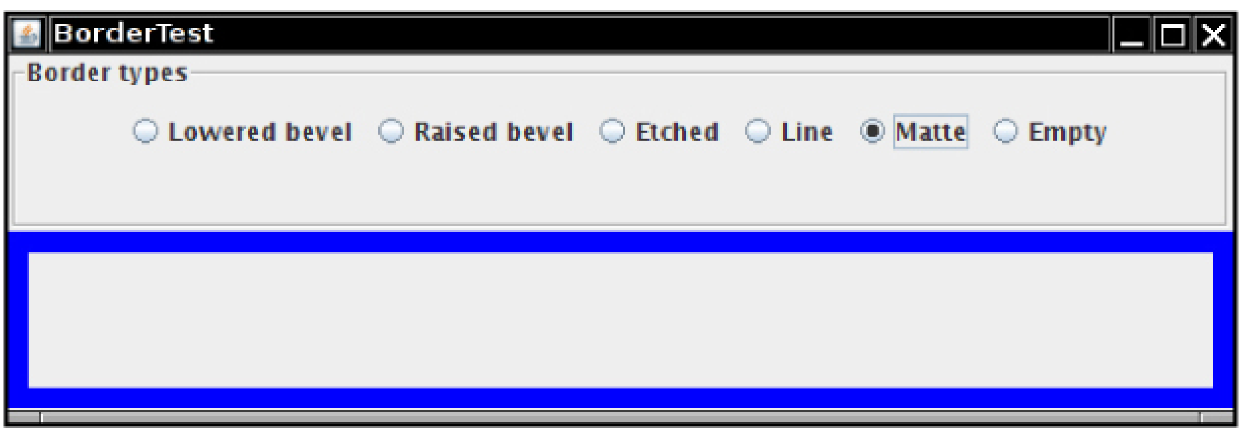


Figure 11.14 Testing border types

2. If you like, add a title to your border by passing your border to `BorderFactory.createTitledBorder`.

3. If you really want to go all out, combine several borders with a call to `BorderFactory.createCompoundBorder`.
4. Add the resulting border to your component by calling the `setBorder` method of the `JComponent` class.

For example, here is how you add an etched border with a title to a panel:

```
Border etched = BorderFactory.createEtchedBorder();
Border titled = BorderFactory.createTitledBorder(etched, "A Title");
panel.setBorder(titled);
```

Different borders have different options for setting border widths and colors; see the API notes for details. True border enthusiasts will appreciate that there is also a `SoftBevelBorder` class for beveled borders with softened corners and that a `LineBorder` can have rounded corners as well. You can construct these borders only by using one of the class constructors—there is no `BorderFactory` method for them.

`javax.swing.BorderFactory` 1.2

- `static Border createLineBorder(Color color)`
- `static Border createLineBorder(Color color, int thickness)`

  creates a simple line border.

- `static MatteBorder createMatteBorder(int top, int left, int bottom, int right, Color color)`
- `static MatteBorder createMatteBorder(int top, int left, int bottom, int right, Icon tileIcon)`

  creates a thick border that is filled with a color or a repeating icon.

- `static Border createEmptyBorder()`
- `static Border createEmptyBorder(int top, int left, int bottom, int right)`

creates an empty border.

- `static Border createEtchedBorder()`
- `static Border createEtchedBorder(Color highlight, Color shadow)`
- `static Border createEtchedBorder(int type)`
- `static Border createEtchedBorder(int type, Color highlight, Color shadow)`

  creates a line border with a 3D effect. The `type` parameter is one of `EtchedBorder.RAISED`, `EtchedBorder.LOWERED`.

- `static Border createBevelBorder(int type)`
- `static Border createBevelBorder(int type, Color highlight, Color shadow)`
- `static Border createLoweredBevelBorder()`
- `static Border createRaisedBevelBorder()`

  creates a border that gives the effect of a lowered or raised surface. The `type` parameter is one of `BevelBorder.RAISED`, `BevelBorder.LOWERED`.

- `static TitledBorder createTitledBorder(String title)`
- `static TitledBorder createTitledBorder(Border border)`
- `static TitledBorder createTitledBorder(Border border, String title)`
- `static TitledBorder createTitledBorder(Border border, String title, int justification, int position)`
- `static TitledBorder createTitledBorder(Border border, String title, int justification, int position, Font font)`
- `static TitledBorder createTitledBorder(Border border, String title, int justification, int position, Font font, Color color)`

  creates a titled border with the specified properties. The `justification` parameter is one of the `TitledBorder` constants `LEFT`, CENTER, RIGHT, LEADING, TRAILING, or DEFAULT_JUSTIFICATION (left), and position is one of ABOVE_TOP, TOP, BELOW_TOP, ABOVE_BOTTOM, BOTTOM, BELOW_BOTTOM, or DEFAULT_POSITION (top).

- static CompoundBorder createCompoundBorder(Border outsideBorder, Border insideBorder)

  combines two borders to a new border.

javax.swing.border.SoftBevelBorder 1.2

- SoftBevelBorder(int type)
- SoftBevelBorder(int type, Color highlight, Color shadow)

  creates a bevel border with softened corners. The type parameter is one of SoftBevelBorder.RAISED, SoftBevelBorder.LOWERED.

javax.swing.border.LineBorder 1.2

- public LineBorder(Color color, int thickness, boolean roundedCorners)

  creates a line border with the given color and thickness. If roundedCorners is true, the border has rounded corners.

javax.swing.JComponent 1.2

- void setBorder(Border border)

  sets the border of this component.

11.4.4 Combo Boxes

If you have more than a handful of alternatives, radio buttons are not a good choice because they take up too much screen space. Instead, you can use a combo box. When the user clicks on this component, a list of choices drops down, and the user can then select one of them (see Figure 11.15).

If the drop-down list box is set to be *editable*, you can edit the current selection as if it were a text field. For that reason, this component is called a *combo box*—it combines the flexibility of a text field with a set of predefined choices. The `JComboBox` class provides a combo box component.

As of Java 7, the `JComboBox` class is a generic class. For example, a `JComboBox<String>` holds objects of type `String`, and a `JComboBox<Integer>` holds integers.

Call the `setEditable` method to make the combo box editable. Note that editing affects only the selected item. It does not change the list of choices in any way.

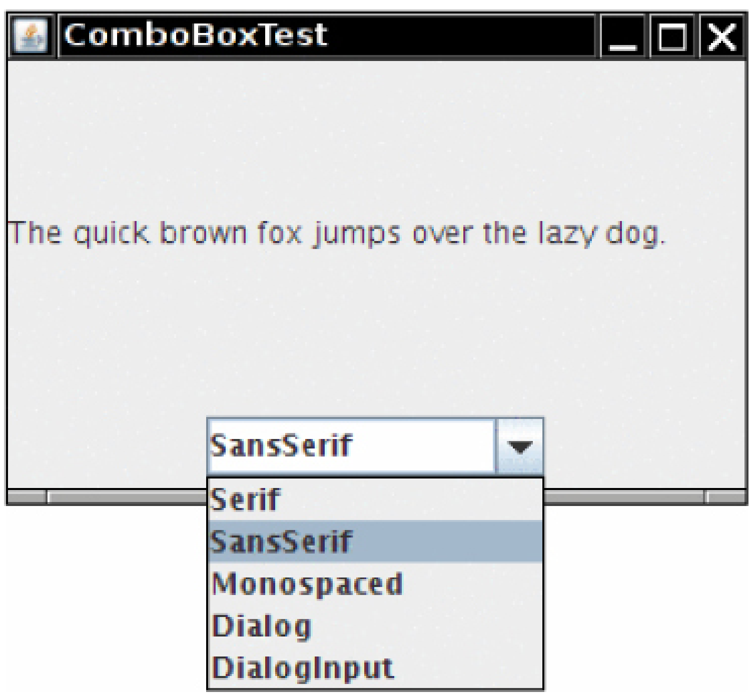


Figure 11.15 A combo box

You can obtain the current selection, which may have been edited if the combo box is editable, by calling the `getSelectedItem` method. However, for an editable combo box, that item may have any type, depending on the editor that takes the user edits and turns the result into an object. (See Volume II, Chapter 6 for a discussion of editors.) If your combo box isn't editable, you are better off calling

```
combo.getItemAt(combo.getSelectedIndex())
```

which gives you the selected item with the correct type.

In the example program, the user can choose a font style from a list of styles (Serif, SansSerif, Monospaced, etc.). The user can also type in another font.

Add the choice items with the `addItem` method. In our program, `addItem` is called only in the constructor, but you can call it any time.

```
var faceCombo = new JComboBox<String>();
faceCombo.addItem("Serif");
faceCombo.addItem("SansSerif");
. . .
```

This method adds the string to the end of the list. You can add new items anywhere in the list with the `insertItemAt` method:

```
faceCombo.insertItemAt("Monospaced", 0); // add at the
beginning
```

You can add items of any type—the combo box invokes each item's `toString` method to display it.

If you need to remove items at runtime, use the `removeItem` or `removeItemAt` method, depending on whether you supply the item to be removed or its position.

```
faceCombo.removeItem("Monospaced");
faceCombo.removeItemAt(0); // remove first item
```

The `removeAllItems` method removes all items at once.

TIP:

If you need to add a large number of items to a combo box, the `addItem` method will perform poorly. Instead, construct a `DefaultComboBoxModel`, populate it by calling `addElement`, and then call the `setModel` method of the `JComboBox` class.

When the user selects an item from a combo box, the combo box generates an action event. To find out which item was selected, call `getSource` on the event parameter to get a reference to the combo box that sent the event. Then call the `getSelectedItem` method to retrieve the currently selected item. You will need to cast the returned value to the appropriate type, usually `String`.

```
ActionListener listener = event ->
   label.setFont(new Font(
      faceCombo.getItemAt(faceCombo.getSelectedIndex()),
      Font.PLAIN,
      DEFAULT_SIZE));
```

Listing 11.4 shows the complete program.

Listing 11.4 `comboBox/ComboBoxFrame.java`

```
package comboBox;

import java.awt.BorderLayout;
import java.awt.Font;

import javax.swing.JComboBox;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JPanel;

```

```java
/**
 * A frame with a sample text label and a combo box for selecting font faces.
 */
public class ComboBoxFrame extends JFrame
{
   private JComboBox<String> faceCombo;
   private JLabel label;
   private static final int DEFAULT_SIZE = 24;

   public ComboBoxFrame()
   {
     // add the sample text label

     label = new JLabel("The quick brown fox jumps over the lazy dog.");
     label.setFont(new Font("Serif", Font.PLAIN, DEFAULT_SIZE));
     add(label, BorderLayout.CENTER);

     // make a combo box and add face names

     faceCombo = new JComboBox<>();
     faceCombo.addItem("Serif");
     faceCombo.addItem("SansSerif");
     faceCombo.addItem("Monospaced");
     faceCombo.addItem("Dialog");
     faceCombo.addItem("DialogInput");

     // the combo box listener changes the label font to the selected face name

     faceCombo.addActionListener(event ->
       label.setFont(
         new Font(faceCombo.getItemAt(faceCombo.getSelectedIndex()),
           Font.PLAIN, DEFAULT_SIZE)));

     // add combo box to a panel at the frame's southern
```

```
border

      var comboPanel = new JPanel();
      comboPanel.add(faceCombo);
      add(comboPanel, BorderLayout.SOUTH);
      pack();
   }
}
```

`javax.swing.JComboBox` 1.2

- `boolean isEditable()`
- `void setEditable(boolean b)`

  gets or sets the `editable` property of this combo box.
- `void addItem(Object item)`

  adds an item to the item list.
- `void insertItemAt(Object item, int index)`

  inserts an item into the item list at a given index.
- `void removeItem(Object item)`

  removes an item from the item list.
- `void removeItemAt(int index)`

  removes the item at an index.
- `void removeAllItems()`

  removes all items from the item list.
- `Object getSelectedItem()`

  returns the currently selected item.

11.4.5 Sliders

Combo boxes let users choose from a discrete set of values. Sliders offer a choice from a continuum of values—for example, any number between 1 and 100.

The most common way of constructing a slider is as follows:

```
var slider = new JSlider(min, max, initialValue);
```

If you omit the minimum, maximum, and initial values, they are initialized with `0`, `100`, and `50`, respectively.

Or if you want the slider to be vertical, use the following constructor call:

```
var slider = new JSlider(SwingConstants.VERTICAL, min, max,
initialValue);
```

These constructors create a plain slider, such as the top slider in Figure 11.16. You will see presently how to add decorations to a slider.

As the user slides the slider bar, the *value* of the slider moves between the minimum and the maximum values. When the value changes, a `ChangeEvent` is sent to all change listeners. To be notified of the change, call the `addChangeListener` method and install an object that implements the functional `ChangeListener` interface. In the callback, retrieve the slider value:

```
ChangeListener listener = event ->
   {
     JSlider slider = (JSlider) event.getSource();
     int value = slider.getValue();
     . . .
   };
```

You can embellish the slider by showing *ticks*. For example, in the sample program, the second slider uses the following settings:

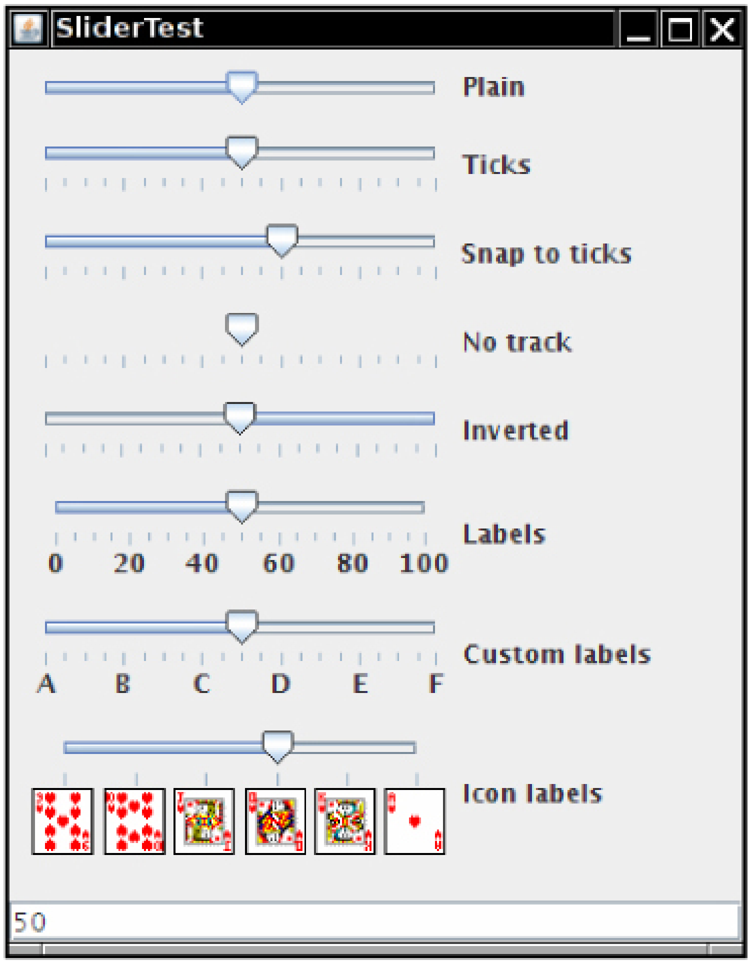


Figure 11.16 Sliders

```
slider.setMajorTickSpacing(20);
slider.setMinorTickSpacing(5);
```

The slider is decorated with large tick marks every 20 units and small tick marks every 5 units. The units refer to slider values, not pixels.

These instructions only set the units for the tick marks. To actually have the tick marks appear, call

```
slider.setPaintTicks(true);
```

The major and minor tick marks are independent. For example, you can set major tick marks every 20 units and minor tick marks every 7 units, but that will give you a very messy scale.

You can force the slider to *snap to ticks*. Whenever the user has finished dragging a slider in snap mode, it is immediately moved to the closest tick. You activate this mode with the call

```
slider.setSnapToTicks(true);
```

CAUTION:

The "snap to ticks" behavior doesn't work as well as you might imagine. Until the slider has actually snapped, the change listener still reports slider values that don't correspond to ticks. And if you click next to the slider—an action that normally advances the slider a bit in the direction of the click—a slider with "snap to ticks" does not move to the next tick.

You can display *tick mark labels* for the major tick marks by calling

```
slider.setPaintLabels(true);
```

For example, with a slider ranging from 0 to 100 and major tick spacing of 20, the ticks are labeled 0, 20, 40, 60, 80, and 100.

You can also supply other tick mark labels, such as strings or icons (see Figure 11.16). The process is a bit convoluted. You need to fill a hash table with keys of type `Integer` and values of type `Component`. You then call the `setLabelTable` method. The components are placed under the tick marks. Usually, `JLabel` objects are used. Here is how you can label ticks as A, B, C, D, E, and F:

```
var labelTable = new Hashtable<Integer, Component>();
labelTable.put(0, new JLabel("A"));
labelTable.put(20, new JLabel("B"));
. . .
```

```
labelTable.put(100, new JLabel("F"));
slider.setLabelTable(labelTable);
```

Listing 11.5 also shows a slider with icons as tick labels.

TIP:

If your tick marks or labels don't show, double-check that you called `setPaintTicks(true)` and `setPaintLabels(true)`.

The fourth slider in Figure 11.16 has no track. To suppress the "track" in which the slider moves, call

```
slider.setPaintTrack(false);
```

The fifth slider has its direction reversed by a call to

```
slider.setInverted(true);
```

The example program in Listing 11.5 shows all these visual effects with a collection of sliders. Each slider has a change event listener installed that places the current slider value into the text field at the bottom of the frame.

Listing 11.5 `slider/SliderFrame.java`

```
package slider;

import java.awt.*;
import java.util.*;
import javax.swing.*;
import javax.swing.event.*;

/**
 * A frame with many sliders and a text field to show slider
```

```
values.
 */
public class SliderFrame extends JFrame
{
   private JPanel sliderPanel;
   private JTextField textField;
   private ChangeListener listener;

   public SliderFrame()
   {
      sliderPanel = new JPanel();
      sliderPanel.setLayout(new GridBagLayout());

      // common listener for all sliders
      listener = event ->
         {
            // update text field when the slider value changes
            JSlider source = (JSlider) event.getSource();
            textField.setText("" + source.getValue());
         };

      // add a plain slider

      var slider = new JSlider();
      addSlider(slider, "Plain");

      // add a slider with major and minor ticks

      slider = new JSlider();
      slider.setPaintTicks(true);
      slider.setMajorTickSpacing(20);
      slider.setMinorTickSpacing(5);
      addSlider(slider, "Ticks");

      // add a slider that snaps to ticks

      slider = new JSlider();
      slider.setPaintTicks(true);
      slider.setSnapToTicks(true);
```

```
        slider.setMajorTickSpacing(20);
        slider.setMinorTickSpacing(5);
        addSlider(slider, "Snap to ticks");

        // add a slider with no track

        slider = new JSlider();
        slider.setPaintTicks(true);
        slider.setMajorTickSpacing(20);
        slider.setMinorTickSpacing(5);
        slider.setPaintTrack(false);
        addSlider(slider, "No track");

        // add an inverted slider

        slider = new JSlider();
        slider.setPaintTicks(true);
        slider.setMajorTickSpacing(20);
        slider.setMinorTickSpacing(5);
        slider.setInverted(true);
        addSlider(slider, "Inverted");

        // add a slider with numeric labels

        slider = new JSlider();
        slider.setPaintTicks(true);
        slider.setPaintLabels(true);
        slider.setMajorTickSpacing(20);
        slider.setMinorTickSpacing(5);
        addSlider(slider, "Labels");

        // add a slider with alphabetic labels

        slider = new JSlider();
        slider.setPaintLabels(true);
        slider.setPaintTicks(true);
        slider.setMajorTickSpacing(20);
        slider.setMinorTickSpacing(5);

```

```
        var labelTable = new Hashtable<Integer, Component>();
        labelTable.put(0, new JLabel("A"));
        labelTable.put(20, new JLabel("B"));
        labelTable.put(40, new JLabel("C"));
        labelTable.put(60, new JLabel("D"));
        labelTable.put(80, new JLabel("E"));
        labelTable.put(100, new JLabel("F"));

        slider.setLabelTable(labelTable);
        addSlider(slider, "Custom labels");

        // add a slider with icon labels

        slider = new JSlider();
        slider.setPaintTicks(true);
        slider.setPaintLabels(true);
        slider.setSnapToTicks(true);
        slider.setMajorTickSpacing(20);
        slider.setMinorTickSpacing(20);

        labelTable = new Hashtable<Integer, Component>();

        // add card images

        labelTable.put(0, new JLabel(new
ImageIcon("nine.gif")));
        labelTable.put(20, new JLabel(new
ImageIcon("ten.gif")));
        labelTable.put(40, new JLabel(new
ImageIcon("jack.gif")));
        labelTable.put(60, new JLabel(new
ImageIcon("queen.gif")));
        labelTable.put(80, new JLabel(new
ImageIcon("king.gif")));
        labelTable.put(100, new JLabel(new
ImageIcon("ace.gif")));

        slider.setLabelTable(labelTable);
        addSlider(slider, "Icon labels");
```

```java

      // add the text field that displays the slider value

      textField = new JTextField();
      add(sliderPanel, BorderLayout.CENTER);
      add(textField, BorderLayout.SOUTH);
      pack();
   }

   /**
    * Adds a slider to the slider panel and hooks up the listener
    * @param slider the slider
    * @param description the slider description
    */
   public void addSlider(JSlider slider, String description)
   {
      slider.addChangeListener(listener);
      var panel = new JPanel();
      panel.add(slider);
      panel.add(new JLabel(description));
      panel.setAlignmentX(Component.LEFT_ALIGNMENT);
      var gbc = new GridBagConstraints();
      gbc.gridy = sliderPanel.getComponentCount();
      gbc.anchor = GridBagConstraints.WEST;
      sliderPanel.add(panel, gbc);
   }
}
```

javax.swing.JSlider 1.2

- `JSlider()`
- `JSlider(int direction)`
- `JSlider(int min, int max)`
- `JSlider(int min, int max, int initialValue)`

- `JSlider(int direction, int min, int max, int initialValue)`

  constructs a horizontal slider with the given direction and minimum, maximum, and initial values. The `direction` parameter is one of `SwingConstants.HORIZONTAL` or `SwingConstants.VERTICAL`. The default is horizontal. Defaults for the minimum, initial, and maximum are `0`, `50`, and `100`.

- `void setPaintTicks(boolean b)`

  displays ticks if `b` is `true`.

- `void setMajorTickSpacing(int units)`
- `void setMinorTickSpacing(int units)`

  sets major or minor ticks at multiples of the given slider units.

- `void setPaintLabels(boolean b)`

  displays tick labels if `b` is `true`.

- `void setLabelTable(Dictionary table)`

  sets the components to use for the tick labels. Each key/value pair in the table has the form `Integer.valueOf(`*value*`)/`*component*.

- `void setSnapToTicks(boolean b)`

  if `b` is `true`, then the slider snaps to the closest tick after each adjustment.

- `void setPaintTrack(boolean b)`

  if `b` is `true`, a track is displayed in which the slider runs.

11.5 Menus

This chapter started by introducing the most common components that you might want to place into a window, such as various kinds of buttons, text fields, and combo boxes. Swing also supports another type of user interface element—pull-down menus that are familiar from GUI applications.

A *menu bar* at the top of a window contains the names of the pull-down menus. Clicking on a name opens the menu containing *menu items* and *submenus*. When the user clicks on a menu item, all menus are closed and a message is sent to the program. Figure 11.17 shows a typical menu with a submenu.

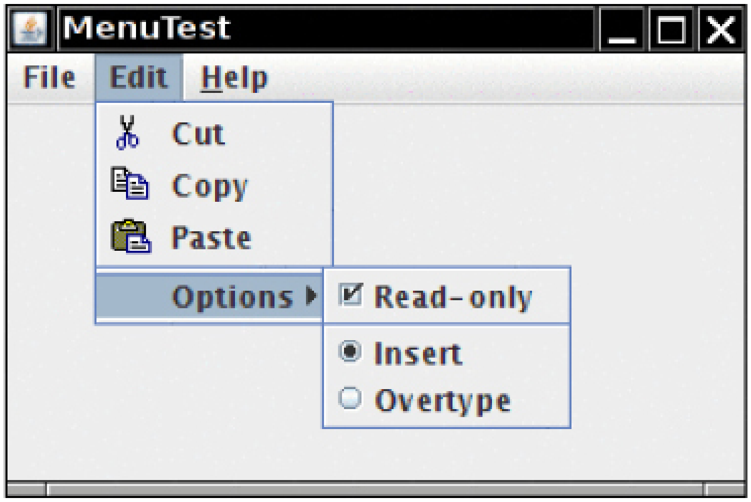


Figure 11.17 A menu with a submenu

11.5.1 Menu Building

Building menus is straightforward. First, create a menu bar:

```
var menuBar = new JMenuBar();
```

A menu bar is just a component that you can add anywhere you like. Normally, you want it to appear at the top of a frame. You can add it there with the `setJMenuBar` method:

```
frame.setJMenuBar(menuBar);
```

For each menu, you create a menu object:

```
var editMenu = new JMenu("Edit");
```

Add the top-level menus to the menu bar:

```
menuBar.add(editMenu);
```

Add menu items, separators, and submenus to the menu object:

```
var pasteItem = new JMenuItem("Paste");
editMenu.add(pasteItem);
editMenu.addSeparator();
JMenu optionsMenu = . . .; // a submenu
editMenu.add(optionsMenu);
```

You can see separators in Figure 11.17 below the Paste and Read-only menu items.

When the user selects a menu item, an action event is triggered. You need to install an action listener for each menu item:

```
ActionListener listener = . . .;
pasteItem.addActionListener(listener);
```

The method `JMenu.add(String s)` conveniently adds a menu item to the end of a menu. For example:

```
editMenu.add("Paste");
```

The `add` method returns the created menu item, so you can capture it and add the listener, as follows:

```
JMenuItem pasteItem = editMenu.add("Paste");
pasteItem.addActionListener(listener);
```

It often happens that menu items trigger commands that can also be activated through other user interface elements such as toolbar buttons. In Section 10.4.5, “Actions,” on p. 623, you saw how to specify commands through `Action` objects. You define a class that implements the `Action` interface, usually by extending the `AbstractAction` convenience class, specify the menu item label in the constructor of the `AbstractAction` object, and override the `actionPerformed` method to hold the menu action handler. For example:

```
var exitAction = new AbstractAction("Exit") // menu item text
goes here
   {
      public void actionPerformed(ActionEvent event)
      {
         // action code goes here
         System.exit(0);
      }
   };
```

You can then add the action to the menu:

```
JMenuItem exitItem = fileMenu.add(exitAction);
```

This command adds a menu item to the menu, using the action name. The action object becomes its listener. This is just a convenient shortcut for

```
var exitItem = new JMenuItem(exitAction);
fileMenu.add(exitItem);
```

`javax.swing.JMenu` 1.2

- `JMenu(String label)`

  constructs a menu with the given label.

- `JMenuItem add(JMenuItem item)`

  adds a menu item (or a menu).

- `JMenuItem add(String label)`

  adds a menu item with the given label to this menu and returns the item.

- `JMenuItem add(Action a)`

  adds a menu item with the given action to this menu and returns the item.

- `void addSeparator()`

  adds a separator line to the menu.

- `JMenuItem insert(JMenuItem menu, int index)`

  adds a new menu item (or submenu) to the menu at a specific index.

- `JMenuItem insert(Action a, int index)`

  adds a new menu item with the given action at a specific index.

- `void insertSeparator(int index)`

  adds a separator to the menu.

- `void remove(int index)`
- `void remove(JMenuItem item)`

  removes a specific item from the menu.

`javax.swing.JMenuItem` 1.2

- `JMenuItem(String label)`

  constructs a menu item with a given label.

- `JMenuItem(Action a)` 1.3

  constructs a menu item for the given action.

`javax.swing.AbstractButton` 1.2

- `void setAction(Action a)` 1.3

  sets the action for this button or menu item.

javax.swing.JFrame 1.2

- `void setJMenuBar(JMenuBar menubar)`

  sets the menu bar for this frame.

11.5.2 Icons in Menu Items

Menu items are very similar to buttons. In fact, the `JMenuItem` class extends the `AbstractButton` class. Just like buttons, menus can have just a text label, just an icon, or both. You can specify the icon with the `JMenuItem(String, Icon)` or `JMenuItem(Icon)` constructor, or you can set it with the `setIcon` method that the `JMenuItem` class inherits from the `AbstractButton` class. Here is an example:

```
var cutItem = new JMenuItem("Cut", new ImageIcon("cut.gif"));
```

In Figure 11.17, you can see icons next to several menu items. By default, the menu item text is placed to the right of the icon. If you prefer the text to be placed on the left, call the `setHorizontalTextPosition` method that the `JMenuItem` class inherits from the `AbstractButton` class. For example, the call

```
cutItem.setHorizontalTextPosition(SwingConstants.LEFT);
```

moves the menu item text to the left of the icon.

You can also add an icon to an action:

```
cutAction.putValue(Action.SMALL_ICON, new
ImageIcon("cut.gif"));
```

Whenever you construct a menu item out of an action, the `Action.NAME` value becomes the text of the menu item and the `Action.SMALL_ICON` value becomes the icon.

Alternatively, you can set the icon in the `AbstractAction` constructor:

```
cutAction = new
   AbstractAction("Cut", new ImageIcon("cut.gif"))
   {
      public void actionPerformed(ActionEvent event)
      {
         . . .
      }
   };
```

javax.swing.JMenuItem 1.2

- `JMenuItem(String label, Icon icon)`

  constructs a menu item with the given label and icon.

javax.swing.AbstractButton 1.2

- `void setHorizontalTextPosition(int pos)`

  sets the horizontal position of the text relative to the icon. The `pos` parameter is `SwingConstants.RIGHT` (text is to the right of icon) or `SwingConstants.LEFT`.

javax.swing.AbstractAction 1.2

- `AbstractAction(String name, Icon smallIcon)` constructs an abstract action with the given name and icon.

11.5.3 Checkbox and Radio Button Menu Items

Checkbox and *radio button* menu items display a checkbox or radio button next to the name (see Figure 11.17). When the user selects the menu item, the item automatically toggles between checked and unchecked.

Apart from the button decoration, treat these menu items just as you would any others. For example, here is how you create a checkbox menu item:

```
var readonlyItem = new JCheckBoxMenuItem("Read-only");
optionsMenu.add(readonlyItem);
```

The radio button menu items work just like regular radio buttons. You must add them to a button group. When one of the buttons in a group is selected, all others are automatically deselected.

```
var group = new ButtonGroup();
var insertItem = new JRadioButtonMenuItem("Insert");
insertItem.setSelected(true);
var overtypeItem = new JRadioButtonMenuItem("Overtype");
group.add(insertItem);
group.add(overtypeItem);
optionsMenu.add(insertItem);
optionsMenu.add(overtypeItem);
```

With these menu items, you don't necessarily want to be notified when the user selects the item. Instead, you can simply use the `isSelected` method to test the current state of the menu item. (Of course, that means you should keep a reference to the menu item stored in an instance field.) Use the `setSelected` method to set the state.

javax.swing.JCheckBoxMenuItem 1.2

- `JCheckBoxMenuItem(String label)`

  constructs the checkbox menu item with the given label.

- `JCheckBoxMenuItem(String label, boolean state)`

  constructs the checkbox menu item with the given label and the given initial state (`true` is checked).

`javax.swing.JRadioButtonMenuItem` 1.2

- `JRadioButtonMenuItem(String label)`

  constructs the radio button menu item with the given label.

- `JRadioButtonMenuItem(String label, boolean state)`

  constructs the radio button menu item with the given label and the given initial state (`true` is checked).

`javax.swing.AbstractButton` 1.2

- `boolean isSelected()`
- `void setSelected(boolean state)`

  gets or sets the selection state of this item (`true` is checked).

11.5.4 Pop-Up Menus

A *pop-up menu* is a menu that is not attached to a menu bar but floats somewhere (see Figure 11.18).

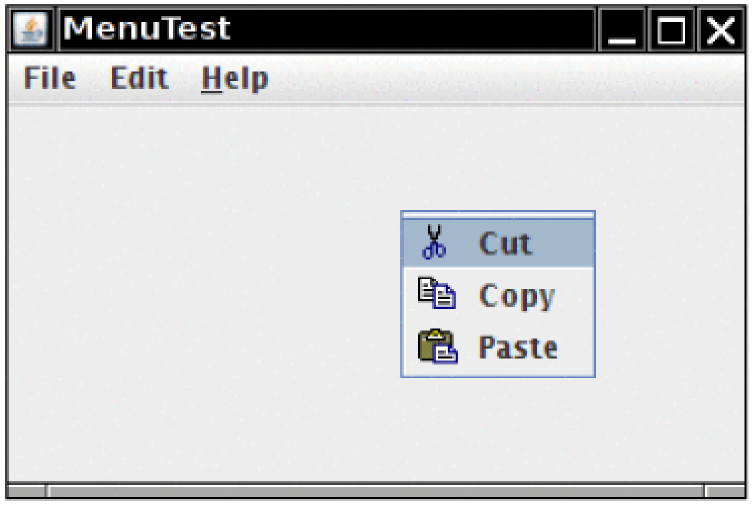


Figure 11.18 A pop-up menu

Create a pop-up menu just as you create a regular menu, except that a pop-up menu has no title.

```
var popup = new JPopupMenu();
```

Then, add your menu items as usual:

```
var item = new JMenuItem("Cut");
item.addActionListener(listener);
popup.add(item);
```

Unlike the regular menu bar that is always shown at the top of the frame, you must explicitly display a pop-up menu by using the `show` method. Specify the parent component and the location of the pop-up, using the coordinate system of the parent. For example:

```
popup.show(panel, x, y);
```

Usually, you want to pop up a menu when the user clicks a particular mouse button—the so-called *pop-up trigger*. In Windows and Linux, the pop-up trigger is the nonprimary (usually, the right) mouse button. To pop up a menu when the user clicks on a component, using the pop-up trigger, simply call the method

```
component.setComponentPopupMenu(popup);
```

Very occasionally, you may place a component inside another component that has a pop-up menu. The child component can inherit the parent component's pop-up menu by calling

```
child.setInheritsPopupMenu(true);
```

javax.swing.JPopupMenu 1.2

- `void show(Component c, int x, int y)`

  shows the pop-up menu over the component `c` with the top left corner at `(x, y)` (in the coordinate space of `c`).

- `boolean isPopupTrigger(MouseEvent event)` 1.3

  returns `true` if the mouse event is the pop-up menu trigger.

java.awt.event.MouseEvent 1.1

- `boolean isPopupTrigger()`

  returns `true` if this mouse event is the pop-up menu trigger.

javax.swing.JComponent 1.2

- `JPopupMenu getComponentPopupMenu()` 5
- `void setComponentPopupMenu(JPopupMenu popup)` 5

gets or sets the pop-up menu for this component.

- `boolean getInheritsPopupMenu()` 5
- `void setInheritsPopupMenu(boolean b)` 5

  gets or sets the `inheritsPopupMenu` property. If the property is set and this component's pop-up menu is `null`, it uses its parent's pop-up menu.

11.5.5 Keyboard Mnemonics and Accelerators

It is a real convenience for the experienced user to select menu items by *keyboard mnemonics*. You can create a keyboard mnemonic for a menu item by specifying a mnemonic letter in the menu item constructor:

```
var aboutItem = new JMenuItem("About", 'A');
```

The keyboard mnemonic is displayed automatically in the menu, with the mnemonic letter underlined (see Figure 11.19). For example, in the item defined in the last example, the label will be displayed as "About" with an underlined letter 'A'. When the menu is displayed, the user just needs to press the A key, and the menu item is selected. (If the mnemonic letter is not part of the menu string, then typing it still selects the item, but the mnemonic is not displayed in the menu. Naturally, such invisible mnemonics are of dubious utility.)

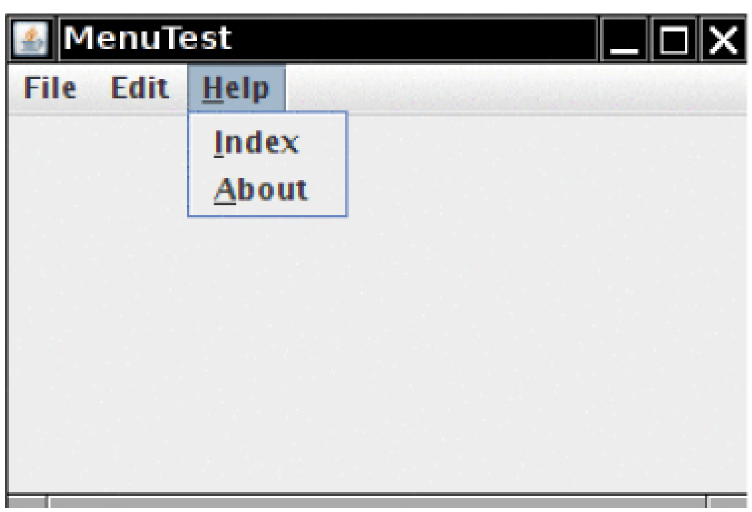


Figure 11.19 Keyboard mnemonics

Sometimes, you don't want to underline the first letter of the menu item that matches the mnemonic. For example, if you have a mnemonic 'A' for the menu item "Save As," then it makes more sense to underline the second 'A' (Save As). You can specify which character you want to have underlined by calling the `setDisplayedMnemonicIndex` method.

If you have an `Action` object, you can add the mnemonic as the value of the `Action.MNEMONIC_KEY` key, as follows:

```
aboutAction.putValue(Action.MNEMONIC_KEY,
Integer.valueOf('A'));
```

You can supply a mnemonic letter only in the constructor of a menu item, not in the constructor for a menu. To attach a mnemonic to a menu, call the `setMnemonic` method:

```
var helpMenu = new JMenu("Help");
helpMenu.setMnemonic('H');
```

To select a top-level menu from the menu bar, press the Alt key together with the mnemonic letter. For example, press Alt+H to select the Help menu from the menu bar.

Keyboard mnemonics let you select a submenu or menu item from the currently open menu. In contrast, *accelerators* are keyboard shortcuts that let you select menu items without ever opening a menu. For example, many programs attach the accelerators Ctrl+O and Ctrl+S to the Open and Save items in the File menu. Use the `setAccelerator` method to attach an accelerator key to a menu item. The `setAccelerator` method takes an object of type `Keystroke`. For example, the following call attaches the accelerator Ctrl+O to the `openItem` menu item:

```
openItem.setAccelerator(KeyStroke.getKeyStroke("ctrl O"));
```

Typing the accelerator key combination automatically selects the menu option and fires an action event, as if the user had selected the menu option manually.

You can attach accelerators only to menu items, not to menus. Accelerator keys don't actually open the menu. Instead, they directly fire the action event associated with a menu.

Conceptually, adding an accelerator to a menu item is similar to the technique of adding an accelerator to a Swing component. However, when the accelerator is added to a menu item, the key combination is automatically displayed in the menu (see Figure 11.20).

NOTE:

Under Windows, Alt+F4 closes a window. But this is not an accelerator to be programmed in Java. It is a shortcut defined by the operating system. This key combination will always trigger the `windowClosing` event for the active window regardless of whether there is a Close item on the menu.

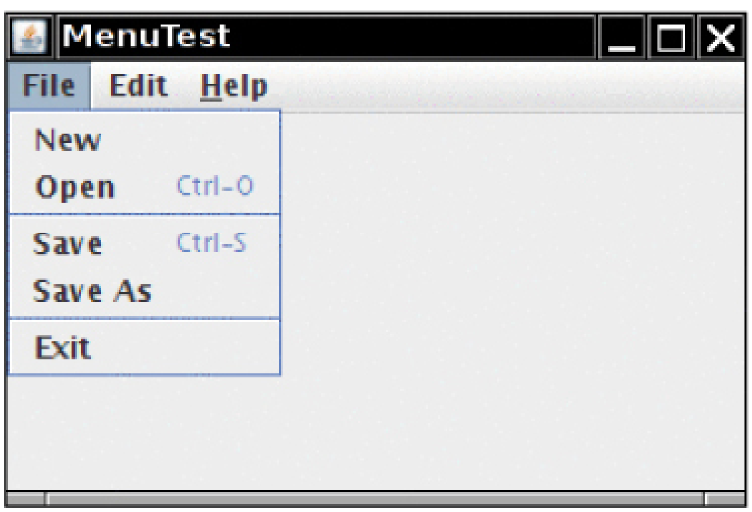


Figure 11.20 Accelerators

`javax.swing.JMenuItem` 1.2

- `JMenuItem(String label, int mnemonic)`

  constructs a menu item with a given label and mnemonic.

- `void setAccelerator(KeyStroke k)`

  sets the keystroke `k` as accelerator for this menu item. The accelerator key is displayed next to the label.

`javax.swing.AbstractButton` 1.2

- `void setMnemonic(int mnemonic)`

  sets the mnemonic character for the button. This character will be underlined in the label.

- `void setDisplayedMnemonicIndex(int index)` 1.4

  sets the index of the character to be underlined in the button text. Use this method if you don't want the first occurrence of the mnemonic character to be underlined.

11.5.6 Enabling and Disabling Menu Items

Occasionally, a particular menu item should be selected only in certain contexts. For example, when a document is opened in read-only mode, the Save menu item is not meaningful. Of course, we could remove the item from the menu with the `JMenu.remove` method, but users would react with some surprise to menus whose content keeps changing. Instead, it is better to deactivate the menu items that lead to temporarily inappropriate commands. A deactivated menu item is shown in gray and cannot be selected (see Figure 11.21).

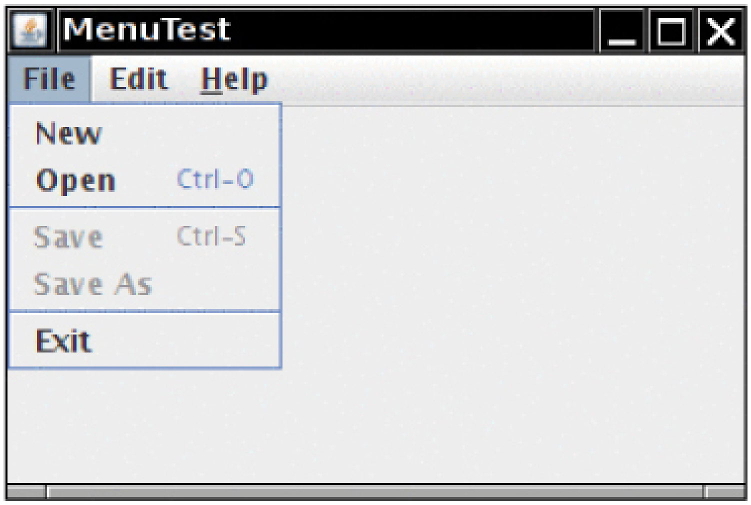


Figure 11.21 Disabled menu items

To enable or disable a menu item, use the `setEnabled` method:

```
saveItem.setEnabled(false);
```

There are two strategies for enabling and disabling menu items. Each time circumstances change, you can call `setEnabled` on the relevant menu items or actions. For example, as soon as a document has been set to read-only mode, you can locate the Save and Save As menu items and disable them. Alternatively, you can disable items just before displaying the menu. To do this, you must register a listener for the "menu selected" event. The `javax.swing.event` package defines a `MenuListener` interface with three methods:

```
void menuSelected(MenuEvent event)
void menuDeselected(MenuEvent event)
void menuCanceled(MenuEvent event)
```

The `menuSelected` method is called *before* the menu is displayed. It can therefore be used to disable or enable menu items. The following code shows how to disable the Save and Save As actions whenever the Read Only checkbox menu item is selected:

```
public void menuSelected(MenuEvent event)
{
   saveAction.setEnabled(!readonlyItem.isSelected());
   saveAsAction.setEnabled(!readonlyItem.isSelected());
}
```

CAUTION:

Disabling menu items just before displaying the menu is a clever idea, but it does not work for menu items that also have accelerator keys. Since the menu is never opened when the accelerator key is pressed, the action is never disabled, and is still triggered by the accelerator key.

`javax.swing.JMenuItem` 1.2

- `void setEnabled(boolean b)`

  enables or disables the menu item.

`javax.swing.event.MenuListener` 1.2

- `void menuSelected(MenuEvent e)`

  is called when the menu has been selected, before it is opened.

- `void menuDeselected(MenuEvent e)`

  is called when the menu has been deselected, after it has been closed.

- `void menuCanceled(MenuEvent e)`

  is called when the menu has been canceled, for example, by a user clicking outside the menu.

Listing 11.6 is a sample program that generates a set of menus. It shows all the features that you saw in this section: nested menus, disabled menu items, checkbox and radio button menu items, a pop-up menu, and keyboard mnemonics and accelerators.

Listing 11.6 `menu/MenuFrame.java`

```
package menu;

import java.awt.event.*;
import javax.swing.*;

/**
 * A frame with a sample menu bar.
 */
public class MenuFrame extends JFrame
{
   private static final int DEFAULT_WIDTH = 300;
   private static final int DEFAULT_HEIGHT = 200;
   private Action saveAction;
   private Action saveAsAction;
   private JCheckBoxMenuItem readonlyItem;
   private JPopupMenu popup;

   /**
    * A sample action that prints the action name to
System.out.
    */
   class TestAction extends AbstractAction
   {
      public TestAction(String name)
      {
         super(name);
      }

      public void actionPerformed(ActionEvent event)
      {
         System.out.println(getValue(Action.NAME) + "
```

```
selected.");
      }
   }

   public MenuFrame()
   {
      setSize(DEFAULT_WIDTH, DEFAULT_HEIGHT);

      var fileMenu = new JMenu("File");
      fileMenu.add(new TestAction("New"));

      // demonstrate accelerators

      var openItem = fileMenu.add(new TestAction("Open"));
      openItem.setAccelerator(KeyStroke.getKeyStroke("ctrl O"));

      fileMenu.addSeparator();

      saveAction = new TestAction("Save");
      JMenuItem saveItem = fileMenu.add(saveAction);
      saveItem.setAccelerator(KeyStroke.getKeyStroke("ctrl S"));

      saveAsAction = new TestAction("Save As");
      fileMenu.add(saveAsAction);
      fileMenu.addSeparator();

      fileMenu.add(new AbstractAction("Exit")
         {
            public void actionPerformed(ActionEvent event)
            {
               System.exit(0);
            }
         });

       // demonstrate checkbox and radio button menus

       readonlyItem = new JCheckBoxMenuItem("Read-only");
```

```java
        readonlyItem.addActionListener(new ActionListener()
          {
             public void actionPerformed(ActionEvent event)
             {
                boolean saveOk = !readonlyItem.isSelected();
                saveAction.setEnabled(saveOk);
                saveAsAction.setEnabled(saveOk);
             }
          });

        var group = new ButtonGroup();

        var insertItem = new JRadioButtonMenuItem("Insert");
        insertItem.setSelected(true);
        var overtypeItem = new JRadioButtonMenuItem("Overtype");

        group.add(insertItem);
        group.add(overtypeItem);

        // demonstrate icons

        var cutAction = new TestAction("Cut");
        cutAction.putValue(Action.SMALL_ICON, new ImageIcon("cut.gif"));
        var copyAction = new TestAction("Copy");
        copyAction.putValue(Action.SMALL_ICON, new ImageIcon("copy.gif"));
        var pasteAction = new TestAction("Paste");
        pasteAction.putValue(Action.SMALL_ICON, new ImageIcon("paste.gif"));

        var editMenu = new JMenu("Edit");
        editMenu.add(cutAction);
        editMenu.add(copyAction);
        editMenu.add(pasteAction);

        // demonstrate nested menus

```

```
        var optionMenu = new JMenu("Options");

        optionMenu.add(readonlyItem);
        optionMenu.addSeparator();
        optionMenu.add(insertItem);
        optionMenu.add(overtypeItem);

        editMenu.addSeparator();
        editMenu.add(optionMenu);

        // demonstrate mnemonics

        var helpMenu = new JMenu("Help");
        helpMenu.setMnemonic('H');

        var indexItem = new JMenuItem("Index");
        indexItem.setMnemonic('I');
        helpMenu.add(indexItem);

        // you can also add the mnemonic key to an action
        var aboutAction = new TestAction("About");
        aboutAction.putValue(Action.MNEMONIC_KEY, Integer.valueOf('A'));
        helpMenu.add(aboutAction);

        // add all top-level menus to menu bar

        var menuBar = new JMenuBar();
        setJMenuBar(menuBar);

        menuBar.add(fileMenu);
        menuBar.add(editMenu);
        menuBar.add(helpMenu);

        // demonstrate pop-ups

        popup = new JPopupMenu();
        popup.add(cutAction);
        popup.add(copyAction);
```

```
            popup.add(pasteAction);

            var panel = new JPanel();
            panel.setComponentPopupMenu(popup);
            add(panel);
        }
    }
```

11.5.7 Toolbars

A toolbar is a button bar that gives quick access to the most commonly used commands in a program (see Figure 11.22).

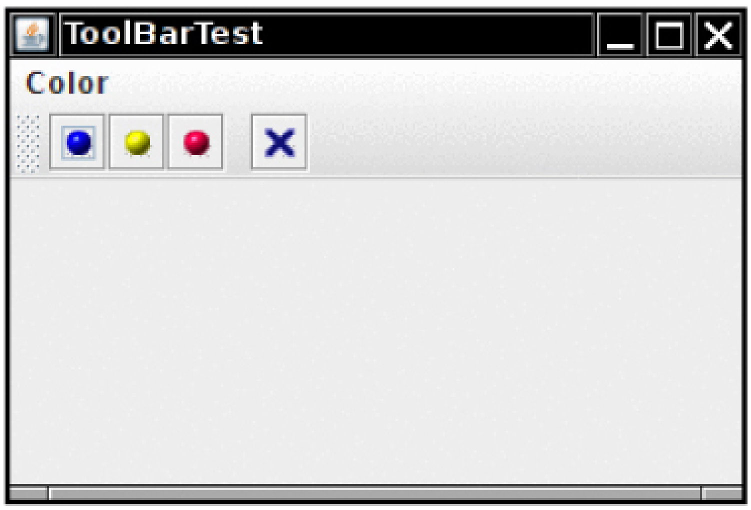


Figure 11.22 A toolbar

What makes toolbars special is that you can move them elsewhere. You can drag the toolbar to one of the four borders of the frame (see Figure 11.23). When you release the mouse button, the toolbar is dropped into the new location (see Figure 11.24).

Figure 11.23 Dragging the toolbar

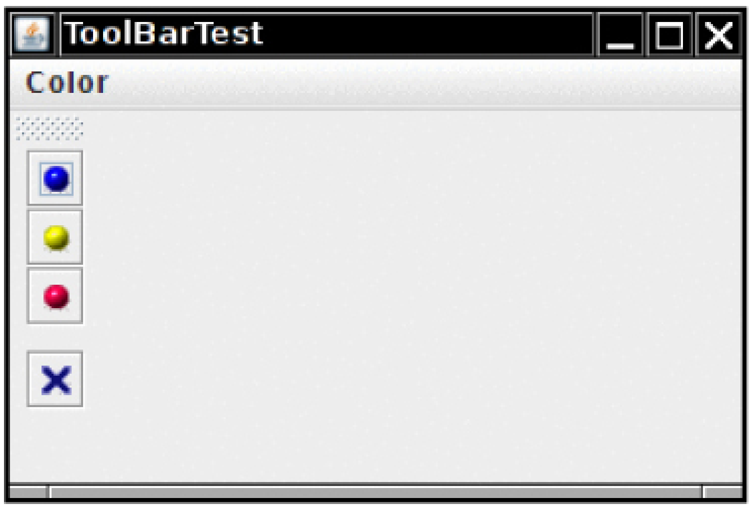


Figure 11.24 The toolbar has been dragged to another border

NOTE:

Toolbar dragging works if the toolbar is inside a container with a border layout, or any other layout manager that supports the `North`, `East`, `South`, and `West` constraints.

The toolbar can even be completely detached from the frame. A detached toolbar is contained in its own frame (see Figure 11.25). When you close the frame containing a detached toolbar, the toolbar jumps back into the original frame.

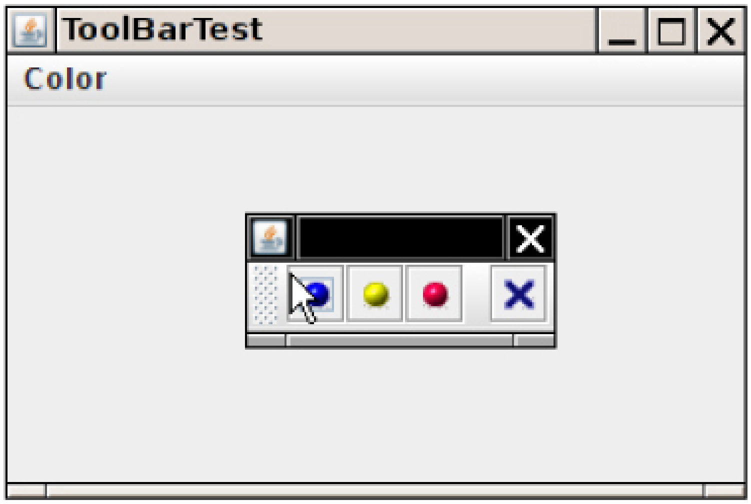


Figure 11.25 Detaching the toolbar

Toolbars are straightforward to program. Add components into the toolbar:

```
var toolbar = new JToolBar();
toolbar.add(blueButton);
```

The `JToolBar` class also has a method to add an `Action` object. Simply populate the toolbar with `Action` objects, like this:

```
toolbar.add(blueAction);
```

The small icon of the action is displayed in the toolbar.

You can separate groups of buttons with a separator:

```
toolbar.addSeparator();
```

For example, the toolbar in Figure 11.22 has a separator between the third and fourth button.

Then, add the toolbar to the frame:

```
add(toolbar, BorderLayout.NORTH);
```

You can also specify a title for the toolbar that appears when the toolbar is undocked:

```
toolbar = new JToolBar(titleString);
```

By default, toolbars are initially horizontal. To have a toolbar start out vertical, use

```
toolbar = new JToolBar(SwingConstants.VERTICAL)
```

or

```
toolbar = new JToolBar(titleString, SwingConstants.VERTICAL)
```

Buttons are the most common components inside toolbars. But there is no restriction on the components that you can add to a toolbar. For example, you can add a combo box to a toolbar.

11.5.8 Tooltips

A disadvantage of toolbars is that users are often mystified by the meanings of the tiny icons in toolbars. To solve this problem, user interface designers invented *tooltips*. A tooltip is activated when the cursor rests for a moment over a button. The tooltip text is displayed inside a colored rectangle. When the user moves the mouse away, the tooltip disappears. (See Figure 11.26.)

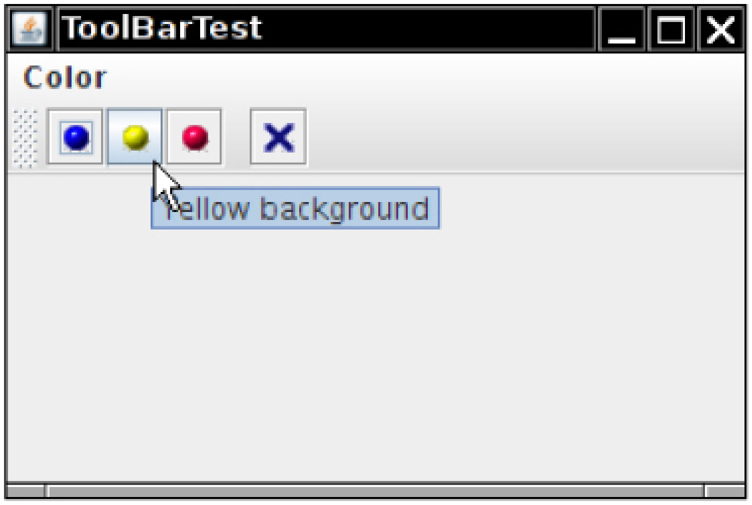


Figure 11.26 A tooltip

In Swing, you can add tooltips to any `JComponent` simply by calling the `setToolTipText` method:

```
exitButton.setToolTipText("Exit");
```

Alternatively, if you use `Action` objects, you associate the tooltip with the `SHORT_DESCRIPTION` key:

```
exitAction.putValue(Action.SHORT_DESCRIPTION, "Exit");
```

`javax.swing.JToolBar` 1.2

- `JToolBar()`
- `JToolBar(String titleString)`
- `JToolBar(int orientation)`
- `JToolBar(String titleString, int orientation)`

  constructs a toolbar with the given title string and orientation. `orientation` is one of `SwingConstants.HORIZONTAL` (the default) or `SwingConstants.VERTICAL`.

- `JButton add(Action a)`

  constructs a new button inside the toolbar with name, icon, short description, and action callback from the given action, and adds the button to the end of the toolbar.

- `void addSeparator()`

  adds a separator to the end of the toolbar.

`javax.swing.JComponent` 1.2

- `void setToolTipText(String text)`

  sets the text that should be displayed as a tooltip when the mouse hovers over the component.

11.6 Sophisticated Layout Management

So far we've been using only the border layout, flow layout, and grid layout for the user interface of our sample applications. For more complex tasks, this is not going to be enough.

Since Java 1.0, the AWT includes the *grid bag layout* that lays out components in rows and columns. The row and column sizes are flexible, and components can span multiple rows and columns. This layout manager is very flexible, but also very complex. The mere mention of the words "grid bag layout" has been known to strike fear in the hearts of Java programmers.

In an unsuccessful attempt to design a layout manager that would free programmers from the tyranny of the grid bag layout, the Swing designers came up with the *box layout*. According to the JDK documentation of the `BoxLayout` class: "Nesting multiple panels with different combinations of horizontal and vertical [*sic*] gives an effect similar to `GridBagLayout`, without the complexity." However, as each box is laid out independently, you cannot use box layouts to arrange neighboring components both horizontally and vertically.

Java 1.4 saw yet another attempt to design a replacement for the grid bag layout—the *spring layout* where you use imaginary springs to connect the components in a container. As the container is resized, the springs stretch or shrink, thereby adjusting the positions of the components. This sounds tedious and confusing, and it is. The spring layout quickly sank into obscurity.

The NetBeans IDE combines a layout tool (called "Matisse") and a layout manager. A user interface designer uses the tool to drop components into a container and to indicate which components should line up. The tool translates the designer's intentions into instructions for the *group layout manager*. This is much more convenient than writing the layout management code by hand.

In the coming sections, I will cover the grid bag layout because it is commonly used and is still the easiest mechanism for programmatically producing layout code. I will show you a strategy that makes grid bag layouts relatively painless in common situations.

Finally, you will see how to write your own layout manager.

11.6.1 The Grid Bag Layout

The grid bag layout is the mother of all layout managers. You can think of a grid bag layout as a grid layout without the limitations. In a grid bag layout, the rows and columns can have variable sizes. You can join adjacent cells to make room for larger components. (Many word processors, as well as HTML, provide similar capabilities for tables: You can start out with a grid and then merge adjacent cells as necessary.) The components need not fill the entire cell area, and you can specify their alignment within cells.

Consider the font selector of Figure 11.27. It consists of the following components:

- Two combo boxes to specify the font face and size
- Labels for these two combo boxes
- Two checkboxes to select bold and italic

• A text area for the sample string

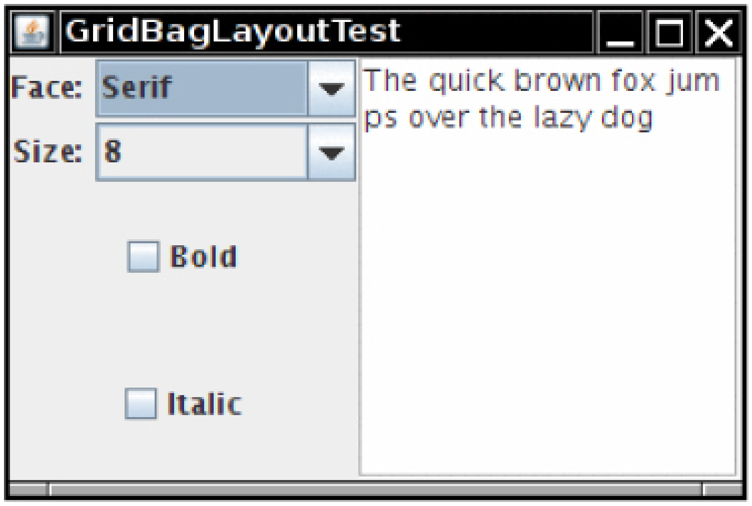


Figure 11.27 A font selector

Now, chop up the container into a grid of cells, as shown in Figure 11.28. (The rows and columns need not have equal size.) Each checkbox spans two columns, and the text area spans four rows.

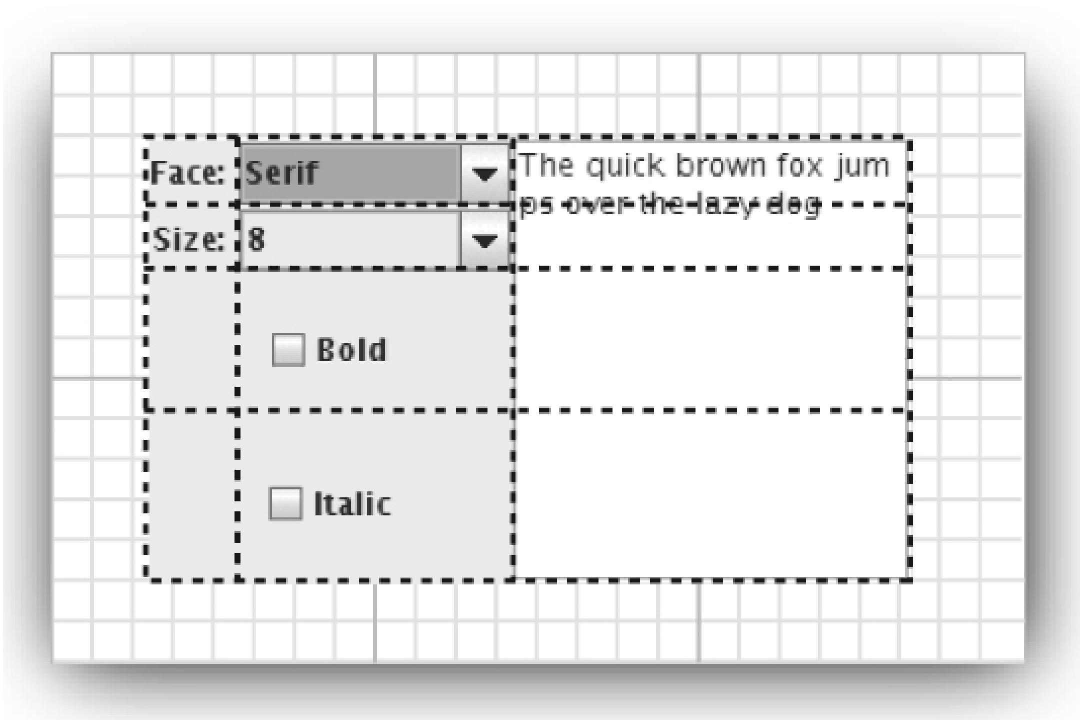


Figure 11.28 Dialog box grid used in design

To describe the layout to the grid bag manager, use the following procedure:

1. Create an object of type `GridBagLayout`. You don't need to tell it how many rows and columns the underlying grid has. Instead, the layout manager will try to guess it from the information you give it later.
2. Set this `GridBagLayout` object to be the layout manager for the component.
3. For each component, create an object of type `GridBagConstraints`. Set field values of the `GridBagConstraints` object to specify how the components are laid out within the grid bag.
4. Finally, add each component with its constraints by using the call

```
add(component, constraints);
```

Here's an example of the code needed. (We'll go over the various constraints in more detail in the sections that follow—so don't worry if you don't know what some of the constraints do.)

```
var layout = new GridBagLayout();
panel.setLayout(layout);
var constraints = new GridBagConstraints();
constraints.weightx = 100;
constraints.weighty = 100;
constraints.gridx = 0;
constraints.gridy = 2;
constraints.gridwidth = 2;
constraints.gridheight = 1;
panel.add(component, constraints);
```

The trick is knowing how to set the state of the `GridBagConstraints` object. We'll discuss this object in the sections that follow.

11.6.1.1 The `gridx`, `gridy`, `gridwidth`, and `gridheight` Parameters

The `gridx`, `gridy`, `gridwidth`, and `gridheight` constraints define where the component is located in the grid. The `gridx` and `gridy` values specify the column and row positions of the upper left corner of the component to be added. The `gridwidth` and `gridheight` values determine how many columns and rows the component occupies.

The grid coordinates start with `0`. In particular, `gridx = 0` and `gridy = 0` denotes the top left corner. The text area in our example has `gridx = 2`, `gridy = 0` because it starts in column 2 (that is, the third column) of row 0. It has `gridwidth = 1` and `gridheight = 4` because it spans one column and four rows.

11.6.1.2 Weight Fields

You always need to set the *weight* fields (`weightx` and `weighty`) for each area in a grid bag layout. If you set the weight to `0`, the area never grows or shrinks beyond its initial size in that direction. In the grid bag layout for Figure 11.27, we set the `weightx` field of the labels to be `0`. This allows the labels to keep constant width when you resize the window. On the other hand, if you set the weights for all areas to `0`, the container will huddle in the center of its allotted area instead of stretching to fill it.

Conceptually, the problem with the weight parameters is that weights are properties of rows and columns, not individual cells. But you need to specify them for cells because the grid bag layout does not expose the rows and columns. The row and column weights are computed as the maxima of the cell weights in each row or column. Thus, if you want a row or column to stay at a fixed size, you need to set the weights of all components in it to zero.

Note that the weights don't actually give the relative sizes of the columns. They tell what proportion of the "slack" space should be allocated to each area if the container exceeds its preferred size. This isn't particularly intuitive. I recommend that you set all weights at `100`. Then, run the program and see how the layout looks. Resize the dialog to see how the rows and columns adjust. If you find that a particular row or column should not grow, set the weights of all components in it to zero. You can tinker with other weight values, but it is usually not worth the effort.

11.6.1.3 The `fill` and `anchor` Parameters

If you don't want a component to stretch out and fill the entire area, set the `fill` constraint. You have four possibilities for this parameter: the valid values are `GridBagConstraints.NONE`, `GridBagConstraints.HORIZONTAL`, `GridBagConstraints.VERTICAL`, and `GridBagConstraints.BOTH`.

If the component does not fill the entire area, you can specify where in the area you want it by setting the `anchor` field. The valid values are `GridBagConstraints.CENTER` (the default), `GridBagConstraints.NORTH`, `GridBagConstraints.NORTHEAST`, `GridBagConstraints.EAST`, and so on.

11.6.1.4 Padding

You can surround a component with additional blank space by setting the `insets` field of `GridBagConstraints`. Set the `left`, `top`, `right`, and `bottom` values of the `Insets` object to the amount of space that you want to have around the component. This is called the *external padding*.

The `ipadx` and `ipady` values set the *internal padding*. These values are added to the minimum width and height of the component. This ensures that the component does not shrink down to its minimum size.

11.6.1.5 Alternative Method to Specify the `gridx`, `gridy`, `gridwidth`, and `gridheight` Parameters

The AWT documentation recommends that instead of setting the `gridx` and `gridy` values to absolute positions, you set them to the constant `GridBagConstraints.RELATIVE`. Then, add the components to the grid bag layout in a standardized order, going from left to right in the first row, then moving along the next row, and so on.

You would still specify the number of rows and columns spanned, by giving the appropriate `gridheight` and `gridwidth` fields. However, if the component extends to the *last* row or column, you don't need to specify the actual number, but the constant `GridBagConstraints.REMAINDER`. This tells the layout manager that the component is the last one in its row.

This scheme does seem to work. But it sounds really goofy to hide the actual placement information from the layout manager and hope that it will rediscover it.

11.6.1.6 A Grid Bag Layout Recipe

In practice, the following recipe makes grid bag layouts relatively trouble-free:

1. Sketch out the component layout on a piece of paper.
2. Find a grid such that the small components are each contained in a cell and the larger components span multiple cells.
3. Label the rows and columns of your grid with 0, 1, 2, 3, . . . You can now read off the `gridx`, `gridy`, `gridwidth`, and `gridheight` values.
4. For each component, ask yourself whether it needs to fill its cell horizontally or vertically. If not, how do you want it aligned? This tells you the `fill` and `anchor` parameters.
5. Set all weights to `100`. However, if you want a particular row or column to always stay at its default size, set the `weightx` or `weighty` to `0` in all components that belong to that row or column.
6. Write the code. Carefully double-check your settings for the `GridBagConstraints`. One wrong constraint can ruin your whole layout.
7. Compile, run, and enjoy.

11.6.1.7 A Helper Class to Tame the Grid Bag Constraints

The most tedious aspect of the grid bag layout is writing the code that sets the constraints. Most programmers write helper functions or a small helper class for this purpose. I present such a class after the complete code for the font dialog example. This class has the following features:

- Its name is short: `GBC` instead of `GridBagConstraints`.
- It extends `GridBagConstraints`, so you can use shorter names such as `GBC.EAST` for the constants.
- Use a `GBC` object when adding a component, such as

```
add(component, new GBC(1, 2));
```

- There are two constructors to set the most common parameters: `gridx` and `gridy`, or `gridx`, `gridy`, `gridwidth`, and `gridheight`.

```
add(component, new GBC(1, 2, 1, 4));
```

- There are convenient setters for the fields that come in `x`/`y` pairs:

```
add(component, new GBC(1, 2).setWeight(100, 100));
```

- The setter methods return `this`, so you can chain them:

```
add(component, new GBC(1, 2).setAnchor(GBC.EAST).setWeight(100,
100));
```

- The `setInsets` methods construct the `Insets` object for you. To get one-pixel insets, simply call

```
add(component, new GBC(1, 2).setAnchor(GBC.EAST).setInsets(1));
```

Listing 11.7 shows the frame class for the font dialog example. The `GBC` helper class is in Listing 11.8. Here is the code that adds the components to the grid bag:

```
add(faceLabel, new GBC(0, 0).setAnchor(GBC.EAST));
add(face, new GBC(1, 0).setFill(GBC.HORIZONTAL).setWeight(100,
0).setInsets(1));
add(sizeLabel, new GBC(0, 1).setAnchor(GBC.EAST));
add(size, new GBC(1, 1).setFill(GBC.HORIZONTAL).setWeight(100,
0).setInsets(1));
add(bold, new GBC(0, 2, 2,
1).setAnchor(GBC.CENTER).setWeight(100, 100));
add(italic, new GBC(0, 3, 2,
1).setAnchor(GBC.CENTER).setWeight(100, 100));
add(sample, new GBC(2, 0, 1,
4).setFill(GBC.BOTH).setWeight(100, 100));
```

Once you understand the grid bag constraints, this kind of code is fairly easy to read and debug.

Listing 11.7 `gridbag/FontFrame.java`

```java
package gridbag;

import java.awt.Font;
import java.awt.GridBagLayout;
import java.awt.event.ActionListener;

import javax.swing.BorderFactory;
import javax.swing.JCheckBox;
import javax.swing.JComboBox;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JTextArea;

/**
 * A frame that uses a grid bag layout to arrange font selection components.
 */
public class FontFrame extends JFrame
{
   public static final int TEXT_ROWS = 10;
   public static final int TEXT_COLUMNS = 20;

   private JComboBox<String> face;
   private JComboBox<Integer> size;
   private JCheckBox bold;
   private JCheckBox italic;
   private JTextArea sample;

   public FontFrame()
   {
      var layout = new GridBagLayout();
      setLayout(layout);

      ActionListener listener = event -> updateSample();

      // construct components

```

```
        var faceLabel = new JLabel("Face: ");

        face = new JComboBox<>(new String[] { "Serif", "SansSerif", "Monospaced",
           "Dialog", "DialogInput" });

        face.addActionListener(listener);

        var sizeLabel = new JLabel("Size: ");

        size = new JComboBox<>(new Integer[] { 8, 10, 12, 15, 18, 24, 36, 48 });

        size.addActionListener(listener);

        bold = new JCheckBox("Bold");
        bold.addActionListener(listener);

        italic = new JCheckBox("Italic");
        italic.addActionListener(listener);

        sample = new JTextArea(TEXT_ROWS, TEXT_COLUMNS);
        sample.setText("The quick brown fox jumps over the lazy dog");
        sample.setEditable(false);
        sample.setLineWrap(true);
        sample.setBorder(BorderFactory.createEtchedBorder());

        // add components to grid, using GBC convenience class

        add(faceLabel, new GBC(0, 0).setAnchor(GBC.EAST));
        add(face, new GBC(1, 0).setFill(GBC.HORIZONTAL).setWeight(100, 0).setInsets(1));
        add(sizeLabel, new GBC(0, 1).setAnchor(GBC.EAST));
        add(size, new GBC(1, 1).setFill(GBC.HORIZONTAL).setWeight(100, 0).setInsets(1));
        add(bold, new GBC(0, 2, 2, 1).setAnchor(GBC.CENTER).setWeight(100, 100));
        add(italic, new GBC(0, 3, 2,
```

```
1).setAnchor(GBC.CENTER).setWeight(100, 100));
      add(sample, new GBC(2, 0, 1,
4).setFill(GBC.BOTH).setWeight(100, 100));
      pack();
      updateSample();
   }

   public void updateSample()
   {
      var fontFace = (String) face.getSelectedItem();
      int fontStyle = (bold.isSelected() ? Font.BOLD : 0)
         + (italic.isSelected() ? Font.ITALIC : 0);
      int fontSize = size.getItemAt(size.getSelectedIndex());
      var font = new Font(fontFace, fontStyle, fontSize);
      sample.setFont(font);
      sample.repaint();
   }
}
```

Listing 11.8 `gridbag/GBC.java`

```
package gridbag;

import java.awt.*;

/**
 * This class simplifies the use of the GridBagConstraints
class.
 * @version 1.01 2004-05-06
 * @author Cay Horstmann
 */
public class GBC extends GridBagConstraints
{
 /**
  * Constructs a GBC with a given gridx and gridy position and
all other grid
  * bag constraint values set to the default.
  * @param gridx the gridx position
```

```
    * @param gridy the gridy position
    */
   public GBC(int gridx, int gridy)
   {
      this.gridx = gridx;
      this.gridy = gridy;
   }

   /**
    * Constructs a GBC with given gridx, gridy, gridwidth, gridheight and all
    * other grid bag constraint values set to the default.
    * @param gridx the gridx position
    * @param gridy the gridy position
    * @param gridwidth the cell span in x-direction
    * @param gridheight the cell span in y-direction
    */
   public GBC(int gridx, int gridy, int gridwidth, int gridheight)
   {
      this.gridx = gridx;
      this.gridy = gridy;
      this.gridwidth = gridwidth;
      this.gridheight = gridheight;
   }

   /**
    * Sets the anchor.
    * @param anchor the anchor value
    * @return this object for further modification
    */
   public GBC setAnchor(int anchor)
   {
      this.anchor = anchor;
      return this;
   }

   /**
    * Sets the fill direction.
```

```
    * @param fill the fill direction
    * @return this object for further modification
    */
   public GBC setFill(int fill)
   {
      this.fill = fill;
      return this;
   }

   /**
    * Sets the cell weights.
    * @param weightx the cell weight in x-direction
    * @param weighty the cell weight in y-direction
    * @return this object for further modification
    */
   public GBC setWeight(double weightx, double weighty)
   {
      this.weightx = weightx;
      this.weighty = weighty;
      return this;
   }

   /**
    * Sets the insets of this cell.
    * @param distance the spacing to use in all directions
    * @return this object for further modification
    */
   public GBC setInsets(int distance)
   {
      this.insets = new Insets(distance, distance, distance, distance);
      return this;
   }

   /**
    * Sets the insets of this cell.
    * @param top the spacing to use on top
    * @param left the spacing to use to the left
    * @param bottom the spacing to use on the bottom
```

```
    * @param right the spacing to use to the right
    * @return this object for further modification
    */
   public GBC setInsets(int top, int left, int bottom, int right)
   {
      this.insets = new Insets(top, left, bottom, right);
      return this;
   }

   /**
    * Sets the internal padding
    * @param ipadx the internal padding in x-direction
    * @param ipady the internal padding in y-direction
    * @return this object for further modification
    */
   public GBC setIpad(int ipadx, int ipady)
   {
      this.ipadx = ipadx;
      this.ipady = ipady;
      return this;
   }
}
```

`java.awt.GridBagConstraints` 1.0

- `int gridx, gridy`

  specifies the starting column and row of the cell. The default is `0`.

- `int gridwidth, gridheight`

  specifies the column and row extent of the cell. The default is `1`.

- `double weightx, weighty`

  specifies the capacity of the cell to grow. The default is `0`.

- `int anchor`

indicates the alignment of the component inside the cell. You can choose between absolute positions:

`NORTHEAST`	`NORTH`	`NORTHWEST`
`WEST`	`CENTER`	`EAST`
`SOUTHWEST`	`SOUTH`	`SOUTHEAST`

or their orientation-independent counterparts:

`FIRST_LINE_END`	`LINE_START`	`LAST_LINE_END`
`PAGE_START`	`CENTER`	`PAGE_END`
`FIRST_LINE_START`	`LAST_LINE_START`	`LINE_END`

Use the latter if your application may be localized for right-to-left or top-to-bottom text. The default is `CENTER`.

- `int fill`

  specifies the fill behavior of the component inside the cell: one of `NONE`, `BOTH`, `HORIZONTAL`, or `VERTICAL`. The default is `NONE`.

- `int ipadx, ipady`

  specifies the “internal” padding around the component. The default is `0`.

- `Insets insets`

  specifies the “external” padding along the cell boundaries. The default is no padding.

- `GridBagConstraints(int gridx, int gridy, int gridwidth, int gridheight, double weightx, double weighty, int anchor, int fill, Insets insets, int ipadx, int ipady)` **1.2**

  constructs a `GridBagConstraints` with all its fields specified in the arguments. This constructor should only be used by automatic code generators because it makes your source code very hard to read.

11.6.2 Custom Layout Managers

You can design your own `LayoutManager` class that manages components in a special way. As a fun example, let's arrange all components in a container to form a circle (see Figure 11.29).

Your own layout manager must implement the `LayoutManager` interface. You need to override the following five methods:

```
void addLayoutComponent(String s, Component c)
void removeLayoutComponent(Component c)
Dimension preferredLayoutSize(Container parent)
Dimension minimumLayoutSize(Container parent)
void layoutContainer(Container parent)
```

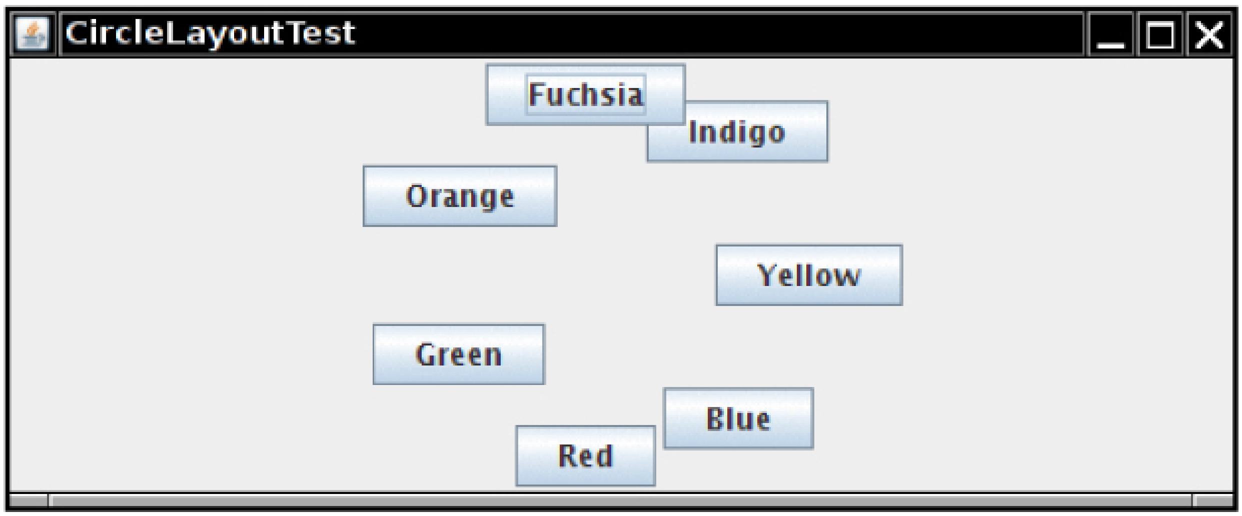


Figure 11.29 Circle layout

The first two methods are called when a component is added or removed. If you don't keep any additional information about the components, you can make them do nothing. The next two methods compute the space required for the minimum and the preferred layout of the components. These are usually the same quantity. The fifth method does the actual work and invokes `setBounds` on all components.

NOTE:

The AWT has a second interface, called `LayoutManager2`, with ten methods to implement rather than five. The main point of the `LayoutManager2` interface is to allow you to use the `add` method with constraints. For example, the `BorderLayout` and `GridBagLayout` implement the `LayoutManager2` interface.

Listing 11.9 shows the code for the `CircleLayout` manager which, uselessly enough, lays out the components along a circle inside the parent. The frame class of the sample program is in Listing 11.10.

Listing 11.9 `circleLayout/CircleLayout.java`

```
package circleLayout;

import java.awt.*;

/**
 * A layout manager that lays out components along a circle.
 */
public class CircleLayout implements LayoutManager
{
   private int minWidth = 0;
   private int minHeight = 0;
   private int preferredWidth = 0;
   private int preferredHeight = 0;
   private boolean sizesSet = false;
   private int maxComponentWidth = 0;
   private int maxComponentHeight = 0;

   public void addLayoutComponent(String name, Component comp)
   {
   }

   public void removeLayoutComponent(Component comp)
   {
   }

```

```
   public void setSizes(Container parent)
   {
     if (sizesSet) return;
     int n = parent.getComponentCount();

     preferredWidth = 0;
     preferredHeight = 0;
     minWidth = 0;
     minHeight = 0;
     maxComponentWidth = 0;
     maxComponentHeight = 0;

     // compute the maximum component widths and heights
     // and set the preferred size to the sum of the component sizes
     for (int i = 0; i < n; i++)
     {
        Component c = parent.getComponent(i);
        if (c.isVisible())
        {
           Dimension d = c.getPreferredSize();
           maxComponentWidth = Math.max(maxComponentWidth, d.width);
           maxComponentHeight = Math.max(maxComponentHeight, d.height);
           preferredWidth += d.width;
           preferredHeight += d.height;
        }
     }
     minWidth = preferredWidth / 2;
     minHeight = preferredHeight / 2;
     sizesSet = true;
   }

   public Dimension preferredLayoutSize(Container parent)
   {
     setSizes(parent);
     Insets insets = parent.getInsets();
     int width = preferredWidth + insets.left + insets.right;
```

```
    int height = preferredHeight + insets.top + insets.bottom;
    return new Dimension(width, height);
  }

  public Dimension minimumLayoutSize(Container parent)
  {
    setSizes(parent);
    Insets insets = parent.getInsets();
    int width = minWidth + insets.left + insets.right;
    int height = minHeight + insets.top + insets.bottom;
    return new Dimension(width, height);
  }

  public void layoutContainer(Container parent)
  {
    setSizes(parent);

    // compute center of the circle

    Insets insets = parent.getInsets();
    int containerWidth = parent.getSize().width - insets.left - insets.right;
    int containerHeight = parent.getSize().height - insets.top - insets.bottom;

    int xcenter = insets.left + containerWidth / 2;
    int ycenter = insets.top + containerHeight / 2;

    // compute radius of the circle

    int xradius = (containerWidth - maxComponentWidth) / 2;
    int yradius = (containerHeight - maxComponentHeight) / 2;
    int radius = Math.min(xradius, yradius);

    // lay out components along the circle

    int n = parent.getComponentCount();
    for (int i = 0; i < n; i++)
```

```
      {
         Component c = parent.getComponent(i);
         if (c.isVisible())
         {
            double angle = 2 * Math.PI * i / n;

            // center point of component
            int x = xcenter + (int) (Math.cos(angle) * radius);
            int y = ycenter + (int) (Math.sin(angle) * radius);

            // move component so that its center is (x, y)
            // and its size is its preferred size
            Dimension d = c.getPreferredSize();
            c.setBounds(x - d.width / 2, y - d.height / 2, d.width, d.height);
         }
      }
   }
}
```

Listing 11.10 `circleLayout/CircleLayoutFrame.java`

```
package circleLayout;

import javax.swing.*;

/**
 * A frame that shows buttons arranged along a circle.
 */
public class CircleLayoutFrame extends JFrame
{
   public CircleLayoutFrame()
   {
      setLayout(new CircleLayout());
      add(new JButton("Yellow"));
      add(new JButton("Blue"));
      add(new JButton("Red"));
      add(new JButton("Green"));
```

```
        add(new JButton("Orange"));
        add(new JButton("Fuchsia"));
        add(new JButton("Indigo"));
        pack();
    }
}
```

java.awt.LayoutManager 1.0

- `void addLayoutComponent(String name, Component comp)`

  adds a component to the layout.

- `void removeLayoutComponent(Component comp)`

  removes a component from the layout.

- `Dimension preferredLayoutSize(Container cont)`

  returns the preferred size dimensions for the container under this layout.

- `Dimension minimumLayoutSize(Container cont)`

  returns the minimum size dimensions for the container under this layout.

- `void layoutContainer(Container cont)`

  lays out the components in a container.

11.7 Dialog Boxes

In GUI applications, you usually want separate dialog boxes to pop up to give information to, or get information from, the user.

Just as with most windowing systems, AWT distinguishes between *modal* and *modeless* dialog boxes. A modal dialog box won't let users interact with the remaining windows of the application until he or she deals with it. Use a modal dialog box when you need information from the user before you can proceed with execution. For example, when the user wants to read a file, a modal file dialog box is the one to pop up. The user must specify a file name before the program can begin the read operation. Only when the user closes the modal dialog box can the application proceed.

A modeless dialog box lets the user enter information in both the dialog box and the remainder of the application. One example of a modeless dialog is a toolbar. The toolbar can stay in place as long as needed, and the user can interact with both the application window and the toolbar as needed.

Let's start this section with the simplest dialogs—modal dialogs with just a single message. Swing has a convenient `JOptionPane` class that lets you put up a simple dialog without writing any special dialog box code. Next, you will see how to write more complex dialogs by implementing your own dialog windows. Finally, you will see how to transfer data from your application into a dialog and back.

We'll conclude the discussion of dialog boxes by looking at the Swing `JFileChooser`.

11.7.1 Option Dialogs

Swing has a set of ready-made simple dialogs that suffice to ask the user for a single piece of information. The `JOptionPane` has four static methods to show these simple dialogs:

`showMessageDialog`	Show a message and wait for the user to click OK
`showConfirmDialog`	Show a message and get a confirmation (like OK/Cancel)
`showOptionDialog`	Show a message and get a user option from a set of options
`showInputDialog`	Show a message and get one line of user input

Figure 11.30 shows a typical dialog. As you can see, the dialog has the following components:

- An icon

• A message

• One or more option buttons

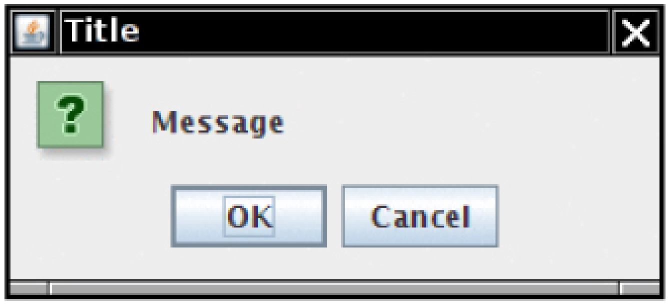


Figure 11.30 An option dialog

The input dialog has an additional component for user input. This can be a text field into which the user can type an arbitrary string, or a combo box from which the user can select one item.

The exact layout of these dialogs and the choice of icons for standard message types depend on the pluggable look-and-feel.

The icon on the left side depends on one of five *message types*:

```
ERROR_MESSAGE
INFORMATION_MESSAGE
WARNING_MESSAGE
QUESTION_MESSAGE
PLAIN_MESSAGE
```

The `PLAIN_MESSAGE` type has no icon. Each dialog type also has a method that lets you supply your own icon instead.

For each dialog type, you can specify a message. This message can be a string, an icon, a user interface component, or any other object. Here is how the message object is displayed:

`String`	Draw the string
`Icon`	Show the icon
`Component`	Show the component
`Object[]`	Show all objects in the array, stacked on top of each other
Any other object	Apply `toString` and show the resulting string

Of course, supplying a message string is by far the most common case. Supplying a `Component` gives you ultimate flexibility because you can make the `paintComponent` method draw anything you want.

The buttons at the bottom depend on the dialog type and the *option type*. When calling `showMessageDialog` and `showInputDialog`, you get only a standard set of buttons (OK and OK/Cancel, respectively). When calling `showConfirmDialog`, you can choose among four option types:

```
DEFAULT_OPTION
YES_NO_OPTION
YES_NO_CANCEL_OPTION
OK_CANCEL_OPTION
```

With the `showOptionDialog` you can specify an arbitrary set of options. You supply an array of objects for the options. Each array element is rendered as follows:

`String`	Make a button with the string as label
`Icon`	Make a button with the icon as label
`Component`	Show the component
Any other object	Apply `toString` and make a button with the resulting string as label

The return values of these functions are as follows:

`showMessageDialog`	None
`showConfirmDialog`	An integer representing the chosen option
`showOptionDialog`	An integer representing the chosen option
`showInputDialog`	The string that the user supplied or selected

The `showConfirmDialog` and `showOptionDialog` return integers to indicate which button the user chose. For the option dialog, this is simply the index of the chosen option or the value `CLOSED_OPTION` if the user closed the dialog instead of choosing an option. For the confirmation dialog, the return value can be one of the following:

```
OK_OPTION
CANCEL_OPTION
YES_OPTION
NO_OPTION
CLOSED_OPTION
```

This all sounds like a bewildering set of choices, but in practice it is simple. Follow these steps:

1. Choose the dialog type (message, confirmation, option, or input).
2. Choose the icon (error, information, warning, question, none, or custom).
3. Choose the message (string, icon, custom component, or a stack of them).
4. For a confirmation dialog, choose the option type (default, Yes/No, Yes/No/Cancel, or OK/Cancel).
5. For an option dialog, choose the options (strings, icons, or custom components) and the default option.
6. For an input dialog, choose between a text field and a combo box.
7. Locate the appropriate method to call in the `JOptionPane` API.

For example, suppose you want to show the dialog in Figure 11.30. The dialog shows a message and asks the user to confirm or cancel. Thus, it is a confirmation dialog. The icon is a question icon. The message is a string. The option type is `OK_CANCEL_OPTION`. Here is the call you would make:

```
int selection = JOptionPane.showConfirmDialog(parent,
   "Message", "Title",
   JOptionPane.OK_CANCEL_OPTION,
   JOptionPane.QUESTION_MESSAGE);
if (selection == JOptionPane.OK_OPTION) . . .
```

TIP:

The message string can contain newline (`'\n'`) characters. Such a string is displayed in multiple lines.

---

javax.swing.JOptionPane 1.2

- `static void showMessageDialog(Component parent, Object message, String title, int messageType, Icon icon)`
- `static void showMessageDialog(Component parent, Object message, String title, int messageType)`
- `static void showMessageDialog(Component parent, Object message)`
- `static void showInternalMessageDialog(Component parent, Object message, String title, int messageType, Icon icon)`
- `static void showInternalMessageDialog(Component parent, Object message, String title, int messageType)`
- `static void showInternalMessageDialog(Component parent, Object message)`

shows a message dialog or an internal message dialog. (An internal dialog is rendered entirely within its owner’s frame.) The parent component can be `null`. The message to show on the dialog can be a string, icon, component, or an array of them. The `messageType` parameter is one of `ERROR_MESSAGE`, `INFORMATION_MESSAGE`, `WARNING_MESSAGE`, `QUESTION_MESSAGE`, `PLAIN_MESSAGE`.

- `static int showConfirmDialog(Component parent, Object message, String title, int optionType, int messageType, Icon icon)`
- `static int showConfirmDialog(Component parent, Object message, String title, int optionType, int messageType)`
- `static int showConfirmDialog(Component parent, Object message, String title, int optionType)`
- `static int showConfirmDialog(Component parent, Object message)`
- `static int showInternalConfirmDialog(Component parent, Object message, String title, int optionType, int messageType, Icon icon)`
- `static int showInternalConfirmDialog(Component parent, Object message, String title, int optionType, int messageType)`
- `static int showInternalConfirmDialog(Component parent, Object message, String title, int optionType)`
- `static int showInternalConfirmDialog(Component parent, Object message)`

  shows a confirmation dialog or an internal confirmation dialog. (An internal dialog is rendered entirely within its owner's frame.) Returns the option selected by the user (one of `OK_OPTION`, `CANCEL_OPTION`, `YES_OPTION`, `NO_OPTION`), or `CLOSED_OPTION` if the user closed the dialog. The parent component can be `null`. The message to show on the dialog can be a string, icon, component, or an array of them. The `messageType` parameter is one of `ERROR_MESSAGE`, `INFORMATION_MESSAGE`, `WARNING_MESSAGE`, `QUESTION_MESSAGE`, `PLAIN_MESSAGE`, and `optionType` is one of `DEFAULT_OPTION`, `YES_NO_OPTION`, `YES_NO_CANCEL_OPTION`, `OK_CANCEL_OPTION`.

- `static int showOptionDialog(Component parent, Object message, String title, int optionType, int messageType, Icon icon, Object[] options, Object default)`

- `static int showInternalOptionDialog(Component parent, Object message, String title, int optionType, int messageType, Icon icon, Object[] options, Object default)`

  shows an option dialog or an internal option dialog. (An internal dialog is rendered entirely within its owner's frame.) Returns the index of the option selected by the user, or `CLOSED_OPTION` if the user canceled the dialog. The parent component can be `null`. The message to show on the dialog can be a string, icon, component, or an array of them. The `messageType` parameter is one of `ERROR_MESSAGE`, `INFORMATION_MESSAGE`, `WARNING_MESSAGE`, `QUESTION_MESSAGE`, `PLAIN_MESSAGE`, and `optionType` is one of `DEFAULT_OPTION`, `YES_NO_OPTION`, `YES_NO_CANCEL_OPTION`, `OK_CANCEL_OPTION`. The `options` parameter is an array of strings, icons, or components.

- `static Object showInputDialog(Component parent, Object message, String title, int messageType, Icon icon, Object[] values, Object default)`
- `static String showInputDialog(Component parent, Object message, String title, int messageType)`
- `static String showInputDialog(Component parent, Object message)`
- `static String showInputDialog(Object message)`
- `static String showInputDialog(Component parent, Object message, Object default)` **1.4**
- `static String showInputDialog(Object message, Object default)` **1.4**
- `static Object showInternalInputDialog(Component parent, Object message, String title, int messageType, Icon icon, Object[] values, Object default)`
- `static String showInternalInputDialog(Component parent, Object message, String title, int messageType)`
- `static String showInternalInputDialog(Component parent, Object message)`

shows an input dialog or an internal input dialog. (An internal dialog is rendered entirely within its owner's frame.) Returns the input string typed by the user, or `null` if the user canceled the dialog. The parent component can be `null`. The message to show on the dialog can be a string, icon, component, or an array of them. The `messageType` parameter is one of `ERROR_MESSAGE`, `INFORMATION_MESSAGE`, `WARNING_MESSAGE`, `QUESTION_MESSAGE`, `PLAIN_MESSAGE`.

11.7.2 Creating Dialogs

In the last section, you saw how to use the `JOptionPane` class to show a simple dialog. In this section, you will see how to create such a dialog by hand.

Figure 11.31 shows a typical modal dialog box—a program information box that is displayed when the user clicks the About button.

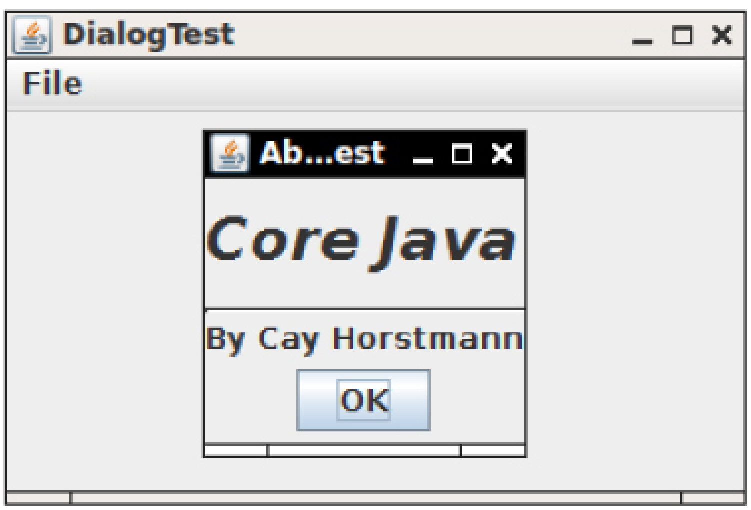


Figure 11.31 An About dialog box

To implement a dialog box, you extend the `JDialog` class. This is essentially the same process as extending `JFrame` for the main window for an application. More precisely:

1. In the constructor of your dialog box, call the constructor of the superclass `JDialog`.
2. Add the user interface components of the dialog box.
3. Add the event handlers.
4. Set the size for the dialog box.

When you call the superclass constructor, you will need to supply the *owner frame*, the title of the dialog, and the *modality*.

The owner frame controls where the dialog is displayed. You can supply `null` as the owner; then, the dialog is owned by a hidden frame.

The modality specifies which other windows of your application are blocked while the dialog is displayed. A modeless dialog does not block other windows. A modal dialog blocks all other windows of the application (except for the children of the dialog). You would use a modeless dialog for a toolbox that the user can always access. On the other hand, you would use a modal dialog if you want to force the user to supply required information before continuing.

Here’s the code for a dialog box:

```
public AboutDialog extends JDialog
{
   public AboutDialog(JFrame owner)
   {
      super(owner, "About DialogTest", true);
      add(new JLabel(
         "<html><h1><i>Core Java</i></h1><hr>By Cay
Horstmann</html>"),
         BorderLayout.CENTER);
         var panel = new JPanel();
         var ok = new JButton("OK");
         ok.addActionListener(event -> setVisible(false));
         panel.add(ok);
         add(panel, BorderLayout.SOUTH);
         setSize(250, 150);
```

```
    }
}
```

As you can see, the constructor adds user interface elements—in this case, labels and a button. It adds a handler to the button and sets the size of the dialog.

To display the dialog box, create a new dialog object and make it visible:

```
var dialog = new AboutDialog(this);
dialog.setVisible(true);
```

Actually, in the sample code below, we create the dialog box only once, and we can reuse it whenever the user clicks the About button.

```
if (dialog == null) // first time
   dialog = new AboutDialog(this);
dialog.setVisible(true);
```

When the user clicks the OK button, the dialog box should close. This is handled in the event handler of the OK button:

```
ok.addActionListener(event -> setVisible(false));
```

When the user closes the dialog by clicking the Close button, the dialog is also hidden. Just as with a `JFrame`, you can override this behavior with the `setDefaultCloseOperation` method.

Listing 11.11 is the code for the frame class of the test program. Listing 11.12 shows the dialog class.

Listing 11.11 `dialog/DialogFrame.java`

```
package dialog;

import javax.swing.JFrame;
```

```java
import javax.swing.JMenu;
import javax.swing.JMenuBar;
import javax.swing.JMenuItem;

/**
 * A frame with a menu whose File->About action shows a dialog.
 */
public class DialogFrame extends JFrame
{
   private static final int DEFAULT_WIDTH = 300;
   private static final int DEFAULT_HEIGHT = 200;
   private AboutDialog dialog;

   public DialogFrame()
   {
      setSize(DEFAULT_WIDTH, DEFAULT_HEIGHT);

      // construct a File menu

      var menuBar = new JMenuBar();
      setJMenuBar(menuBar);
      var fileMenu = new JMenu("File");
      menuBar.add(fileMenu);

      // add About and Exit menu items

      // the About item shows the About dialog

      var aboutItem = new JMenuItem("About");
      aboutItem.addActionListener(event ->
         {
            if (dialog == null) // first time
               dialog = new AboutDialog(DialogFrame.this);
            dialog.setVisible(true); // pop up dialog
         });
      fileMenu.add(aboutItem);

      // the Exit item exits the program
```

```java

      var exitItem = new JMenuItem("Exit");
      exitItem.addActionListener(event -> System.exit(0));
      fileMenu.add(exitItem);
   }
}
```

Listing 11.12 `dialog/AboutDialog.java`

```java
package dialog;

import java.awt.BorderLayout;

import javax.swing.JButton;
import javax.swing.JDialog;
import javax.swing.JFrame;
import javax.swing.JLabel;
import javax.swing.JPanel;

/**
 * A sample modal dialog that displays a message and waits for the user to click
 * the OK button.
 */
public class AboutDialog extends JDialog
{
   public AboutDialog(JFrame owner)
   {
      super(owner, "About DialogTest", true);

      // add HTML label to center

      add(
         new JLabel(
            "<html><h1><i>Core Java</i></h1><hr>By Cay Horstmann</html>"),
         BorderLayout.CENTER);

```

```
        // OK button closes the dialog

        var ok = new JButton("OK");
        ok.addActionListener(event -> setVisible(false));

        // add OK button to southern border

        var panel = new JPanel();
        panel.add(ok);
        add(panel, BorderLayout.SOUTH);

        pack();
    }
}
```

`javax.swing.JDialog` 1.2

- `public JDialog(Frame parent, String title, boolean modal)`

  constructs a dialog. The dialog is not visible until it is explicitly shown.

11.7.3 Data Exchange

The most common reason to put up a dialog box is to get information from the user. You have already seen how easy it is to make a dialog box object: Give it initial data and call `setVisible(true)` to display the dialog box on the screen. Now let's see how to transfer data in and out of a dialog box.

Consider the dialog box in Figure 11.32 that could be used to obtain a user name and a password to connect to some online service.

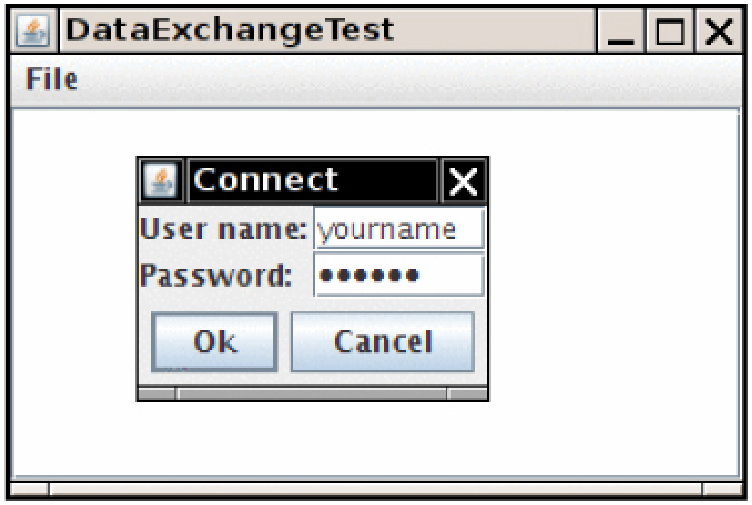


Figure 11.32 Password dialog box

Your dialog box should provide methods to set default data. For example, the `PasswordChooser` class of the example program has a method, `setUser`, to place default values into the next fields:

```
public void setUser(User u)
{
   username.setText(u.getName());
}
```

Once you set the defaults (if desired), show the dialog by calling `setVisible(true)`. The dialog is now displayed.

The user then fills in the information and clicks the OK or Cancel button. The event handlers for both buttons call `setVisible(false)`, which terminates the call to `setVisible(true)`. Alternatively, the user may close the dialog. If you did not install a window listener for the dialog, the default window closing operation applies: The dialog becomes invisible, which also terminates the call to `setVisible(true)`.

The important issue is that the call to `setVisible(true)` blocks until the user has dismissed the dialog. This makes it easy to implement modal dialogs.

You want to know whether the user has accepted or canceled the dialog. Our sample code sets the `ok` flag to `false` before showing the dialog. Only the event handler for the OK button sets the `ok` flag to `true`; that's how you retrieve the user input from the dialog.

NOTE:

Transferring data out of a modeless dialog is not as simple. When a modeless dialog is displayed, the call to `setVisible(true)` does not block and the program continues running while the dialog is displayed. If the user selects items on a modeless dialog and then clicks OK, the dialog needs to send an event to some listener in the program.

The example program contains another useful improvement. When you construct a `JDialog` object, you need to specify the owner frame. However, quite often you want to show the same dialog with different owner frames. It is better to pick the owner frame *when you are ready to show the dialog*, not when you construct the `PasswordChooser` object.

The trick is to have the `PasswordChooser` extend `JPanel` instead of `JDialog`. Build a `JDialog` object on the fly in the `showDialog` method:

```
public boolean showDialog(Frame owner, String title)
{
   ok = false;
   if (dialog == null || dialog.getOwner() != owner)
   {
      dialog = new JDialog(owner, true);
      dialog.add(this);
      dialog.pack();
   }
   dialog.setTitle(title);
   dialog.setVisible(true);
   return ok;
}
```

Note that it is safe to have `owner` equal to `null`.

You can do even better. Sometimes, the owner frame isn't readily available. It is easy enough to compute it from any `parent` component, like this:

```
Frame owner;
if (parent instanceof Frame)
   owner = (Frame) parent;
else
   owner = (Frame)
SwingUtilities.getAncestorOfClass(Frame.class, parent);
```

We use this enhancement in our sample program. The `JOptionPane` class also uses this mechanism.

Many dialogs have a *default button*, which is automatically selected if the user presses a trigger key (Enter in most look-and-feel implementations). The default button is specially marked, often with a thick outline.

Set the default button in the *root pane* of the dialog:

```
dialog.getRootPane().setDefaultButton(okButton);
```

If you follow the suggestion of laying out the dialog in a panel, then you must be careful to set the default button only after you wrapped the panel into a dialog. The panel dialog itself has no root pane.

Listing 11.13 is for the frame class of the program that illustrates the data flow into and out of a dialog box. Listing 11.14 shows the dialog class.

Listing 11.13 `dataExchange/DataExchangeFrame.java`

```
package dataExchange;

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

/**
```

```
 * A frame with a menu whose File->Connect action shows a password dialog.
 */
public class DataExchangeFrame extends JFrame
{
   public static final int TEXT_ROWS = 20;
   public static final int TEXT_COLUMNS = 40;
   private PasswordChooser dialog = null;
   private JTextArea textArea;

   public DataExchangeFrame()
   {
      // construct a File menu

      var mbar = new JMenuBar();
      setJMenuBar(mbar);
      var fileMenu = new JMenu("File");
      mbar.add(fileMenu);

      // add Connect and Exit menu items

      var connectItem = new JMenuItem("Connect");
      connectItem.addActionListener(new ConnectAction());
      fileMenu.add(connectItem);

      // the Exit item exits the program

      var exitItem = new JMenuItem("Exit");
      exitItem.addActionListener(event -> System.exit(0));
      fileMenu.add(exitItem);

      textArea = new JTextArea(TEXT_ROWS, TEXT_COLUMNS);
      add(new JScrollPane(textArea), BorderLayout.CENTER);
      pack();
   }

   /**
    * The Connect action pops up the password dialog.
    */
```

```
   private class ConnectAction implements ActionListener
   {
      public void actionPerformed(ActionEvent event)
      {
         // if first time, construct dialog

         if (dialog == null) dialog = new PasswordChooser();

         // set default values
         dialog.setUser(new User("yourname", null));

         // pop up dialog
         if (dialog.showDialog(DataExchangeFrame.this, "Connect"))
         {
            // if accepted, retrieve user input
            User u = dialog.getUser();
            textArea.append("user name = " + u.getName() + ", password = "
               + (new String(u.getPassword())) + "\n");
         }
      }
   }
}
```

Listing 11.14 `dataExchange/PasswordChooser.java`

```
package dataExchange;

import java.awt.BorderLayout;
import java.awt.Component;
import java.awt.Frame;
import java.awt.GridLayout;

import javax.swing.JButton;
import javax.swing.JDialog;
import javax.swing.JLabel;
import javax.swing.JPanel;
```

```
import javax.swing.JPasswordField;
import javax.swing.JTextField;
import javax.swing.SwingUtilities;

/**
 * A password chooser that is shown inside a dialog.
 */
public class PasswordChooser extends JPanel
{
   private JTextField username;
   private JPasswordField password;
   private JButton okButton;
   private boolean ok;
   private JDialog dialog;

   public PasswordChooser()
   {
      setLayout(new BorderLayout());

      // construct a panel with user name and password fields

      var panel = new JPanel();
      panel.setLayout(new GridLayout(2, 2));
      panel.add(new JLabel("User name:"));
      panel.add(username = new JTextField(""));
      panel.add(new JLabel("Password:"));
      panel.add(password = new JPasswordField(""));
      add(panel, BorderLayout.CENTER);

      // create Ok and Cancel buttons that terminate the dialog

      okButton = new JButton("Ok");
      okButton.addActionListener(event ->
         {
            ok = true;
            dialog.setVisible(false);
         });

```

```
      var cancelButton = new JButton("Cancel");
      cancelButton.addActionListener(event -> dialog.setVisible(false));

      // add buttons to southern border

      var buttonPanel = new JPanel();
      buttonPanel.add(okButton);
      buttonPanel.add(cancelButton);
      add(buttonPanel, BorderLayout.SOUTH);
   }

   /**
    * Sets the dialog defaults.
    * @param u the default user information
    */
   public void setUser(User u)
   {
      username.setText(u.getName());
   }

   /**
    * Gets the dialog entries.
    * @return a User object whose state represents the dialog entries
    */
   public User getUser()
   {
      return new User(username.getText(), password.getPassword());
   }

   /**
    * Show the chooser panel in a dialog.
    * @param parent a component in the owner frame or null
    * @param title the dialog window title
    */
   public boolean showDialog(Component parent, String title)
   {
```

```
      ok = false;

      // locate the owner frame

      Frame owner = null;
      if (parent instanceof Frame)
         owner = (Frame) parent;
      else
         owner = (Frame) SwingUtilities.getAncestorOfClass(Frame.class, parent);

      // if first time, or if owner has changed, make new dialog

      if (dialog == null || dialog.getOwner() != owner)
      {
         dialog = new JDialog(owner, true);
         dialog.add(this);
         dialog.getRootPane().setDefaultButton(okButton);
         dialog.pack();
      }

      // set title and show dialog

      dialog.setTitle(title);
      dialog.setVisible(true);
      return ok;
   }
}
```

javax.swing.SwingUtilities 1.2

- `Container getAncestorOfClass(Class c, Component comp)`

  returns the innermost parent container of the given component that belongs to the given class or one of its subclasses.

`javax.swing.JComponent` 1.2

- `JRootPane getRootPane()`

  gets the root pane enclosing this component, or `null` if this component does not have an ancestor with a root pane.

`javax.swing.JRootPane` 1.2

- `void setDefaultButton(JButton button)`

  sets the default button for this root pane. To deactivate the default button, call this method with a `null` parameter.

`javax.swing.JButton` 1.2

- `boolean isDefaultButton()`

  returns `true` if this button is the default button of its root pane.

11.7.4 File Dialogs

In an application, you often want to be able to open and save files. A good file dialog box that shows files and directories and lets the user navigate the file system is hard to write, and you definitely don't want to reinvent that wheel. Fortunately, Swing provides a `JFileChooser` class that allows you to display a file dialog box similar to the one that most native applications use. `JFileChooser` dialogs are always modal. Note that the `JFileChooser` class is not a subclass of `JDialog`. Instead of calling `setVisible(true)`, call `showOpenDialog` to display a dialog for opening a file, or call `showSaveDialog` to display a dialog for saving a file. The button for accepting a file is then automatically labeled Open or Save. You can also supply your own button label with the `showDialog` method. Figure 11.33 shows an example of the file chooser dialog box.

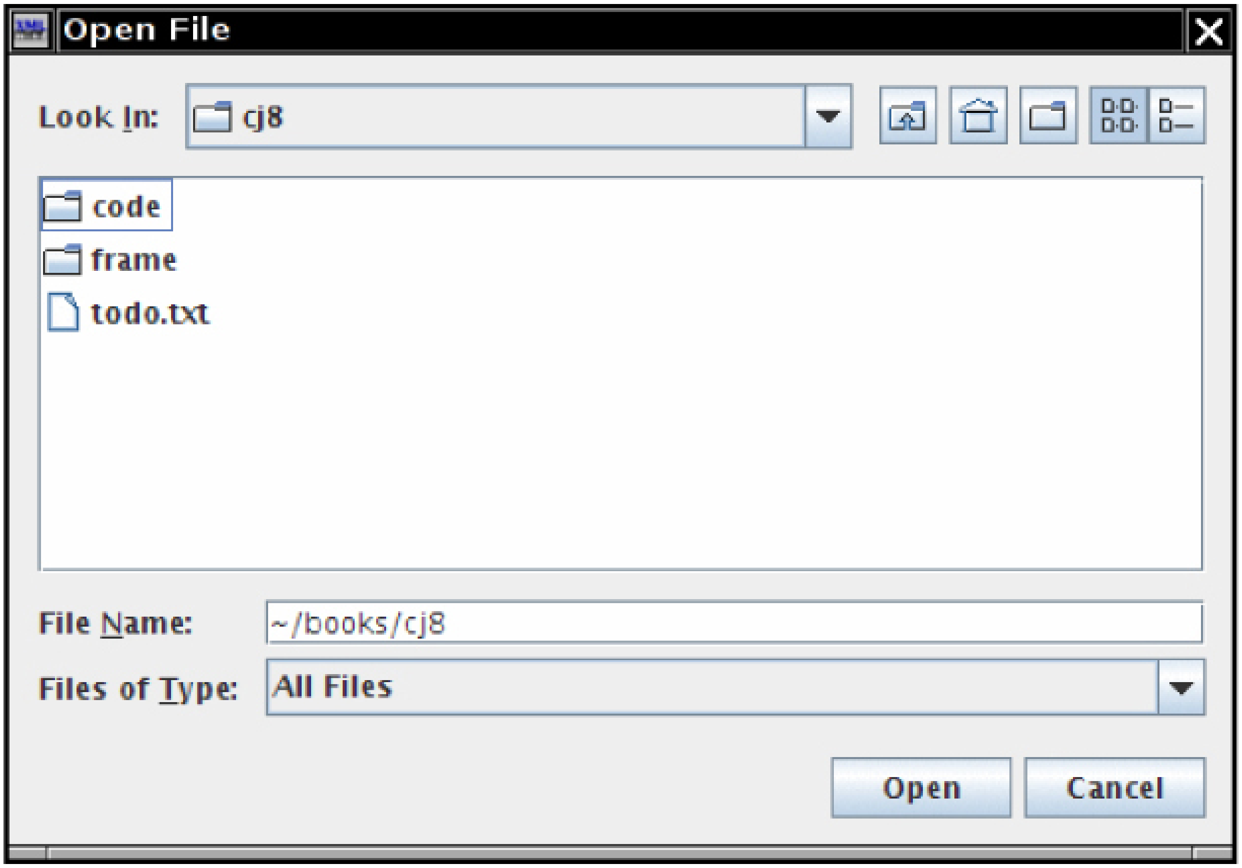


Figure 11.33 A file chooser dialog box

Here are the steps to put up a file dialog box and recover what the user chooses from the box:

1. Make a `JFileChooser` object. Unlike the constructor for the `JDialog` class, you do not supply the parent component. This allows you to reuse a file chooser dialog with multiple frames.

   For example:

   ```
   var chooser = new JFileChooser();
   ```

TIP:

Reusing a file chooser object is a good idea because the `JFileChooser` constructor can be quite slow, especially on Windows when the user has many mapped network drives.

---

2. Set the directory by calling the `setCurrentDirectory` method.

   For example, to use the current working directory

   ```
   chooser.setCurrentDirectory(new File("."));
   ```

   you need to supply a `File` object. `File` objects are explained in detail in Chapter 2 of Volume II. All you need to know for now is that the constructor `File(String filename)` turns a file or directory name into a `File` object.

3. If you have a default file name that you expect the user to choose, supply it with the `setSelectedFile` method:

   ```
   chooser.setSelectedFile(new File(filename));
   ```

4. To enable the user to select multiple files in the dialog, call the `setMultiSelectionEnabled` method. This is, of course, entirely optional and not all that common.

   ```
   chooser.setMultiSelectionEnabled(true);
   ```

5. If you want to restrict the display of files in the dialog to those of a particular type (for example, all files with extension `.gif`), you need to set a *file filter*. We discuss file filters later in this section.

6. By default, a user can select only files with a file chooser. If you want the user to select directories, use the `setFileSelectionMode` method. Call it with `JFileChooser.FILES_ONLY` (the default), `JFileChooser.DIRECTORIES_ONLY`, or `JFileChooser.FILES_AND_DIRECTORIES`.

7. Show the dialog box by calling the `showOpenDialog` or `showSaveDialog` method. You must supply the parent component in these calls:

```
int result = chooser.showOpenDialog(parent);
```

or

```
int result = chooser.showSaveDialog(parent);
```

The only difference between these calls is the label of the "approve button"—the button that the user clicks to finish the file selection. You can also call the `showDialog` method and pass an explicit text for the approve button:

```
int result = chooser.showDialog(parent, "Select");
```

These calls return only when the user has approved, canceled, or dismissed the file dialog. The return value is `JFileChooser.APPROVE_OPTION`, `JFileChooser.CANCEL_OPTION`, or `JFileChooser.ERROR_OPTION`.

8. Get the selected file or files with the `getSelectedFile()` or `getSelectedFiles()` method. These methods return either a single `File` object or an array of `File` objects. If you just need the name of the file object, call its `getPath` method. For example:

```
String filename = chooser.getSelectedFile().getPath();
```

For the most part, these steps are simple. The major difficulty with using a file dialog is to specify a subset of files from which the user should choose. For example, suppose the user should choose a GIF image file. Then, the file chooser should only display files with the extension `.gif`. It should also give the user some kind of feedback that the displayed files are of a particular category, such as "GIF Images." But the situation can be more complex. If the user should choose a JPEG image file, the extension can be either `.jpg` or `.jpeg`. Instead of a way to codify these complexities, the designers of the file chooser provided a more elegant mechanism: to restrict the displayed files, supply an object that extends the abstract class `javax.swing.filechooser.FileFilter`. The file chooser passes each file to the file filter and displays only those files that the filter accepts.

At the time of this writing, two such subclasses are supplied: the default filter that accepts all files, and a filter that accepts all files with a given extension. However, it is easy to write ad-hoc file filters. Simply implement the two abstract methods of the `FileFilter` superclass:

```
public boolean accept(File f);
public String getDescription();
```

The first method tests whether a file should be accepted. The second method returns a description of the file type that can be displayed in the file chooser dialog.

NOTE:

An unrelated `FileFilter` interface in the `java.io` package has a single method, `boolean accept(File f)`. It is used in the `listFiles` method of the `File` class to list files in a directory. I do not know why the designers of Swing didn't extend this interface—perhaps the Java class library has now become so complex that even the programmers at Sun were no longer aware of all the standard classes and interfaces.

You will need to resolve the name conflict between these two identically named types if you import both the `java.io` and the `javax.swing.filechooser` packages. The simplest remedy is to import `javax.swing.filechooser.FileFilter`, not `javax.swing.filechooser.*`.

Once you have a file filter object, use the `setFileFilter` method of the `JFileChooser` class to install it into the file chooser object:

```
chooser.setFileFilter(new FileNameExtensionFilter("Image
files", "gif", "jpg"));
```

You can install multiple filters to the file chooser by calling

```
chooser.addChoosableFileFilter(filter1);
chooser.addChoosableFileFilter(filter2);
. . .
```

The user selects a filter from the combo box at the bottom of the file dialog. By default, the “All files” filter is always present in the combo box. This is a good idea—just in case a user of your program needs to select a file with a nonstandard extension. However, if you want to suppress the “All files” filter, call

```
chooser.setAcceptAllFileFilterUsed(false)
```

CAUTION:

If you reuse a single file chooser for loading and saving different file types, call

```
chooser.resetChoosableFilters()
```

to clear any old file filters before adding new ones.

Finally, you can customize the file chooser by providing special icons and file descriptions for each file that the file chooser displays. Do this by supplying an object of a class extending the `FileView` class in the `javax.swing.filechooser` package. This is definitely an advanced technique. Normally, you don’t need to supply a file view—the pluggable look-and-feel supplies one for you. But if you want to show different icons for special file types, you can install your own file view. You need to extend the `FileView` class and implement five methods:

```
Icon getIcon(File f)
String getName(File f)
String getDescription(File f)
```

```
String getTypeDescription(File f)
Boolean isTraversable(File f)
```

Then, use the `setFileView` method to install your file view into the file chooser.

The file chooser calls your methods for each file or directory that it wants to display. If your method returns `null` for the icon, name, or description, the file chooser then consults the default file view of the look-and-feel. That is good, because it means you need to deal only with the file types for which you want to do something different.

The file chooser calls the `isTraversable` method to decide whether to open a directory when a user clicks on it. Note that this method returns a `Boolean` object, not a `boolean` value! This seems weird, but it is actually convenient—if you aren't interested in deviating from the default file view, just return `null`. The file chooser will then consult the default file view. In other words, the method returns a `Boolean` to let you choose among three options: true (`Boolean.TRUE`), false (`Boolean.FALSE`), or don't care (`null`).

The example program contains a simple file view class. That class shows a particular icon whenever a file matches a file filter. We use it to display a palette icon for all image files.

```
class FileIconView extends FileView
{
   private FileFilter filter;
   private Icon icon;
   public FileIconView(FileFilter aFilter, Icon anIcon)
   {
      filter = aFilter;
      icon = anIcon;
   }
   public Icon getIcon(File f)
   {
      if (!f.isDirectory() && filter.accept(f))
         return icon;
      else return null;
```

```
        }
    }
```

Install this file view into your file chooser with the `setFileView` method:

```
chooser.setFileView(new FileIconView(filter,
    new ImageIcon("palette.gif")));
```

The file chooser will then show the palette icon next to all files that pass the `filter` and use the default file view to show all other files. Naturally, we use the same filter that we set in the file chooser.

Finally, you can customize a file dialog by adding an *accessory* component. For example, Figure 11.34 shows a preview accessory next to the file list. This accessory displays a thumbnail view of the currently selected file.

An accessory can be any Swing component. In our case, we extend the `JLabel` class and set its icon to a scaled copy of the graphics image:

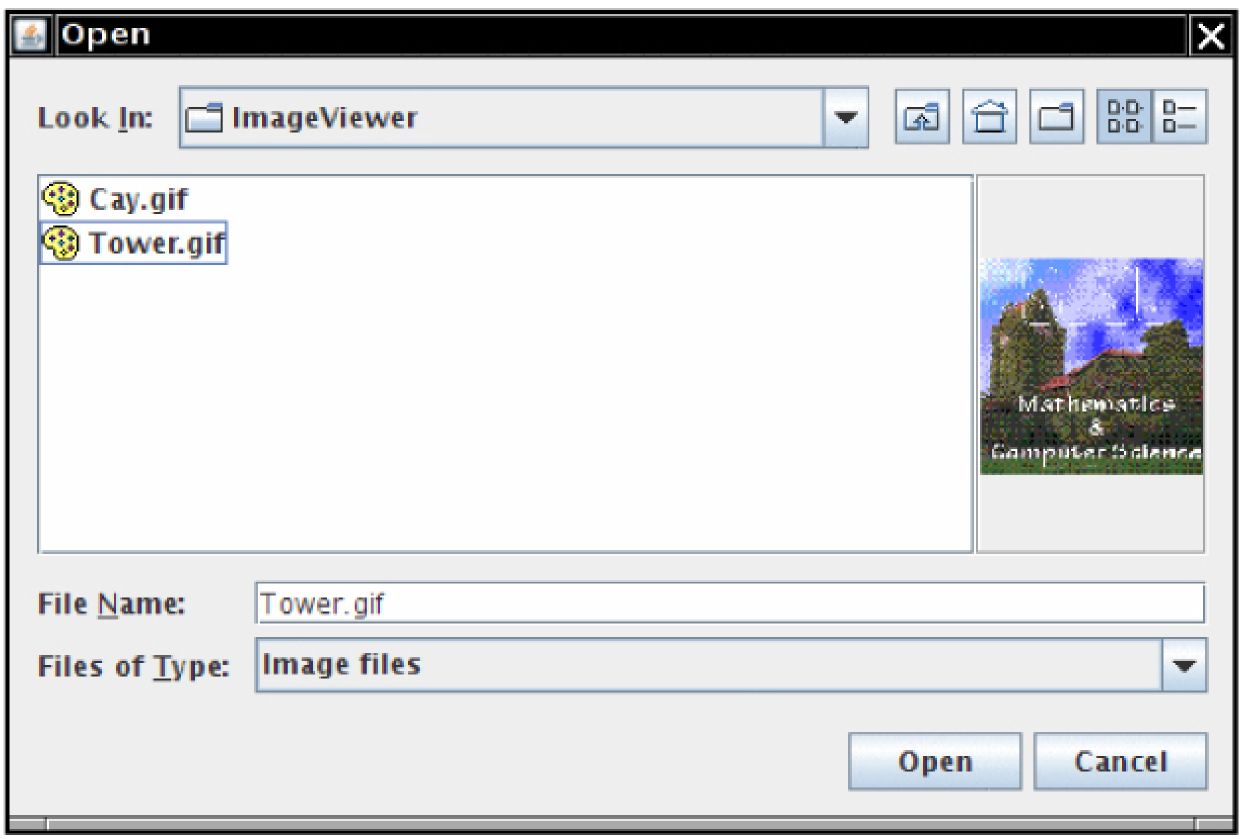


Figure 11.34 A file dialog with a preview accessory

```
class ImagePreviewer extends JLabel
{
   public ImagePreviewer(JFileChooser chooser)
   {
       setPreferredSize(new Dimension(100, 100));
       setBorder(BorderFactory.createEtchedBorder());
   }
   public void loadImage(File f)
   {
       var icon = new ImageIcon(f.getPath());
       if(icon.getIconWidth() > getWidth())
          icon = new
ImageIcon(icon.getImage().getScaledInstance(
             getWidth(), -1, Image.SCALE_DEFAULT));
       setIcon(icon);
       repaint();
   }
}
```

There is just one challenge. We want to update the preview image whenever the user selects a different file. The file chooser uses the “JavaBeans” mechanism of notifying interested listeners whenever one of its properties changes. The selected file is a property that you can monitor by installing a `PropertyChangeListener`. Here is the code that you need to trap the notifications:

```
chooser.addPropertyChangeListener(event ->
{
   if (event.getPropertyName() ==
JFileChooser.SELECTED_FILE_CHANGED_PROPERTY)
   {
       var newFile = (File) event.getNewValue();
       // update the accessory
       . . .
   }
});
```

`javax.swing.JFileChooser` 1.2

- `JFileChooser()`

  creates a file chooser dialog box that can be used for multiple frames.

- `void setCurrentDirectory(File dir)`

  sets the initial directory for the file dialog box.

- `void setSelectedFile(File file)`
- `void setSelectedFiles(File[] file)`

  sets the default file choice for the file dialog box.

- `void setMultiSelectionEnabled(boolean b)`

  sets or clears the multiple selection mode.

- `void setFileSelectionMode(int mode)`

  lets the user select files only (the default), directories only, or both files and directories. The `mode` parameter is one of `JFileChooser.FILES_ONLY`, `JFileChooser.DIRECTORIES_ONLY`, and `JFileChooser.FILES_AND_DIRECTORIES`.

- `int showOpenDialog(Component parent)`
- `int showSaveDialog(Component parent)`
- `int showDialog(Component parent, String approveButtonText)`

  shows a dialog in which the approve button is labeled "Open", "Save", or with the `approveButtonText` string. Returns `APPROVE_OPTION`, `CANCEL_OPTION` (if the user selected the cancel button or dismissed the dialog), or `ERROR_OPTION` (if an error occurred).

- `File getSelectedFile()`
- `File[] getSelectedFiles()`

  gets the file or files that the user selected (or returns `null` if the user didn't select any file).

- `void setFileFilter(FileFilter filter)` sets the file mask for the file dialog box. All files for which `filter.accept` returns `true` will be displayed. Also, adds the filter to the list of choosable filters.

- `void addChoosableFileFilter(FileFilter filter)`

  adds a file filter to the list of choosable filters.

- `void setAcceptAllFileFilterUsed(boolean b)`

  includes or suppresses an "All files" filter in the filter combo box.

- `void resetChoosableFileFilters()`

  clears the list of choosable filters. Only the "All files" filter remains unless it is explicitly suppressed.

- `void setFileView(FileView view)`

  sets a file view to provide information about the files that the file chooser displays.

- `void setAccessory(JComponent component)`

  sets an accessory component.

javax.swing.filechooser.FileFilter 1.2

- `boolean accept(File f)`

  returns `true` if the file chooser should display this file.

- `String getDescription()`

  returns a description of this file filter—for example, `"Image files (*.gif,*.jpeg)"`.

javax.swing.filechooser.FileNameExtensionFilter 6

- `FileNameExtensionFilter(String description, String... extensions)`

  constructs a file filter with the given description that accepts all directories and all files whose names end in a period followed by one of the given extension strings.

`javax.swing.filechooser.FileView` 1.2

- `String getName(File f)`

  returns the name of the file `f`, or `null`. Normally, this method simply returns `f.getName()`.

- `String getDescription(File f)`

  returns a human-readable description of the file `f`, or `null`. For example, if `f` is an HTML document, this method might return its title.

- `String getTypeDescription(File f)`

  returns a human-readable description of the type of the file `f`, or `null`. For example, if `f` is an HTML document, this method might return a string `"Hypertext document"`.

- `Icon getIcon(File f)`

  returns an icon for the file `f`, or `null`. For example, if `f` is a JPEG file, this method might return a thumbnail icon.

- `Boolean isTraversable(File f)`

  returns `Boolean.TRUE` if `f` is a directory that the user can open. This method might return `Boolean.FALSE` if a directory is conceptually a compound document. Like all `FileView` methods, this method can return `null` to signify that the file chooser should consult the default view instead.

This ends our discussion of Swing programming. Turn to Volume II for more advanced Swing components and sophisticated graphics techniques.

Chapter 12. Concurrency

In this chapter

You are probably familiar with *multitasking*—your operating system's ability to have more than one program working at what seems like the same time. For example, you can print while editing or downloading your email. Nowadays, you are likely to have a computer with more than one CPU, but the number of concurrently executing processes is not limited by the number of CPUs. The operating system assigns CPU time slices to each process, giving the impression of parallel activity.

Multithreaded programs extend the idea of multitasking by taking it one level lower: Individual programs will appear to do multiple tasks at the same time. Each task is executed in a *thread*, which is short for thread of control. Programs that can run more than one thread at once are said to be *multithreaded*.

So, what is the difference between multiple *processes* and multiple *threads*? The essential difference is that while each process has a complete set of its own variables, threads share the same data. This sounds somewhat risky, and indeed it can be, as you will see later in this chapter. However, shared variables make communication between threads more efficient and easier to program than interprocess communication. Moreover, on some operating systems, threads are more "lightweight" than processes—it takes less overhead to create and destroy individual threads than it does to launch new processes.

Multithreading is extremely useful in practice. For example, a browser should be able to simultaneously download multiple images. A web server needs to be able to serve concurrent requests. Graphical user interface (GUI) programs have a separate thread for gathering user interface events from the host operating environment. This chapter shows you how to add multithreading capability to your Java applications.

Fair warning: Concurrent programming can get very complex. In this chapter, I cover all the tools that an application programmer is likely to need. However, for more intricate system-level programming, we suggest that you turn to a more advanced reference, such as *Java Concurrency in Practice* by Brian Goetz et al. (Addison-Wesley Professional, 2006).

12.1 What Are Threads?

Let us start by looking at a simple program that uses two threads. This program moves money between bank accounts. We make use of a `Bank` class that stores the balances of a given number of accounts. The `transfer` method transfers an amount from one account to another. See Listing 12.2 for the implementation.

In the first thread, we will move money from account 0 to account 1. The second thread moves money from account 2 to account 3.

Here is a simple procedure for running a task in a separate thread:

1. Place the code for the task into the `run` method of a class that implements the `Runnable` interface. That interface is very simple, with a single method:

   ```
   public interface Runnable
   {
     void run();
   }
   ```

Since `Runnable` is a functional interface, you can make an instance with a lambda expression:

```
Runnable r = () ->
  {
     task code
  };
```

2. Construct a `Thread` object from the `Runnable`:

```
var t = new Thread(r);
```

3. Start the thread:

```
t.start();
```

To make a separate thread for transferring money, we only need to place the code for the transfer inside the `run` method of a `Runnable`, and then start a thread:

```
Runnable r = () ->
   {
      try
      {
         for (int i = 0; i < STEPS; i++)
         {
            double amount = MAX_AMOUNT * Math.random();
            bank.transfer(0, 1, amount);
            Thread.sleep((int) (DELAY * Math.random()));
         }
      }
      catch (InterruptedException e)
      {
      }
   };
var t = new Thread(r);
t.start();
```

For a given number of steps, this thread transfers a random amount, and then sleeps for a random delay.

We need to catch an `InterruptedException` that the `sleep` method threatens to throw. We will discuss this exception in Section 12.3.1, "Interrupting Threads," on p. 757. Typically, interruption is used to request that a thread terminates. Accordingly, our `run` method exits when an `InterruptedException` occurs.

Our program starts a second thread as well that moves money from account 2 to account 3. When you run this program, you get a printout like this:

```
Thread[Thread-1,5,main]  606.77 from 2 to 3 Total
Balance:  400000.00
Thread[Thread-0,5,main]   98.99 from 0 to 1 Total
Balance:  400000.00
Thread[Thread-1,5,main]  476.78 from 2 to 3 Total
Balance:  400000.00
Thread[Thread-0,5,main]  653.64 from 0 to 1 Total
Balance:  400000.00
Thread[Thread-1,5,main]  807.14 from 2 to 3 Total
Balance:  400000.00
Thread[Thread-0,5,main]  481.49 from 0 to 1 Total
Balance:  400000.00Thread[Thread-0,5,main]  203.73 from 0 to 1
Total Balance:  400000.00
Thread[Thread-1,5,main]  111.76 from 2 to 3 Total
Balance:  400000.00
Thread[Thread-1,5,main]  794.88 from 2 to 3 Total
Balance:  400000.00
. . .
```

As you can see, the output of the two threads is interleaved, showing that they run concurrently. In fact, sometimes the output is a little messier when two output lines are interleaved.

That's all there is to it! You now know how to run tasks concurrently. The remainder of this chapter tells you how to control the interaction between threads.

The complete code is shown in Listing 12.1.

NOTE:

You can also define a thread by forming a subclass of the `Thread` class, like this:

```
class MyThread extends Thread
{
   public void run()
   {
      task code
   }
}
```

Then you construct an object of the subclass and call its `start` method. However, this approach is no longer recommended. You should decouple the *task* that is to be run in parallel from the *mechanism* of running it. If you have many tasks, it is too expensive to create a separate thread for each of them. Instead, you can use a thread pool—see Section 12.6.2, "Executors," on p. 818.

CAUTION:

Do *not* call the `run` method of the `Thread` class or the `Runnable` object. Calling the `run` method directly merely executes the task in the *same* thread—no new thread is started. Instead, call the `Thread.start` method. It creates a new thread that executes the `run` method.

Listing 12.1 `threads/ThreadTest.java`

```
package threads;

/**
 * @version 1.30 2004-08-01
 * @author Cay Horstmann
 */
public class ThreadTest
{
   public static final int DELAY = 10;
   public static final int STEPS = 100;
   public static final double MAX_AMOUNT = 1000;

   public static void main(String[] args)
   {
      var bank = new Bank(4, 100000);
      Runnable task1 = () ->
      {
         try
         {
            for (int i = 0; i < STEPS; i++)
            {
               double amount = MAX_AMOUNT * Math.random();
               bank.transfer(0, 1, amount);
               Thread.sleep((int) (DELAY * Math.random()));
            }
         }
         catch (InterruptedException e)
         {
         }
      };

      Runnable task2 = () ->
      {
         try
         {
            for (int i = 0; i < STEPS; i++)
            {
               double amount = MAX_AMOUNT * Math.random();
               bank.transfer(2, 3, amount);
               Thread.sleep((int) (DELAY * Math.random()));
```

```
            }
         }
         catch (InterruptedException e)
         {
         }
      };

      new Thread(task1).start();
      new Thread(task2).start();
   }
}
```

Listing 12.2 `threads/Bank.java`

```
package threads;

import java.util.*;

/**
 * A bank with a number of bank accounts.
 */
public class Bank
{
   private final double[] accounts;

   /**
    * Constructs the bank.
    * @param n the number of accounts
    * @param initialBalance the initial balance for each account
    */
   public Bank(int n, double initialBalance)
   {
      accounts = new double[n];
      Arrays.fill(accounts, initialBalance);
   }

   /**
```

```
     * Transfers money from one account to another.
     * @param from the account to transfer from
     * @param to the account to transfer to
     * @param amount the amount to transfer
     */
    public void transfer(int from, int to, double amount)
    {
       if (accounts[from] < amount) return;
       System.out.print(Thread.currentThread());
       accounts[from] -= amount;
       System.out.printf(" %10.2f from %d to %d", amount, from, to);
       accounts[to] += amount;
       System.out.printf(" Total Balance: %10.2f%n", getTotalBalance());
    }

    /**
     * Gets the sum of all account balances.
     * @return the total balance
     */
    public double getTotalBalance()
    {
       double sum = 0;

       for (double a : accounts)
          sum += a;
       return sum;
    }

    /**
     * Gets the number of accounts in the bank.
     * @return the number of accounts
     */
    public int size()
    {
       return accounts.length;
    }
}
```

`java.lang.Thread` 1.0

- `Thread(Runnable target)`

  constructs a new thread that calls the `run()` method of the specified target.

- `void start()`

  starts this thread, causing the `run()` method to be called. This method will return immediately. The new thread runs concurrently.

- `void run()`

  calls the `run` method of the associated `Runnable`.

- `static void sleep(long millis)`

  sleeps for the given number of milliseconds.

`java.lang.Runnable` 1.0

- `void run()`

  must be overridden and supplied with instructions for the task that you want to have executed.

12.2 Thread States

Threads can be in one of six states:

- New
- Runnable
- Blocked
- Waiting

• Timed waiting

• Terminated

Each of these states is explained in the sections that follow.

To determine the current state of a thread, simply call the `getState` method.

12.2.1 New Threads

When you create a thread with the `new` operator—for example, `new Thread(r)`—the thread is not yet running. This means that it is in the *new* state. When a thread is in the new state, the program has not started executing code inside of it. A certain amount of bookkeeping needs to be done before a thread can run.

12.2.2 Runnable Threads

Once you invoke the `start` method, the thread is in the *runnable* state. A runnable thread may or may not actually be running. It is up to the operating system to give the thread time to run. (The Java specification does not call this a separate state, though. A running thread is still in the runnable state.)

Once a thread is running, it doesn't necessarily keep running. In fact, it is desirable that running threads occasionally pause so that other threads have a chance to run. The details of thread scheduling depend on the services that the operating system provides. Preemptive scheduling systems give each runnable thread a slice of time to perform its task. When that slice of time is exhausted, the operating system *preempts* the thread and gives another thread an opportunity to work (see Figure 12.2). When selecting the next thread, the operating system takes into account the thread *priorities*—see Section 12.3.5, "Thread Priorities," on p. 763 for more information.

All modern desktop and server operating systems use preemptive scheduling. However, small devices such as cell phones may use cooperative scheduling. In such a device, a thread loses control only when it calls the `yield` method, or when it is blocked or waiting.

On a machine with multiple processors, each processor can run a thread, and you can have multiple threads run in parallel. Of course, if there are more threads than processors, the scheduler still has to do time slicing.

Always keep in mind that a runnable thread may or may not be running at any given time. (This is why the state is called “runnable” and not “running.”)

`java.lang.Thread` 1.0

• `static void yield()`

causes the currently executing thread to yield to another thread. Note that this is a static method.

12.2.3 Blocked and Waiting Threads

When a thread is blocked or waiting, it is temporarily inactive. It doesn’t execute any code and consumes minimal resources. It is up to the thread scheduler to reactivate it. The details depend on how the inactive state was reached.

- When the thread tries to acquire an intrinsic object lock (but not a `Lock` in the `java.util.concurrent` library) that is currently held by another thread, it becomes *blocked*. (We discuss `java.util.concurrent` locks in Section 12.4.3, “Lock Objects,” on p. 769 and intrinsic object locks in Section 12.4.5, “The `synchronized` Keyword,” on p. 778.) The thread becomes unblocked when all other threads have relinquished the lock and the thread scheduler has allowed this thread to hold it.
- When the thread waits for another thread to notify the scheduler of a condition, it enters the *waiting* state. We discuss conditions in Section 12.4.4, “Condition Objects,” on p. 772. This happens by calling the `Object.wait` or `Thread.join` method, or by waiting for a `Lock` or `Condition` in the `java.util.concurrent` library. In practice, the difference between the blocked and waiting state is not significant.

- Several methods have a timeout parameter. Calling them causes the thread to enter the *timed waiting* state. This state persists either until the timeout expires or the appropriate notification has been received. Methods with timeout include `Thread.sleep` and the timed versions of `Object.wait`, `Thread.join`, `Lock.tryLock`, and `Condition.await`.

Figure 12.1 shows the states that a thread can have and the possible transitions from one state to another. When a thread is blocked or waiting (or, of course, when it terminates), another thread will be scheduled to run. When a thread is reactivated (for example, because its timeout has expired or it has succeeded in acquiring a lock), the scheduler checks to see if it has a higher priority than the currently running threads. If so, it preempts one of the current threads and picks a new thread to run.

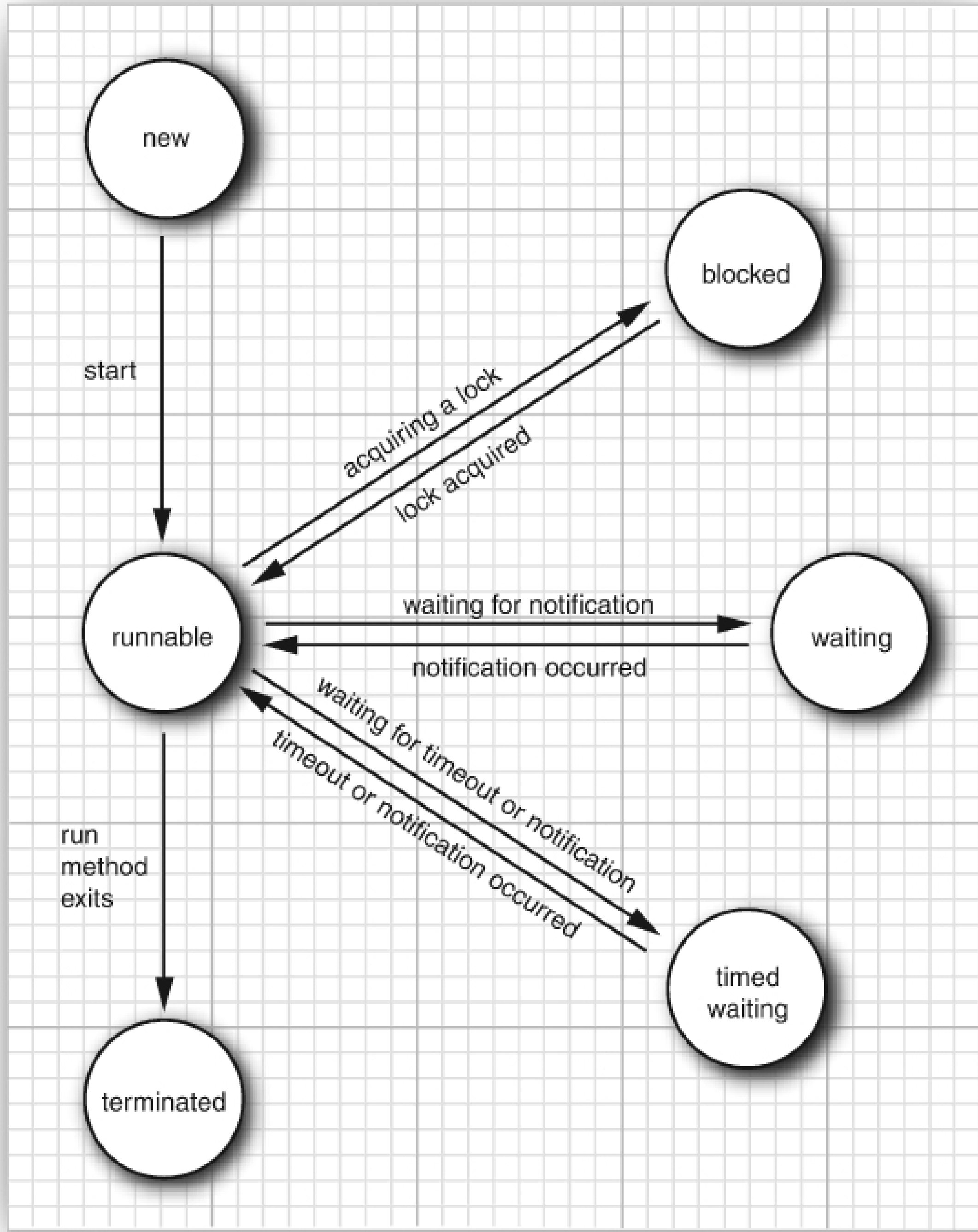


Figure 12.1 Thread states

12.2.4 Terminated Threads

A thread is terminated for one of two reasons:

• It dies a natural death because the `run` method exits normally.

• It dies abruptly because an uncaught exception terminates the `run` method.

In particular, you can kill a thread by invoking its `stop` method. That method throws a `ThreadDeath` error object that kills the thread. However, the `stop` method is deprecated, and you should never call it in your own code.

java.lang.Thread 1.0

• `void join()`

waits for the specified thread to terminate.

• `void join(long millis)`

waits for the specified thread to die or for the specified number of milliseconds to pass.

• `Thread.State getState()` 5

gets the state of this thread: one of `NEW`, `RUNNABLE`, `BLOCKED`, `WAITING`, `TIMED_WAITING`, or `TERMINATED`.

• `void stop()`

stops the thread. This method is deprecated.

• `void suspend()`

suspends this thread's execution. This method is deprecated for removal.

• `void resume()`

resumes this thread. This method is only valid after `suspend()` has been invoked. This method is deprecated for removal.

12.3 Thread Properties

In the following sections, we discuss miscellaneous properties of threads: the interrupted status, daemon threads, handlers for uncaught exceptions, as well as some legacy features that you should not use.

12.3.1 Interrupting Threads

A thread terminates when its `run` method returns—by executing a `return` statement, after executing the last statement in the method body, or if an exception occurs that is not caught in the method. In the initial release of Java, there also was a `stop` method that another thread could call to terminate a thread. However, that method is now deprecated. We discuss the reason in Section 12.4.12, "Why the `stop` and `suspend` Methods Are Deprecated," on p. 793.

Other than with the deprecated `stop` method, there is no way to *force* a thread to terminate. However, the `interrupt` method can be used to *request* termination of a thread.

When the `interrupt` method is called on a thread, the *interrupted status* of the thread is set. This is a `boolean` flag that is present in every thread. Each thread should occasionally check whether it has been interrupted.

To find out whether the interrupted status was set, first call the static `Thread.currentThread` method to get the current thread, and then call the `isInterrupted` method:

```
while (!Thread.currentThread().isInterrupted() && more work to
do)
{
   do more work
}
```

However, if a thread is blocked, it cannot check the interrupted status. This is where the `InterruptedException` comes in. When the `interrupt` method is called on a thread that blocks on a call such as `sleep` or `wait`, the blocking call is terminated by an `InterruptedException`. (There are blocking I/O calls that cannot be interrupted; you should consider interruptible alternatives. See Chapters 2 and 4 of Volume II for details.)

There is no language requirement that a thread which is interrupted should terminate. Interrupting a thread simply grabs its attention. The interrupted thread can decide how to react to the interruption. Some threads are so important that they should handle the exception and continue. But quite commonly, a thread will simply want to interpret an interruption as a request for termination. The `run` method of such a thread has the following form:

```
Runnable r = () ->
   {
      try
      {
         . . .
         while (!Thread.currentThread().isInterrupted() && more work to do)
         {
            do more work
         }
      }
      catch(InterruptedException e)
      {
         // thread was interrupted during sleep or wait
      }
      finally
      {
         cleanup, if required
      }
      // exiting the run method terminates the thread
   };
```

The `isInterrupted` check is neither necessary nor useful if you call the `sleep` method (or another interruptible method) after every work iteration. If you call the `sleep` method when the interrupted status is set, it doesn't sleep. Instead, it clears the status (!) and throws an `InterruptedException`. Therefore, if your loop calls `sleep`, don't check the interrupted status. Instead, catch the `InterruptedException`, like this:

```
Runnable r = () ->
   {
```

```
      try
      {
         . . .
         while (more work to do)
         {
            do more work
            Thread.sleep(delay);
         }
      }
      catch(InterruptedException e)
      {
         // thread was interrupted during sleep
      }
      finally
      {
         cleanup, if required
      }
      // exiting the run method terminates the thread
   };
```

NOTE:

There are two very similar methods, `interrupted` and `isInterrupted`. The `interrupted` method is a static method that checks whether the *current* thread has been interrupted. Furthermore, calling the `interrupted` method *clears* the interrupted status of the thread. On the other hand, the `isInterrupted` method is an instance method that you can use to check whether any thread has been interrupted. Calling it does not change the interrupted status.

You'll find lots of published code in which the `InterruptedException` is squelched at a low level, like this:

```
void mySubTask()
{
```

```
      . . .
      try
      {
         sleep(delay);
      }
      catch (InterruptedException e)
      {
      }
      // don't ignore!
      . . .
   }
```

Don't do that! If you can't think of anything good to do in the `catch` clause, you still have two reasonable choices:

- In the `catch` clause, call `Thread.currentThread().interrupt()` to set the interrupted status. Then the caller can test it.

```
   void mySubTask()
   {
      . . .
      try
      {
         sleep(delay);
      }
      catch (InterruptedException e)
      {
         Thread.currentThread().interrupt();
      }
      . . .
   }
```

- Or, even better, tag your method with `throws InterruptedException` and drop the `try` block. Then the caller (or, ultimately, the `run` method) can catch it.

```
   void mySubTask() throws InterruptedException
   {
      . . .
```

```
        sleep(delay);
        . . .
    }
```

java.lang.Thread 1.0

- `void interrupt()`

  sends an interrupt request to a thread. The interrupted status of the thread is set to `true`. If the thread is currently blocked by a call to `sleep`, then an `InterruptedException` is thrown.

- `static boolean interrupted()`

  tests whether the *current* thread (that is, the thread that is executing this instruction) has been interrupted. Note that this is a static method. The call has a side effect—it resets the interrupted status of the current thread to `false`.

- `boolean isInterrupted()`

  tests whether a thread has been interrupted. Unlike the `static interrupted` method, this call does not change the interrupted status of the thread.

- `static Thread currentThread()`

  returns the `Thread` object representing the currently executing thread.

12.3.2 Daemon Threads

You can turn a thread into a *daemon thread* by calling

```
t.setDaemon(true);
```

There is nothing demonic about such a thread. A daemon is simply a thread that has no other role in life than to serve others. Examples are timer threads that send regular “timer ticks” to other threads or threads that clean up stale cache entries. When only daemon threads remain, the virtual machine exits. There is no point in keeping the program running if all remaining threads are daemons.

java.lang.Thread 1.0

- `void setDaemon(boolean isDaemon)`

  marks this thread as a daemon thread or a user thread. This method must be called before the thread is started.

12.3.3 Thread Names

By default, threads have catchy names such as `Thread-2`. You can set any name with the `setName` method:

```
var t = new Thread(runnable);
t.setName("Web crawler");
```

That can be useful in thread dumps.

12.3.4 Handlers for Uncaught Exceptions

The `run` method of a thread cannot throw any checked exceptions, but it can be terminated by an unchecked exception. In that case, the thread dies.

However, there is no `catch` clause to which the exception can be propagated. Instead, just before the thread dies, the exception is passed to a handler for uncaught exceptions.

The handler must belong to a class that implements the `Thread.UncaughtExceptionHandler` interface. That interface has a single method,

```
void uncaughtException(Thread t, Throwable e)
```

You can install a handler into any thread with the `setUncaughtExceptionHandler` method. You can also install a default handler for all threads with the static method `setDefaultUncaughtExceptionHandler` of the `Thread` class. A replacement handler might use the logging API to send reports of uncaught exceptions into a log file.

If you don't install a default handler, the default handler is `null`. However, if you don't install a handler for an individual thread, the handler is the thread's `ThreadGroup` object.

NOTE:

A thread group is a collection of threads that can be managed together. By default, all threads that you create belong to the same thread group, but it is possible to establish other groupings. Since there are now better features for operating on collections of threads, I recommend that you do not use thread groups in your programs.

The `ThreadGroup` class implements the `Thread.UncaughtExceptionHandler` interface. Its `uncaughtException` method takes the following action:

1. If the thread group has a parent, then the `uncaughtException` method of the parent group is called.
2. Otherwise, if the `Thread.getDefaultUncaughtExceptionHandler` method returns a non-`null` handler, it is called.
3. Otherwise, if the `Throwable` is an instance of `ThreadDeath`, nothing happens.
4. Otherwise, the name of the thread and the stack trace of the `Throwable` are printed on `System.err`.

That is the stack trace that you have undoubtedly seen many times in your programs.

java.lang.Thread 1.0

- `static void setDefaultUncaughtExceptionHandler(Thread.UncaughtExceptionHandler handler)` 5
- `static Thread.UncaughtExceptionHandler getDefaultUncaughtExceptionHandler()` 5

  sets or gets the default handler for uncaught exceptions.

- `void setUncaughtExceptionHandler(Thread.UncaughtExceptionHandler handler)` 5
- `Thread.UncaughtExceptionHandler getUncaughtExceptionHandler()` 5

  sets or gets the handler for uncaught exceptions. If no handler is installed, the thread group object is the handler.

java.lang.Thread.UncaughtExceptionHandler 5

- `void uncaughtException(Thread t, Throwable e)`

  defined to log a custom report when a thread is terminated with an uncaught exception.

java.lang.ThreadGroup 1.0

- `void uncaughtException(Thread t, Throwable e)`

  calls this method of the parent thread group if there is a parent, or calls the default handler of the `Thread` class if there is a default handler, or otherwise prints a stack trace to the standard error stream.

(However, if `e` is a `ThreadDeath` object, the stack trace is suppressed. `ThreadDeath` objects are generated by the deprecated `stop` method.)

12.3.5 Thread Priorities

In the Java programming language, every thread has a *priority*. By default, a thread inherits the priority of the thread that constructed it. You can increase or decrease the priority of any thread with the `setPriority` method. You can set the priority to any value between `MIN_PRIORITY` (defined as `1` in the `Thread` class) and `MAX_PRIORITY` (defined as `10`). `NORM_PRIORITY` is defined as `5`.

Whenever the thread scheduler has a chance to pick a new thread, it prefers threads with higher priority. However, thread priorities are *highly system-dependent*. When the virtual machine relies on the thread implementation of the host platform, the Java thread priorities are mapped to the priority levels of the host platform, which may have more or fewer thread priority levels.

For example, Windows has seven priority levels. Some of the Java priorities will map to the same operating system level. In the Oracle JVM for Linux, thread priorities are ignored altogether—all threads have the same priority.

Thread priorities may have been useful in early versions of Java that didn't use operating systems threads. You should not use them nowadays.

`java.lang.Thread` 1.0

- `void setPriority(int newPriority)`

  sets the priority of this thread. The priority must be between `Thread.MIN_PRIORITY` and `Thread.MAX_PRIORITY`. Use `Thread.NORM_PRIORITY` for normal priority.

- `static int MIN_PRIORITY`

  is the minimum priority that a `Thread` can have. The minimum priority value is `1`.

- `static int NORM_PRIORITY`

  is the default priority of a `Thread`. The default priority is `5`.

- `static int MAX_PRIORITY`

  is the maximum priority that a `Thread` can have. The maximum priority value is `10`.

12.4 Synchronization

In most practical multithreaded applications, two or more threads need to share access to the same data. What happens if two threads have access to the same object and each calls a method that modifies the state of the object? As you might imagine, the threads can step on each other's toes. Depending on the order in which the data were accessed, corrupted objects can result. Such a situation is often called a *race condition*.

12.4.1 An Example of a Race Condition

To avoid corruption of shared data by multiple threads, you must learn how to *synchronize the access*. In this section, you'll see what happens if you do not use synchronization. In the next section, you'll see how to synchronize data access.

In the next test program, we continue working with our simulated bank. Unlike the example in Section 12.1, "What Are Threads?," on p. 748, we randomly select the source and destination of the transfer. Since this will cause problems, let us look more carefully at the code for the `transfer` method of the `Bank` class.

```
public void transfer(int from, int to, double amount)
   // CAUTION: unsafe when called from multiple threads
{
   System.out.print(Thread.currentThread());
   accounts[from] -= amount;
   System.out.printf(" %10.2f from %d to %d", amount, from,
to);
```

```
      accounts[to] += amount;
      System.out.printf(" Total Balance: %10.2f%n",
   getTotalBalance());
   }
```

Here is the code for the `Runnable` instances. The `run` method keeps moving money out of a given bank account. In each iteration, the `run` method picks a random target account and a random amount, calls `transfer` on the bank object, and then sleeps.

```
   Runnable r = () ->
      {
         try
         {
            while (true)
            {
               int toAccount = (int) (bank.size() *
   Math.random());
               double amount = MAX_AMOUNT * Math.random();
               bank.transfer(fromAccount, toAccount,
   amount);            Thread.sleep((int) (DELAY *
   Math.random()));
            }
         }
         catch (InterruptedException e)
         {
         }
      };
```

When this simulation runs, we do not know how much money is in any one bank account at any time. But we do know that the total amount of money in all the accounts should remain unchanged because all we do is move money from one account to another.

At the end of each transaction, the `transfer` method recomputes the total and prints it.

This program never finishes. Just press Ctrl+C to kill the program.

Here is a typical printout:

```
. . .
Thread[Thread-11,5,main]    588.48 from 11 to 44 Total
Balance:  100000.00
Thread[Thread-12,5,main]    976.11 from 12 to 22 Total
Balance:  100000.00
Thread[Thread-14,5,main]    521.51 from 14 to 22 Total
Balance:  100000.00
Thread[Thread-13,5,main]    359.89 from 13 to 81 Total
Balance:  100000.00
. . .
Thread[Thread-36,5,main]    401.71 from 36 to 73 Total
Balance:  99291.06
Thread[Thread-35,5,main]    691.46 from 35 to 77 Total
Balance:  99291.06
Thread[Thread-37,5,main]     78.64 from 37 to 3 Total
Balance:  99291.06
Thread[Thread-34,5,main]    197.11 from 34 to 69 Total
Balance:  99291.06
Thread[Thread-36,5,main]    85.96 from 36 to 4 Total
Balance:  99291.06
. . .
Thread[Thread-4,5,main]Thread[Thread-33,5,main]     7.31 from
31 to 32 Total Balance:
99979.24
     627.50 from 4 to 5 Total Balance:  99979.24
. . .
```

As you can see, something is very wrong. For a few transactions, the bank balance remains at $100,000, which is the correct total for 100 accounts of $1,000 each. But after some time, the balance changes slightly. When you run this program, errors may happen quickly, or it may take a very long time for the balance to become corrupted. This situation does not inspire confidence, and you would probably not want to deposit your hard-earned money in such a bank.

See if you can spot the problems with the code in Listing 12.3 and the `Bank` class in Listing 12.2. We will unravel the mystery in the next section.

Listing 12.3 `unsynch/UnsynchBankTest.java`

```
package unsynch;

/**
 * This program shows data corruption when multiple threads access a data structure.
 * @version 1.32 2018-04-10
 * @author Cay Horstmann
 */
public class UnsynchBankTest
{
   public static final int NACCOUNTS = 100;
   public static final double INITIAL_BALANCE = 1000;
   public static final double MAX_AMOUNT = 1000;
   public static final int DELAY = 10;

   public static void main(String[] args)
   {
      var bank = new Bank(NACCOUNTS, INITIAL_BALANCE);
      for (int i = 0; i < NACCOUNTS; i++)
      {
         int fromAccount = i;
         Runnable r = () ->
            {
               try
               {
                  while (true)
                  {
                     int toAccount = (int) (bank.size() * Math.random());
                     double amount = MAX_AMOUNT * Math.random();
                     bank.transfer(fromAccount, toAccount, amount);
                     Thread.sleep((int) (DELAY *
```

```
Math.random()));
                  }
               }
               catch (InterruptedException e)
               {
               }
            };
         var t = new Thread(r);
         t.start();
      }
   }
}
```

12.4.2 The Race Condition Explained

In the previous section, we ran a program in which several threads updated bank account balances. After a while, errors crept in and some amount of money was either lost or spontaneously created. This problem occurs when two threads are simultaneously trying to update an account. Suppose two threads simultaneously carry out the instruction

```
accounts[to] += amount;
```

The problem is that these are not *atomic* operations. The instruction might be processed as follows:

1. Load `accounts[to]` into a register.
2. Add `amount`.
3. Move the result back to `accounts[to]`.

Now, suppose the first thread executes Steps 1 and 2, and then it is preempted. Suppose the second thread awakens and updates the same entry in the `account` array. Then, the first thread awakens and completes its Step 3.

That action wipes out the modification of the other thread. As a result, the total is no longer correct (see Figure 12.2).

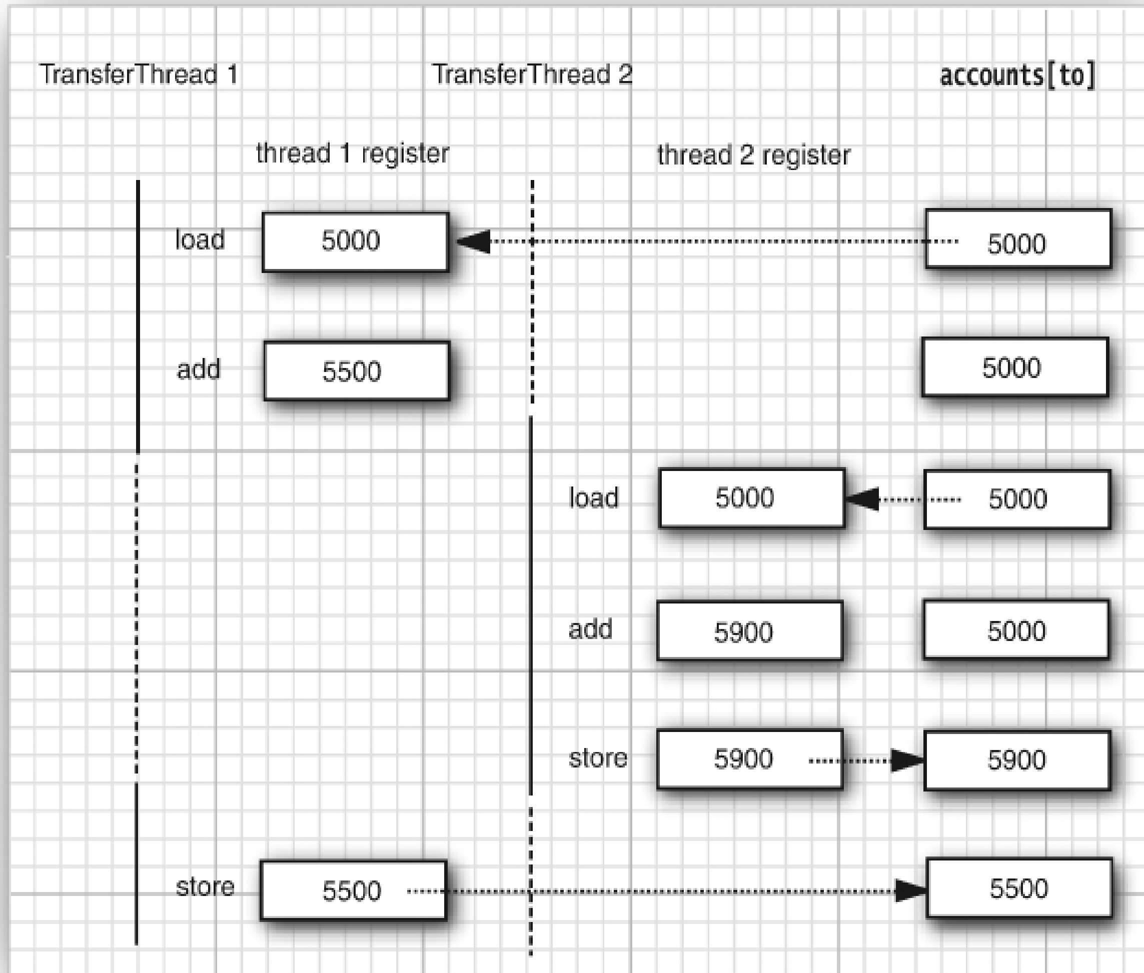


Figure 12.2 Simultaneous access by two threads

Our test program detects this corruption. (Of course, there is a slight chance of false alarms if the thread is interrupted as it is performing the tests!)

NOTE:

You can actually peek at the virtual machine bytecodes that execute each statement in our class. Run the command

```
javap -c -v Bank
```

to decompile the `Bank.class` file. For example, the line

```
accounts[to] += amount;
```

is translated into the following bytecodes:

```
aload_0
getfield        #2; //Field accounts:[D
iload_2
dup2
daload
dload_3
dadd
dastore
```

What these codes mean does not matter. The point is that the increment command is made up of several instructions, and the thread executing them can be interrupted at any instruction.

What is the chance of this corruption occurring? On a modern processor with multiple cores, the risk of corruption is quite high. I boosted the chance of observing the problem on a single-core processor by interleaving the print statements with the statements that update the balance.

If you omit the print statements, the risk of corruption is lower because each thread does so little work before going to sleep again, and it is unlikely that the scheduler will preempt it in the middle of the computation. However, the risk of corruption does not go away completely. If you run lots of threads on a heavily loaded machine, the program will still fail even after you have eliminated the print statements. The failure may take a few minutes or hours or days to occur. Frankly, there are few things worse in the life of a programmer than an error that only manifests itself irregularly.

The real problem is that the work of the `transfer` method can be interrupted in the middle. If we could ensure that the method runs to completion before the thread loses control, the state of the bank account object would never be corrupted.

12.4.3 Lock Objects

There are two mechanisms for protecting a code block from concurrent access. The Java language provides a `synchronized` keyword for this purpose, and Java 5 introduced the `ReentrantLock` class. The `synchronized` keyword automatically provides a lock as well as an associated "condition," which makes it powerful and convenient for most cases that require explicit locking. However, I believe that it is easier to understand the `synchronized` keyword after you have seen locks and conditions in isolation. The `java.util.concurrent` framework provides separate classes for these fundamental mechanisms, which I explain here and in Section 12.4.4, "Condition Objects," on p. 772. Once you have understood these building blocks, I present the `synchronized` keyword in Section 12.4.5, "The `synchronized` Keyword," on p. 778.

The basic outline for protecting a code block with a `ReentrantLock` is:

```
myLock.lock(); // a ReentrantLock object
try
{
   critical section
}
finally
{
   myLock.unlock(); // make sure the lock is unlocked even if
an exception is thrown
}
```

This construct guarantees that only one thread at a time can enter the critical section. As soon as one thread locks the lock object, no other thread can get past the `lock` statement. When other threads call `lock`, they are deactivated until the first thread unlocks the lock object.

CAUTION:

It is critically important that the `unlock` operation is enclosed in a `finally` clause. If the code in the critical section throws an exception, the lock must be unlocked. Otherwise, the other threads will be blocked forever.

NOTE:

When you use locks, you cannot use the `try`-with-resources statement. First off, the unlock method isn't called `close`. But even if it was renamed, the `try`-with-resources statement wouldn't work. Its header expects the declaration of a new variable. But when you use a lock, you want to keep using the same variable that is shared among threads.

Let us use a lock to protect the `transfer` method of the `Bank` class.

```
public class Bank
{
   private Lock bankLock = new ReentrantLock();
   . . .
   public void transfer(int from, int to, int amount)
   {
      bankLock.lock();
      try
      {
         System.out.print(Thread.currentThread());
         accounts[from] -= amount;
         System.out.printf(" %10.2f from %d to %d", amount,
from, to);
         accounts[to] += amount;
         System.out.printf(" Total Balance: %10.2f%n",
getTotalBalance());
      }
      finally
```

```
         {
            bankLock.unlock();
         }
      }
   }
```

Suppose one thread calls `transfer` and gets preempted before it is done. Suppose a second thread also calls `transfer`. The second thread cannot acquire the lock and is blocked in the call to the `lock` method. It is deactivated and must wait for the first thread to finish executing the `transfer` method. When the first thread unlocks the lock, then the second thread can proceed (see Figure 12.3).

Try it out. Add the locking code to the `transfer` method and run the program again. You can run it forever, and the bank balance will not become corrupted.

Note that each `Bank` object has its own `ReentrantLock` object. If two threads try to access the same `Bank` object, then the lock serves to serialize the access. However, if two threads access different `Bank` objects, each thread acquires a different lock and neither thread is blocked. This is as it should be, because the threads cannot interfere with one another when they manipulate different `Bank` instances.

The lock is called *reentrant* because a thread can repeatedly acquire a lock that it already owns. The lock has a *hold count* that keeps track of the nested calls to the `lock` method. The thread has to call `unlock` for every call to `lock` in order to relinquish the lock. Because of this feature, code protected by a lock can call another method that uses the same locks.

For example, the `transfer` method calls the `getTotalBalance` method, which also locks the `bankLock` object, which now has a hold count of `2`. When the `getTotalBalance` method exits, the hold count is back to `1`. When the `transfer` method exits, the hold count is `0`, and the thread relinquishes the lock.

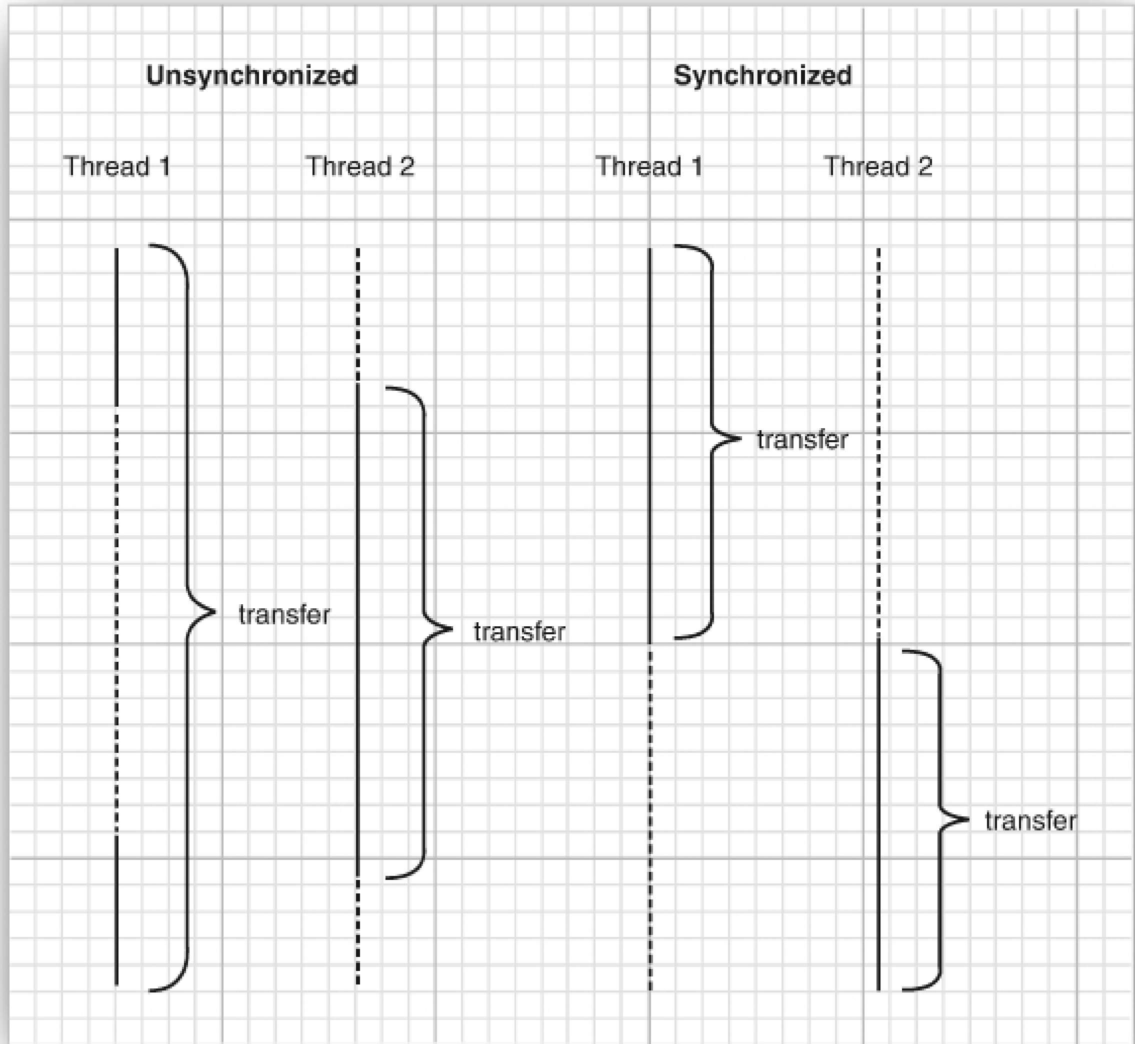


Figure 12.3 Comparison of unsynchronized and synchronized threads

In general, you will want to protect blocks of code that update or inspect a shared object, so you can be assured that these operations run to completion before another thread can use the same object.

CAUTION:

Be careful to ensure that the code in a critical section is not bypassed by throwing an exception. If an exception is thrown before the end of the section, the `finally` clause will relinquish the lock, but the object may be in a damaged state.

`java.util.concurrent.locks.Lock` 5

- `void lock()`

  acquires this lock; blocks if the lock is currently owned by another thread.

- `void unlock()`

  releases this lock.

`java.util.concurrent.locks.ReentrantLock` 5

- `ReentrantLock()`

  constructs a reentrant lock that can be used to protect a critical section.

- `ReentrantLock(boolean fair)`

  constructs a lock with the given fairness policy. A fair lock favors the thread that has been waiting for the longest time. However, this fairness guarantee can be a significant drag on performance. Therefore, by default, locks are not required to be fair.

CAUTION:

It sounds nice to be fair, but fair locks are *a lot slower* than regular locks. You should only enable fair locking if you truly know what you are doing and have a specific reason to consider fairness essential for your program.

Even if you use a fair lock, you have no guarantee that the thread scheduler is fair. If the thread scheduler chooses to neglect a thread that has been waiting a long time for the lock, it doesn't get the chance to be treated fairly by the lock.

12.4.4 Condition Objects

Often, a thread enters a critical section only to discover that it can't proceed until a condition is fulfilled. Use a *condition object* to manage threads that have acquired a lock but cannot do useful work. In this section, I introduce the implementation of condition objects in the Java library. (For historical reasons, condition objects are often called *condition variables*.)

Let us refine our simulation of the bank. We do not want to transfer money out of an account that does not have the funds to cover the transfer. Note that we cannot use code like

```
if (bank.getBalance(from) >= amount)
  bank.transfer(from, to, amount);
```

It is entirely possible that the current thread will be deactivated between the successful outcome of the test and the call to `transfer`.

```
if (bank.getBalance(from) >= amount)
  // thread might be deactivated at this point
  bank.transfer(from, to, amount);
```

By the time the thread is running again, the account balance may have fallen below the withdrawal amount. You must make sure that no other thread can modify the balance between the test and the transfer action. You do so by protecting both the test and the transfer action with a lock:

```
public void transfer(int from, int to, int amount)
{
   bankLock.lock();
```

```
   try
   {
      while (accounts[from] < amount)
      {
         // wait
         . . .
      }
      // transfer funds
      . . .
   }
   finally
   {
      bankLock.unlock();
   }
}
```

Now, what do we do when there is not enough money in the account? We wait until some other thread has added funds. But this thread has just gained exclusive access to the `bankLock`, so no other thread has a chance to make a deposit. This is where condition objects come in.

A lock object can have one or more associated condition objects. You obtain a condition object with the `newCondition` method. It is customary to give each condition object a name that evokes the condition that it represents. For example, here we set up a condition object to represent the "sufficient funds" condition.

```
class Bank
{
   private Condition sufficientFunds;
   . . .
   public Bank()
   {
      . . .
      sufficientFunds = bankLock.newCondition();
   }
}
```

If the `transfer` method finds that sufficient funds are not available, it calls

```
sufficientFunds.await();
```

The current thread is now deactivated and gives up the lock. This lets in another thread that can, we hope, increase the account balance.

There is an essential difference between a thread that is waiting to acquire a lock and a thread that has called `await`. Once a thread calls the `await` method, it enters a *wait set* for that condition. The thread is *not* made runnable when the lock is available. Instead, it stays deactivated until another thread has called the `signalAll` method on the same condition.

When another thread has transferred money, it should call

```
sufficientFunds.signalAll();
```

This call reactivates all threads waiting for the condition. When the threads are removed from the wait set, they are again runnable and the scheduler will eventually activate them again. At that time, they will attempt to reenter the object. As soon as the lock is available, one of them will acquire the lock *and continue where it left off*, returning from the call to `await`.

At this time, the thread should test the condition again. There is no guarantee that the condition is now fulfilled—the `signalAll` method merely signals to the waiting threads that it *may be* fulfilled at this time and that it is worth checking for the condition again.

NOTE:

In general, a call to `await` should be inside a loop of the form

```
while (!(OK to proceed))
   condition.await();
```

It is crucially important that *some* other thread calls the `signalAll` method eventually. When a thread calls `await`, it has no way of reactivating itself. It puts its faith in the other threads. If none of them bother to reactivate the waiting thread, it will never run again. This can lead to unpleasant *deadlock* situations. If all other threads are blocked and the last active thread calls `await` without unblocking one of the others, it also blocks. No thread is left to unblock the others, and the program hangs.

When should you call `signalAll`? The rule of thumb is to call `signalAll` whenever the state of an object changes in a way that might be advantageous to waiting threads. For example, whenever an account balance changes, the waiting threads should be given another chance to inspect the balance. In our example, we call `signalAll` when we have finished the funds transfer.

```
public void transfer(int from, int to, int amount)
{
   bankLock.lock();
   try
   {
      while (accounts[from] < amount)
         sufficientFunds.await();
      // transfer funds       . . .
      sufficientFunds.signalAll();
   }
   finally
   {
      bankLock.unlock();
   }
}
```

Note that the call to `signalAll` does not immediately activate a waiting thread. It only unblocks the waiting threads so that they can compete for entry into the object after the current thread has relinquished the lock.

Another method, `signal`, unblocks only a single thread from the wait set, chosen at random. That is more efficient than unblocking all threads, but there is a danger. If the randomly chosen thread finds that it still cannot proceed, it becomes blocked again. If no other thread calls `signal` again, the system deadlocks.

CAUTION:

A thread can only call `await`, `signalAll`, or `signal` on a condition if it owns the lock of the condition.

If you run the sample program in Listing 12.4, you will notice that nothing ever goes wrong. The total balance stays at $100,000 forever. No account ever has a negative balance. (Again, press Ctrl+C to terminate the program.) You may also notice that the program runs a bit slower—that is the price you pay for the added bookkeeping involved in the synchronization mechanism.

In practice, using conditions correctly can be quite challenging. Before you start implementing your own condition objects, you should consider using one of the constructs described in Section 12.5, "Thread-Safe Collections," on p. 797.

Listing 12.4 `synch/Bank.java`

```
package synch;

import java.util.*;
import java.util.concurrent.locks.*;

/**
 * A bank with a number of bank accounts that uses locks for serializing access.
 */
public class Bank10  {
   private final double[] accounts;
   private Lock bankLock;
   private Condition sufficientFunds;

```

```
   /**
    * Constructs the bank.
    * @param n the number of accounts
    * @param initialBalance the initial balance for each account
    */
   public Bank(int n, double initialBalance)
   {
      accounts = new double[n];
      Arrays.fill(accounts, initialBalance);
      bankLock = new ReentrantLock();
      sufficientFunds = bankLock.newCondition();
   }

   /**
    * Transfers money from one account to another.
    * @param from the account to transfer from
    * @param to the account to transfer to
    * @param amount the amount to transfer
    */
   public void transfer(int from, int to, double amount) throws InterruptedException
   {
      bankLock.lock();
      try
      {
         while (accounts[from] < amount)
            sufficientFunds.await();
         System.out.print(Thread.currentThread());
         accounts[from] -= amount;
         System.out.printf(" %10.2f from %d to %d", amount, from, to);
         accounts[to] += amount;
         System.out.printf(" Total Balance: %10.2f%n", getTotalBalance());
         sufficientFunds.signalAll();
      }
      finally
      {
```

```
            bankLock.unlock();
         }
      }

      /**
       * Gets the sum of all account balances.
       * @return the total balance
       */
      public double getTotalBalance()
      {
         bankLock.lock();
         try
         {
            double sum = 0;

            for (double a : accounts)
               sum += a;

            return sum;
         }
         finally
         {
            bankLock.unlock();
         }
      }

      /**
       * Gets the number of accounts in the bank.
       * @return the number of accounts
       */
      public int size()
      {
         return accounts.length;
      }
   }
```

java.util.concurrent.locks.Lock 5

- `Condition newCondition()`

returns a condition object associated with this lock.

java.util.concurrent.locks.Condition 5

- `void await()`

  puts this thread on the wait set for this condition.

- `void signalAll()`

  unblocks all threads in the wait set for this condition.

- `void signal()`

  unblocks one randomly selected thread in the wait set for this condition.

12.4.5 The `synchronized` Keyword

In the preceding sections, you saw how to use `Lock` and `Condition` objects. Before going any further, let us summarize the key points about locks and conditions:

- A lock protects sections of code, allowing only one thread to execute the code at a time.
- A lock manages threads that are trying to enter a protected code segment.
- A lock can have one or more associated condition objects.
- Each condition object manages threads that have entered a protected code section but that cannot proceed.

The `Lock` and `Condition` interfaces give programmers a high degree of control over locking. However, in most situations, you don't need that control—you can use a mechanism that is built into the Java language. Ever since version 1.0, *every object* in Java has an intrinsic lock. If a method is declared with the `synchronized` keyword, the object's lock protects the entire method. That is, to call the method, a thread must acquire the intrinsic object lock.

In other words,

```
public synchronized void method()
{
   method body
}
```

is the equivalent of

```
public void method()
{
   this.intrinsicLock.lock();
   try
   {
      method body
   }
   finally
   {
      this.intrinsicLock.unlock();
   }
}
```

For example, instead of using an explicit lock, we can simply declare the `transfer` method of the `Bank` class as `synchronized`.

The intrinsic object lock has a single associated condition. The `wait` method adds a thread to the wait set, and the `notifyAll`/`notify` methods unblock waiting threads. In other words, calling `wait` or `notifyAll` is the equivalent of

```
intrinsicCondition.await();
intrinsicCondition.signalAll();
```

NOTE:

The `wait`, `notifyAll`, and `notify` methods are `final` methods of the `Object` class. The `Condition` methods had to be named `await`, `signalAll`, and `signal` so that they don't conflict with those methods.

For example, you can implement the `Bank` class in Java like this:

```
class Bank
{
   private double[] accounts;

   public synchronized void transfer(int from, int to, int
amount)
         throws InterruptedException
   {
      while (accounts[from] < amount)
         wait(); // wait on intrinsic object lock's single
condition
      accounts[from] -= amount;
      accounts[to] += amount;
      notifyAll(); // notify all threads waiting on the
condition
   }

   public synchronized double getTotalBalance()
   {
      . . .
   }
}
```

As you can see, using the `synchronized` keyword yields code that is much more concise. Of course, to understand this code, you have to know that each object has an intrinsic lock, and that the lock has an intrinsic condition. The lock manages the threads that try to enter a `synchronized` method. The condition manages the threads that have called `wait`.

TIP:

Synchronized methods are relatively straightforward. However, beginners often struggle with conditions. Before you use `wait/notifyAll`, you should consider using one of the constructs described in Section 12.5, "Thread-Safe Collections," on p. 797.

It is also legal to declare static methods as synchronized. If such a method is called, it acquires the intrinsic lock of the associated class object. For example, if the `Bank` class has a static synchronized method, then the lock of the `Bank.class` object is locked when it is called. As a result, no other thread can call this or any other synchronized static method of the same class.

The intrinsic locks and conditions have some limitations. Among them:

- You cannot interrupt a thread that is trying to acquire a lock.
- You cannot specify a timeout when trying to acquire a lock.
- Having a single condition per lock can be inefficient.

What should you use in your code—`Lock` and `Condition` objects or synchronized methods? Here is my recommendation:

- It is best to use neither `Lock/Condition` nor the `synchronized` keyword. In many situations, you can use one of the mechanisms of the `java.util.concurrent` package that do all the locking for you. For example, in Section 12.5.1, "Blocking Queues," on p. 797, you will see how to use a blocking queue to synchronize threads that work on a common task. You should also explore parallel streams—see Chapter 1 of Volume II.
- If the `synchronized` keyword works for your situation, by all means, use it. You'll write less code and have less room for error. Listing 12.5 shows the bank example, implemented with synchronized methods.

- Use `Lock`/`Condition` if you really need the additional power that these constructs give you.

Listing 12.5 `synch2/Bank.java`

```
package synch2;

import java.util.*;

/**
 * A bank with a number of bank accounts that uses synchronization primitives.
 */
public class Bank
{
   private final double[] accounts;

   /**
    * Constructs the bank.
    * @param n the number of accounts
    * @param initialBalance the initial balance for each account
    */
    public Bank(int n, double initialBalance)
    {
       accounts = new double[n];
       Arrays.fill(accounts, initialBalance);
    }

    /**
     * Transfers money from one account to another.
     * @param from the account to transfer from
     * @param to the account to transfer to
     * @param amount the amount to transfer
     */
    public synchronized void transfer(int from, int to, double amount)
          throws InterruptedException
    {
       while (accounts[from] < amount)
```

```
            wait();
         System.out.print(Thread.currentThread());
         accounts[from] -= amount;
         System.out.printf(" %10.2f from %d to %d", amount, from, to);
         accounts[to] += amount;
         System.out.printf(" Total Balance: %10.2f%n", getTotalBalance());
         notifyAll();
      }

      /**
       * Gets the sum of all account balances.
       * @return the total balance
       */
      public synchronized double getTotalBalance()
      {
         double sum = 0;

         for (double a : accounts)
            sum += a;

         return sum;
      }

      /**
       * Gets the number of accounts in the bank.
       * @return the number of accounts
       */
      public int size()
      {
         return accounts.length;
      }
   }
```

java.lang.Object 1.0

- `void notifyAll()`

  unblocks the threads that called `wait` on this object. This method can only be called from within a synchronized method or block. The method throws an `IllegalMonitorStateException` if the current thread is not the owner of the object's lock.

- `void notify()`

  unblocks one randomly selected thread among the threads that called `wait` on this object. This method can only be called from within a synchronized method or block. The method throws an `IllegalMonitorStateException` if the current thread is not the owner of the object's lock.

- `void wait()`

  causes a thread to wait until it is notified. This method can only be called from within a synchronized method or block. It throws an `IllegalMonitorStateException` if the current thread is not the owner of the object's lock.

- `void wait(long millis)`
- `void wait(long millis, int nanos)`

  causes a thread to wait until it is notified or until the specified amount of time has passed. These methods can only be called from within a synchronized method or block. They throw an `IllegalMonitorStateException` if the current thread is not the owner of the object's lock. The number of nanoseconds may not exceed 1,000,000.

12.4.6 Synchronized Blocks

As we just discussed, every Java object has a lock. A thread can acquire the lock by calling a synchronized method. There is a second mechanism for acquiring the lock: by entering a *synchronized block*. When a thread enters a block of the form

```
synchronized (obj) // this is the syntax for a synchronized
block
{
    critical section
}
```

then it acquires the lock for `obj`.

You will sometimes find "ad hoc" locks, such as

```
public class Bank
{
   private double[] accounts;
   private Lock lock = new Object();   . . .
   public void transfer(int from, int to, int amount)
   {
      synchronized (lock) // an ad-hoc lock
      {
         accounts[from] -= amount;
         accounts[to] += amount;
      }
      System.out.println(. . .);
   }
}
```

Here, the `lock` object is created only to use the lock that every Java object possesses.

CAUTION:

With synchronized blocks, be careful about the lock object. For example, this will not work:

```
private final String lock = "LOCK";
. . .
synchronized (lock) { . . . } // Don't lock on string literal!
```

If this occurs twice in the same program, the locks are *the same object* since string literals are shared. This can lead to a deadlock.

Also, stay away from using primitive type wrappers as locks:

```
private final Integer lock = new Integer(42); // Don't lock on
wrappers
```

The constructor call `new Integer(0)` is deprecated, and you don't want a maintenance programmer to change the call to `Integer.valueOf(42)`. If done twice with the same magic number, the lock will be accidentally shared.

If you need to modify a static field, lock on the specific class, not on the value returned by `getClass()`:

```
synchronized (MyClass.class) { staticCounter++; } // OK
synchronized (getClass()) { staticCounter++; } // Don't
```

If the method containing this code is called from a subclass, then `getClass()` returns a different `Class` object! You are no longer guaranteed mutual exclusion!

In general, if you must use `synchronized` blocks, *know your lock object*! You must use the same lock for all protected access paths, and nobody else must use your lock.

Sometimes, programmers use the lock of an object to implement additional atomic operations—a practice known as *client-side locking*. Consider, for example, the `Vector` class, which is a list whose methods are synchronized. Now suppose we stored our bank balances in a `Vector<Double>`. Here is a naive implementation of a `transfer` method:

```
public void transfer(Vector<Double> accounts, int from, int to,
int amount) // ERROR
{
   accounts.set(from, accounts.get(from) - amount);
   accounts.set(to, accounts.get(to) + amount);
   System.out.println(. . .);
}
```

The get and set methods of the Vector class are synchronized, but that doesn't help us. It is entirely possible for a thread to be preempted in the transfer

method after the first call to get has been completed. Another thread may then store a different value into the same position. However, we can hijack the lock:

```
public void transfer(Vector<Double> accounts, int from, int to,
int amount)
{
   synchronized (accounts)
   {
      accounts.set(from, accounts.get(from) - amount);
      accounts.set(to, accounts.get(to) + amount);
   }
   System.out.println(. . .);
}
```

This approach works, but it is entirely dependent on the fact that the Vector class uses the intrinsic lock for all of its mutator methods. However, is this really a fact? The documentation of the Vector class makes no such promise. You have to carefully study the source code and hope that future versions do not introduce unsynchronized mutators. As you can see, client-side locking is very fragile and not generally recommended.

NOTE:

The Java virtual machine has built-in support for synchronized methods. However, synchronized blocks are compiled into a lengthy sequence of bytecodes to manage the intrinsic lock.

12.4.7 The Monitor Concept

Locks and conditions are powerful tools for thread synchronization, but they are not very object-oriented. For many years, researchers have looked for ways to make multithreading safe without forcing programmers to think about explicit locks. One of the most successful solutions is the *monitor* concept that was pioneered by Per Brinch Hansen and Tony Hoare in the 1970s. In the terminology of Java, a monitor has these properties:

- A monitor is a class with only private fields.
- Each object of that class has an associated lock.
- All methods are locked by that lock. In other words, if a client calls `obj.method()`, then the lock for `obj` is automatically acquired at the beginning of the method call and relinquished when the method returns. Since all fields are private, this arrangement ensures that no thread can access the fields while another thread manipulates them.
- The lock can have any number of associated conditions.

Earlier versions of monitors had a single condition, with a rather elegant syntax. You can simply call `await accounts[from] >= amount` without using an explicit condition variable. However, research showed that indiscriminate retesting of conditions can be inefficient. This problem is solved with explicit condition variables, each managing a separate set of threads.

The Java designers loosely adapted the monitor concept. *Every object* in Java has an intrinsic lock and an intrinsic condition. If a method is declared with the `synchronized` keyword, it acts like a monitor method. The condition variable is accessed by calling `wait`/`notifyAll`/`notify`.

However, a Java object differs from a monitor in three important ways, compromising thread safety:

- Fields are not required to be `private`.
- Methods are not required to be `synchronized`.
- The intrinsic lock is available to clients.

This disrespect for security enraged Per Brinch Hansen. In a scathing review of the multithreading primitives in Java, he wrote: “It is astounding to me that Java’s insecure parallelism is taken seriously by the programming community, a quarter of a century after the invention of monitors and Concurrent Pascal. It has no merit” [Java’s Insecure Parallelism, *ACM SIGPLAN Notices* 34:38–45, April 1999].

12.4.8 Volatile Fields

Sometimes, it seems excessive to pay the cost of synchronization just to read or write an instance field or two. After all, what can go wrong? Unfortunately, with modern processors and compilers, there is plenty of room for error.

- Computers with multiple processors can temporarily hold memory values in registers or local memory caches. As a consequence, threads running in different processors may see different values for the same memory location!
- Compilers can reorder instructions for maximum throughput. Compilers won’t choose an ordering that changes the meaning of the code, but they make the assumption that memory values are only changed when there are explicit instructions in the code. However, a memory value can be changed by another thread!

If you use locks to protect code that can be accessed by multiple threads, you won’t have these problems. Compilers are required to respect locks by flushing local caches as necessary and not inappropriately reordering instructions. The details are explained in the Java Memory Model and Thread Specification developed by JSR 133 (see `www.jcp.org/en/jsr/detail?id=133`). Much of the specification is highly complex and technical, but the document also contains a number of clearly explained examples. A more accessible overview article by Brian Goetz is available at `www.ibm.com/developerworks/library/j-jtp02244`.

NOTE:

Brian Goetz coined the following “synchronization motto”: “If you write a variable which may next be read by another thread, or you read a variable which may have last been written by another thread, you must use synchronization.”

The `volatile` keyword offers a lock-free mechanism for synchronizing access to an instance field. If you declare a field as `volatile`, then the compiler and the virtual machine take into account that the field may be concurrently updated by another thread.

For example, suppose an object has a `boolean` flag `done` that is set by one thread and queried by another thread. As we already discussed, you can use a lock:

```
private boolean done;
public synchronized boolean isDone() { return done; }
public synchronized void setDone() { done = true; }
```

Perhaps it is not a good idea to use the intrinsic object lock. The `isDone` and `setDone` methods can block if another thread has locked the object. If that is a concern, one can use a separate lock just for this variable. But this is getting to be a lot of trouble.

In this case, it is reasonable to declare the field as `volatile`:

```
private volatile boolean done;
public boolean isDone() { return done; }
public void setDone() { done = true; }
```

The compiler will insert the appropriate code to ensure that a change to the `done` variable in one thread is visible from any other thread that reads the variable.

CAUTION:

Volatile variables do not provide any atomicity. For example, the method

```
public void flipDone() { done = !done; } // not atomic
```

is not guaranteed to flip the value of the field. There is no guarantee that the reading, flipping, and writing is uninterrupted.

12.4.9 Final Variables

As you saw in the preceding section, you cannot safely read a field from multiple threads unless you use locks or the `volatile` modifier.

There is one other situation in which it is safe to access a shared field—when it is declared `final`. Consider

```
final var accounts = new HashMap<String, Double>();
```

Other threads get to see the `accounts` variable after the constructor has finished.

Without using `final`, there would be no guarantee that other threads would see the updated value of `accounts`—they might all see `null`, not the constructed `HashMap`.

Of course, the operations on the map are not thread-safe. If multiple threads mutate and read the map, you still need synchronization.

12.4.10 Atomics

You can declare shared variables as `volatile` provided you perform no operations other than assignment.

There are a number of classes in the `java.util.concurrent.atomic` package that use efficient machine-level instructions to guarantee atomicity of other operations without using locks. For example, the `AtomicInteger` class has methods `incrementAndGet` and `decrementAndGet` that atomically increment or decrement an integer. For example, you can safely generate a sequence of numbers like this:

```
public static AtomicLong nextNumber = new AtomicLong();
// in some thread. . .
long id = nextNumber.incrementAndGet();
```

The `incrementAndGet` method atomically increments the `AtomicLong` and returns the post-increment value. That is, the operations of getting the value, adding 1, setting it, and producing the new value cannot be interrupted. It is guaranteed that the correct value is computed and returned, even if multiple threads access the same instance concurrently.

There are methods for atomically setting, adding, and subtracting values, but if you want to make a more complex update, you have to use the `compareAndSet` method. For example, suppose you want to keep track of the largest value that is observed by different threads. The following won't work:

```
public static AtomicLong largest = new AtomicLong();
// in some thread. . .
largest.set(Math.max(largest.get(), observed)); // ERROR--race
condition!
```

This update is not atomic. Instead, provide a lambda expression for updating the variable, and the update is done for you. In our example, we can call

```
largest.updateAndGet(x -> Math.max(x, observed));
```

or

```
largest.accumulateAndGet(observed, Math::max);
```

The `accumulateAndGet` method takes a binary operator that is used to combine the atomic value and the supplied argument.

There are also methods `getAndUpdate` and `getAndAccumulate` that return the old value.

NOTE:

These methods are also provided for the classes `AtomicInteger`, `AtomicIntegerArray`, `AtomicIntegerFieldUpdater`, `AtomicLongArray`, `AtomicLongFieldUpdater`, `AtomicReference`, `AtomicReferenceArray`, and `AtomicReferenceFieldUpdater`.

When you have a very large number of threads accessing the same atomic values, performance suffers because the optimistic updates require too many retries. The `LongAdder` and `LongAccumulator` classes solve this problem. A `LongAdder` is composed of multiple variables whose collective sum is the current value. Multiple threads can update different summands, and new summands are automatically provided when the number of threads increases. This is efficient in the common situation where the value of the sum is not needed until after all work has been done. The performance improvement can be substantial.

If you anticipate high contention, you should simply use a `LongAdder` instead of an `AtomicLong`. The method names are slightly different. Call `increment` to increment a counter or `add` to add a quantity, and `sum` to retrieve the total.

```
var adder = new LongAdder();
for (. . .)
   pool.submit(() ->
      {
         while (. . .)
```

```
            {
               . . .
               if (. . .) adder.increment();
            }
         });
   . . .
   long total = adder.sum();
```

NOTE:

Of course, the `increment` method does *not* return the old value. Doing that would undo the efficiency gain of splitting the sum into multiple summands.

The `LongAccumulator` generalizes this idea to an arbitrary accumulation operation. In the constructor, you provide the operation, as well as its neutral element. To incorporate new values, call `accumulate`. Call `get` to obtain the current value. The following has the same effect as a `LongAdder`:

```
var adder = new LongAccumulator(Long::sum, 0);
// in some thread. . .
adder.accumulate(value);
```

Internally, the accumulator has variables a_1, a_2, . . ., a_n. Each variable is initialized with the neutral element (`0` in our example).

When `accumulate` is called with value v, then one of them is atomically updated as $a_i = a_i \ op \ v$, where *op* is the accumulation operation written in infix form. In our example, a call to `accumulate` computes $a_i = a_i + v$ for some i.

The result of `get` is $a_1 \ op \ a_2 \ op \ . . . \ op \ a_n$. In our example, that is the sum of the accumulators, $a_1 + a_2 + . . . + a_n$.

If you choose a different operation, you can compute maximum or minimum. In general, the operation must be associative and commutative. That means that the final result must be independent of the order in which the intermediate values were combined.

There are also `DoubleAdder` and `DoubleAccumulator` that work in the same way, except with `double` values.

12.4.11 Deadlocks

Locks and conditions cannot solve all problems that might arise in multithreading. Consider the following situation:

1. Account 1: $200
2. Account 2: $300
3. Thread 1: Transfer $300 from Account 1 to Account 2
4. Thread 2: Transfer $400 from Account 2 to Account 1

As Figure 12.4 indicates, Threads 1 and 2 are clearly blocked. Neither can proceed because the balances in Accounts 1 and 2 are insufficient.

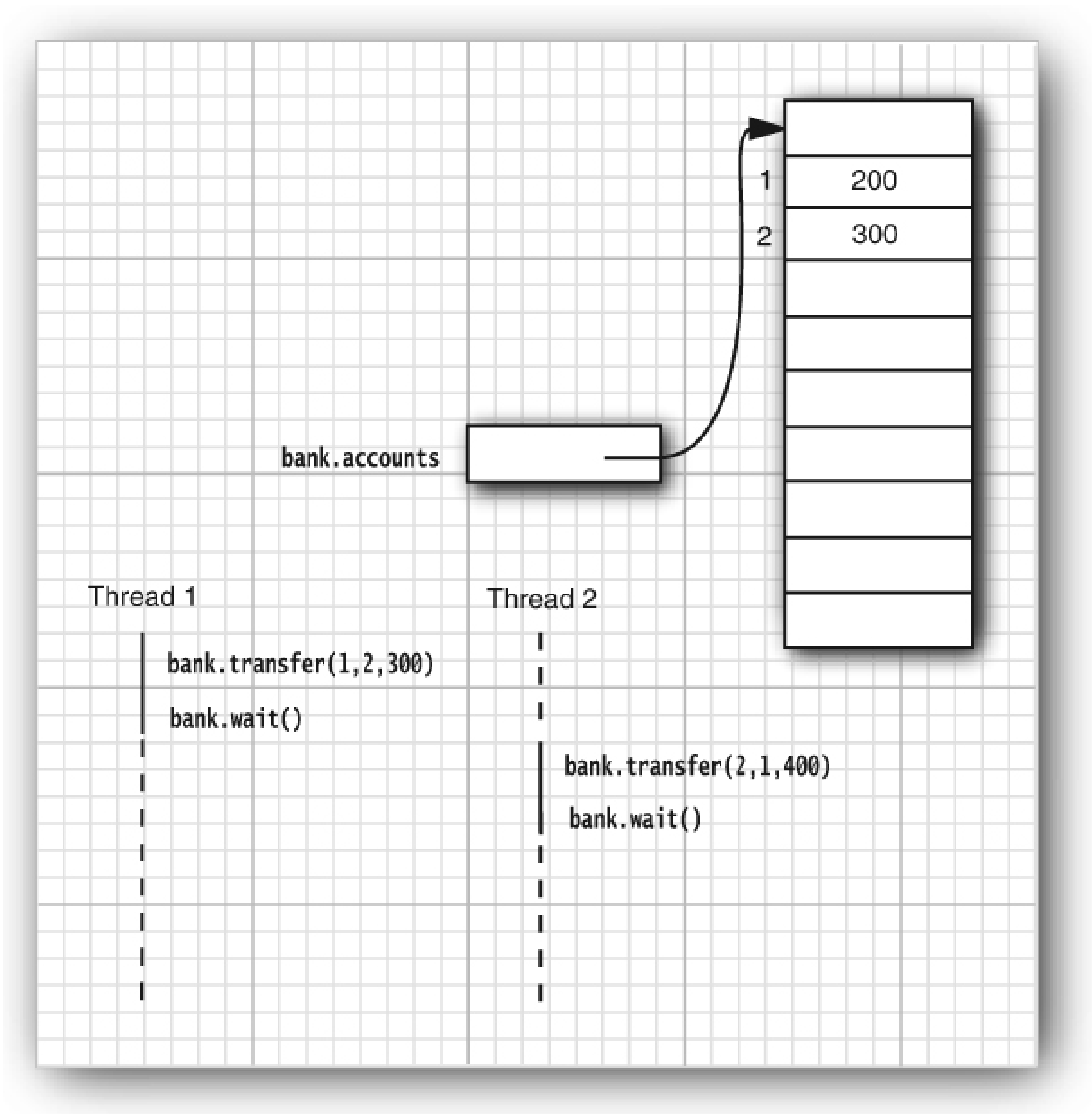


Figure 12.4 A deadlock situation

It is possible that all threads get blocked because each is waiting for more money. Such a situation is called a *deadlock*.

In our program, a deadlock cannot occur for a simple reason. Each transfer amount is for, at most, $1,000. Since there are 100 accounts and a total of $100,000 in them, at least one of the accounts must have at least $1,000 at any time. The thread moving money out of that account can therefore proceed.

But if you change the `run` method of the threads to remove the $1,000 transaction limit, deadlocks can occur quickly. Try it out. Set `NACCOUNTS` to `10`. Construct each transfer runnable with a `max` value of `2 * INITIAL_BALANCE` and run the program. The program will run for a while and then hang.

TIP:

When the program hangs, press Ctrl+\. You will get a thread dump that lists all threads. Each thread has a stack trace, telling you where it is currently blocked. Alternatively, run `jconsole`, as described in Chapter 7, and consult the Threads panel (see Figure 12.5).

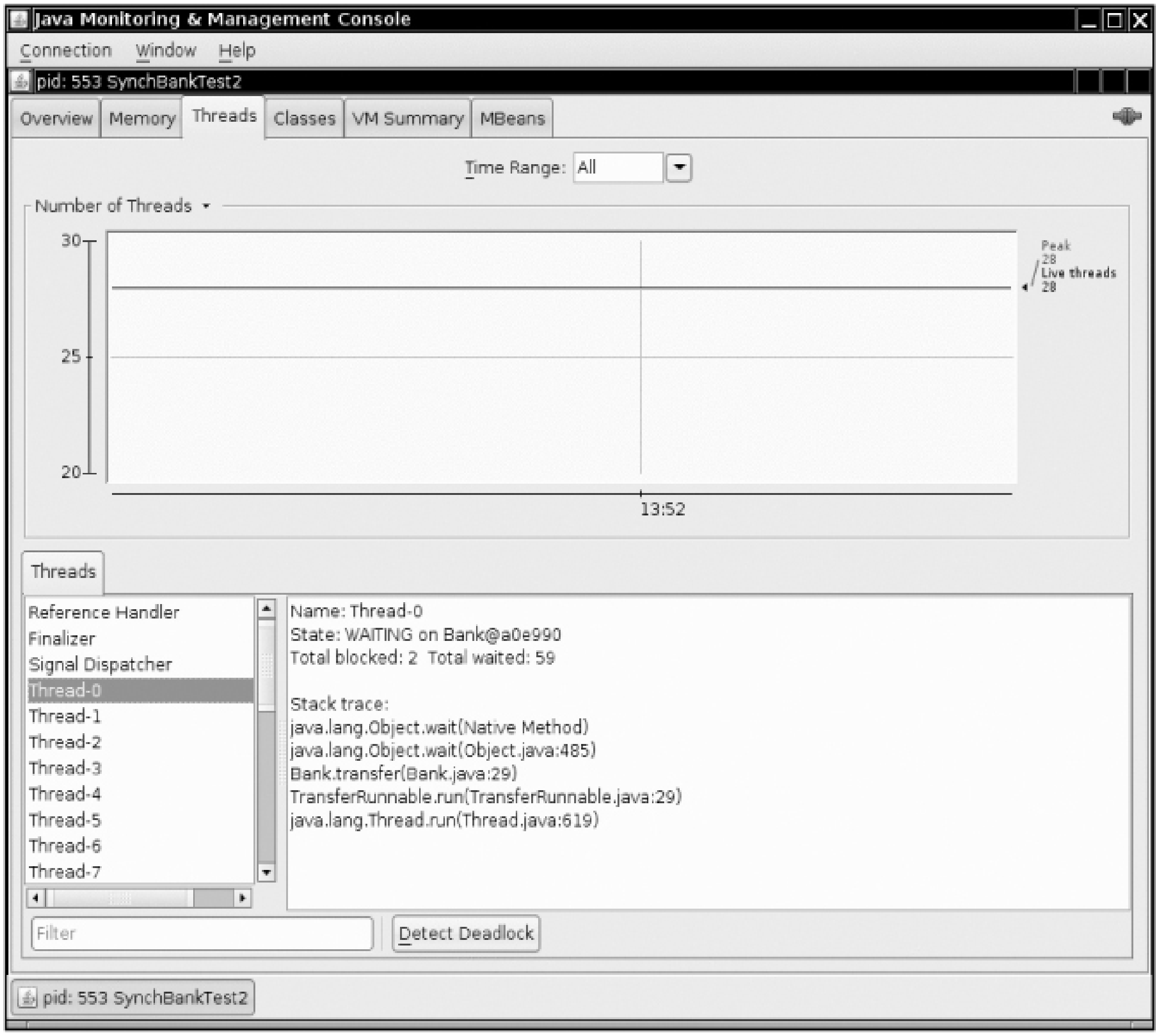


Figure 12.5 The Threads panel in jconsole

Another way to create a deadlock is to make the `i`th thread responsible for putting money into the `i`th account, rather than for taking it out of the `i`th account. In this case, there is a chance that all threads will gang up on one account, each trying to remove more money from it than it contains. Try it out. In the `SynchBankTest` program, turn to the `run` method of the `TransferRunnable` class. In the call to `transfer`, flip `fromAccount` and `toAccount`. Run the program and see how it deadlocks almost immediately.

Here is another situation in which a deadlock can occur easily. Change the `signalAll` method to `signal` in the `SynchBankTest` program. You will find that the program eventually hangs. (Again, set `NACCOUNTS` to `10` to observe the effect more quickly.) Unlike `signalAll`, which notifies all threads that are waiting for added funds, the `signal` method unblocks only one thread. If that thread can't proceed, all threads can be blocked. Consider the following sample scenario of a developing deadlock:

1. Account 1: $1,990
2. All other accounts: $990 each
3. Thread 1: Transfer $995 from Account 1 to Account 2
4. All other threads: Transfer $995 from their account to another account

Clearly, all threads but Thread 1 are blocked, because there isn't enough money in their accounts.

Thread 1 proceeds. Afterward, we have the following situation:

1. Account 1: $995
2. Account 2: $1,985
3. All other accounts: $990 each

Then, Thread 1 calls `signal`. The `signal` method picks a thread at random to unblock. Suppose it picks Thread 3. That thread is awakened, finds that there isn't enough money in its account, and calls `await` again. But Thread 1 is still running. A new random transaction is generated, say,

1. Thread 1: Transfer $997 from Account 1 to Account 2

Now, Thread 1 also calls `await`, and *all* threads are blocked. The system has deadlocked.

The culprit here is the call to `signal`. It only unblocks one thread, and it may not pick the thread that is essential to make progress. (In our scenario, Thread 2 must proceed to take money out of Account 2.)

Unfortunately, there is nothing in the Java programming language to avoid or break these deadlocks. You must design your program to ensure that a deadlock situation cannot occur.

12.4.12 Why the `stop` and `suspend` Methods Are Deprecated

The initial release of Java defined a `stop` method that simply terminates a thread, and a `suspend` method that blocks a thread until another thread calls `resume`. The `stop` and `suspend` methods have something in common: Both attempt to control the behavior of a given thread without the thread's cooperation.

The `stop`, `suspend`, and `resume` methods have been deprecated. The `stop` method is inherently unsafe, and experience has shown that the `suspend` method frequently leads to deadlocks. In this section, you will see why these methods are problematic and what you can do to avoid problems.

Let us turn to the `stop` method first. This method terminates all pending methods, including the `run` method. When a thread is stopped, it immediately gives up the locks on all objects that it has locked. This can leave objects in an inconsistent state. For example, suppose a `TransferRunnable` is stopped in the middle of moving money from one account to another, after the withdrawal and before the deposit. Now the bank object is *damaged*. Since the lock has been relinquished, the damage is observable from the other threads that have not been stopped.

When a thread wants to stop another thread, it has no way of knowing when the `stop` method is safe and when it leads to damaged objects. Therefore, the method has been deprecated. You should interrupt a thread when you want it to stop. The interrupted thread can then stop when it is safe to do so.

NOTE:

Some authors claim that the `stop` method has been deprecated because it can cause objects to be permanently locked by a stopped thread. However, that claim is not valid. A stopped thread exits all synchronized methods it has called—technically, by throwing a `ThreadDeath` exception. As a consequence, the thread relinquishes the intrinsic object locks that it holds.

Next, let us see what is wrong with the `suspend` method. Unlike `stop`, `suspend` won't damage objects. However, if you suspend a thread that owns a lock, then the lock is unavailable until the thread is resumed. If the thread that calls the `suspend` method tries to acquire the same lock, the program deadlocks: The suspended thread waits to be resumed, and the suspending thread waits for the lock.

This situation occurs frequently in graphical user interfaces. Suppose we have a graphical simulation of our bank. A button labeled Pause suspends the transfer threads, and a button labeled Resume resumes them.

```
pauseButton.addActionListener(event ->
   {
      for (int i = 0; i < threads.length; i++)
         threads[i].suspend(); // don't do this
   });

resumeButton.addActionListener(event ->
   {
      for (int i = 0; i < threads.length; i++)
         threads[i].resume();
   });
```

Suppose a `paintComponent` method paints a chart of each account, calling a `getBalances` method to get an array of balances.

As you will see in Section 12.7.3, "Long-Running Tasks in User Interface Callbacks," on p. 839, both the button actions and the repainting occur in the same thread, the *event dispatch thread*. Consider the following scenario:

1. One of the transfer threads acquires the lock of the `bank` object.
2. The user clicks the Pause button.
3. All transfer threads are suspended; one of them still holds the lock on the `bank` object.
4. For some reason, the account chart needs to be repainted.
5. The `paintComponent` method calls the `getBalances` method.
6. That method tries to acquire the lock of the `bank` object.

Now the program is frozen.

The event dispatch thread can't proceed because the lock is owned by one of the suspended threads. Thus, the user can't click the Resume button, and the threads won't ever resume.

If you want to safely suspend a thread, introduce a variable `suspendRequested` and test it in a safe place of your `run` method—in a place where your thread doesn't lock objects that other threads need. When your thread finds that the `suspendRequested` variable has been set, it should keep waiting until it becomes available again.

12.4.13 On-Demand Initialization

Sometimes, you have a data structure that you only want to initialize when it is first needed. And you want to ensure that initialization happens exactly once. Instead of designing your own mechanism, make use of the fact that the virtual machine executes a static initializer exactly once when the class is first used. The virtual machine ensures this with a lock, so you don't have to program your own.

```
public class OnDemandData
{
   // private constructor to ensure only one object is
constructed
   private OnDemandData()
   {
      . . .
   }

   public static OnDemandData getInstance()
   {
      return Holder.INSTANCE;
   }

   // only initialized on first use, i.e. in the first call to
getInstance
   private static Holder
```

```
    {
       // VM guarantees that this happens at most once
       static final OnDemandData INSTANCE = new OnDemandData();
    }
}
```

CAUTION:

To use this idiom, you must ensure that the constructor doesn't throw any exceptions. The virtual machine will not make a second attempt to initialize the holder class.

12.4.14 Thread-Local Variables

In the preceding sections, we discussed the risks of sharing variables between threads. Sometimes, you can avoid sharing by giving each thread its own instance, using the `ThreadLocal` helper class. For example, the `SimpleDateFormat` class is not thread-safe. Suppose we have a static variable

```
public static final SimpleDateFormat dateFormat = new
SimpleDateFormat("yyyy-MM-dd");
```

If two threads execute an operation such as

```
String dateStamp = dateFormat.format(new Date());
```

then the result can be garbage since the internal data structures used by the `dateFormat` can be corrupted by concurrent access. You could use synchronization, which is expensive, or you could construct a local `SimpleDateFormat` object whenever you need it, but that is also wasteful.

To construct one instance per thread, use the following code:

```
public static final ThreadLocal<SimpleDateFormat> dateFormat
   = ThreadLocal.withInitial(() -> new SimpleDateFormat("yyyy-
MM-dd"));
```

To access the actual formatter, call

```
String dateStamp = dateFormat.get().format(new Date());
```

The first time you call `get` in a given thread, the lambda in the constructor is called. From then on, the `get` method returns the instance belonging to the current thread.

A similar problem is the generation of random numbers in multiple threads. The `java.util.Random` class is thread-safe. But it is still inefficient if multiple threads need to wait for a single shared generator.

You could use the `ThreadLocal` helper to give each thread a separate generator, but Java 7 provides a convenience class for you. Simply make a call such as

```
int random = ThreadLocalRandom.current().nextInt(upperBound);
```

The call `ThreadLocalRandom.current()` returns a random number generator instance that is unique to the current thread.

Thread-local variables are also sometimes used to make objects available to all methods that collaborate on a task, without having to pass the object from one caller to another. Suppose, for example, that you want to share a database connection. Declare a variable

```
public static final ThreadLocal<Connection> connection =
ThreadLocal.withInitial(() -> null);
```

When the task starts, initialize the connection for this thread:

```
connection.set(connect(url, username, password));
```

The task calls some methods, all within the same thread, and eventually one of them needs the connection:

```
var result = connection.get().executeQuery(query);
```

Note that the same call may happen on multiple threads. Each of them gets its own connection object.

CAUTION:

In the preceding example, it is crucially important that only one task uses the thread. When executing tasks with a thread pool, you don't want to make your database connection available to the other tasks that share the same thread.

`java.lang.ThreadLocal<T>` 1.2

- `T get()`

  gets the current value of this thread. If `get` is called for the first time, the value is obtained by calling `initialize`.

- `void set(T t)`

  sets a new value for this thread.

- `void remove()`

  removes the value for this thread.

- `static <S> ThreadLocal<S> withInitial(Supplier<? extends S> supplier)` 8

  creates a thread-local variable whose initial value is produced by invoking the given supplier.

`java.util.concurrent.ThreadLocalRandom` 7

- `static ThreadLocalRandom current()`

  returns an instance of the `Random` class that is unique to the current thread.

12.5 Thread-Safe Collections

If multiple threads concurrently modify a data structure, such as a hash table, it is easy to damage that data structure. (See Chapter 9 for more information on hash tables.) For example, one thread may begin to insert a new element. Suppose it is preempted in the middle of rerouting the links between the hash table's buckets. If another thread starts traversing the same list, it may follow invalid links and create havoc, perhaps throwing exceptions or getting trapped in an infinite loop.

You can protect a shared data structure by supplying a lock, but it is usually easier to choose a thread-safe implementation instead. In the following sections, we discuss the other thread-safe collections that the Java library provides.

12.5.1 Blocking Queues

Many threading problems can be formulated elegantly and safely by using one or more queues. Producer threads insert items into the queue, and consumer threads retrieve them. The queue lets you safely hand over data from one thread to another. For example, consider our bank transfer program. Instead of accessing the bank object directly, the transfer threads insert transfer instruction objects into a queue. Another thread removes the instructions from the queue and carries out the transfers. Only that thread has access to the internals of the bank object. No synchronization is necessary. (Of course, the implementors of the thread-safe queue classes had to worry about locks and conditions, but that was their problem, not yours.)

A *blocking queue* causes a thread to block when you try to add an element when the queue is currently full or to remove an element when the queue is empty. Blocking queues are a useful tool for coordinating the work of multiple threads. Worker threads can periodically deposit intermediate results into a blocking queue. Other worker threads remove the intermediate results and modify them further. The queue automatically balances the workload. If the first set of threads runs slower than the second, the second set blocks while waiting for the results. If the first set of threads runs faster, the queue fills up until the second set catches up. Table 12.1 shows the methods for blocking queues.

Table 12.1 Blocking Queue Methods

Method	Normal Action	Action in Special Circumstances
`add`	Adds an element	Throws an `IllegalStateException` if the queue is full
`element`	Returns the head element	Throws a `NoSuchElementException` if the queue is empty
`offer`	Adds an element and returns `true`	Returns `false` if the queue is full
`peek`	Returns the head element	Returns `null` if the queue is empty
`poll`	Removes and returns the head element	Returns `null` if the queue is empty
`put`	Adds an element	Blocks if the queue is full
`remove`	Removes and returns the head element	Throws a `NoSuchElementException` if the queue is empty
`take`	Removes and returns the head element	Blocks if the queue is empty

The blocking queue methods fall into three categories that differ by the action they perform when the queue is full or empty. If you use the queue as a thread management tool, use the `put` and `take` methods. The `add`, `remove`, and `element` operations throw an exception when you try to add to a full queue or get the head of an empty queue. Of course, in a multithreaded program, the queue might become full or empty at any time, so you will instead want to use the `offer`, `poll`, and `peek` methods. These methods simply return with a failure indicator instead of throwing an exception if they cannot carry out their tasks.

NOTE:

The `poll` and `peek` methods return `null` to indicate failure. Therefore, it is illegal to insert `null` values into these queues.

There are also variants of the `offer` and `poll` methods with a timeout. For example, the call

```
boolean success = q.offer(x, 100, TimeUnit.MILLISECONDS);
```

tries for 100 milliseconds to insert an element to the tail of the queue. If it succeeds, it returns `true`; otherwise, it returns `false` when it times out. Similarly, the call

```
Object head = q.poll(100, TimeUnit.MILLISECONDS);
```

tries for 100 milliseconds to remove the head of the queue. If it succeeds, it returns the head; otherwise, it returns `null` when it times out.

The `put` method blocks if the queue is full, and the `take` method blocks if the queue is empty. These are the equivalents of `offer` and `poll` with no timeout.

The `java.util.concurrent` package supplies several variations of blocking queues. By default, the `LinkedBlockingQueue` has no upper bound on its capacity, but a maximum capacity can be optionally specified. The `LinkedBlockingDeque` is a double-ended version. The `ArrayBlockingQueue` is constructed with a given capacity and an optional parameter to require fairness. If fairness is specified, then the longest-waiting threads are given preferential treatment. As always, fairness exacts a significant performance penalty, and you should only use it if your problem specifically requires it.

The `PriorityBlockingQueue` is a priority queue, not a first-in/first-out queue. Elements are removed in order of their priority. The queue has unbounded capacity, but retrieval will block if the queue is empty. (See Chapter 9 for more information on priority queues.)

A `DelayQueue` contains objects that implement the `Delayed` interface:

```
interface Delayed extends Comparable<Delayed>
{
   long getDelay(TimeUnit unit);
}
```

The `getDelay` method returns the remaining delay of the object. A negative value indicates that the delay has elapsed. Elements can only be removed from a `DelayQueue` if their delay has elapsed. You also need to implement the `compareTo` method. The `DelayQueue` uses that method to sort the entries.

Java 7 adds a `TransferQueue` interface that allows a producer thread to wait until a consumer is ready to take on an item. When a producer calls

```
q.transfer(item);
```

the call blocks until another thread removes it. The `LinkedTransferQueue` class implements this interface.

The program in Listing 12.6 shows how to use a blocking queue to control a set of threads. The program searches through all files in a directory and its subdirectories, printing lines that contain a given keyword.

A producer thread enumerates all files in all subdirectories and places them in a blocking queue. This operation is fast, and the queue would quickly fill up with all files in the file system if it was not bounded.

We also start a large number of search threads. Each search thread takes a file from the queue, opens it, prints all lines containing the keyword, and then takes the next file. We use a trick to terminate the application when no further work is required. In order to signal completion, the enumeration thread places a dummy object into the queue. (This is similar to a dummy suitcase with a label “last bag” in a baggage claim belt.) When a search thread takes the dummy, it puts it back and terminates.

Note that no explicit thread synchronization is required. In this application, we use the queue data structure as a synchronization mechanism.

Listing 12.6 `blockingQueue/BlockingQueueTest.java`

```
package blockingQueue;

import java.io.*;
import java.nio.charset.*;
import java.nio.file.*;
import java.util.*;
import java.util.concurrent.*;
import java.util.stream.*;

/**
 * @version 1.03 2018-03-17
 * @author Cay Horstmann
 */
public class BlockingQueueTest
{
   private static final int FILE_QUEUE_SIZE = 10;
   private static final int SEARCH_THREADS = 100;
   private static final Path DUMMY = Path.of("");
   private static BlockingQueue<Path> queue = new
ArrayBlockingQueue<>(FILE_QUEUE_SIZE);

   public static void main(String[] args)
   {
      try (var in = new Scanner(System.in))
      {
```

```
      System.out.print("Enter base directory (e.g. /opt/jdk-11-src): ");
      String directory = in.nextLine();
      System.out.print("Enter keyword (e.g. volatile): ");
      String keyword = in.nextLine();

      Runnable enumerator = () -> {
         try
         {
            enumerate(Path.of(directory));
            queue.put(DUMMY);
         }
         catch (IOException e)
         {
            e.printStackTrace();
         }
         catch (InterruptedException e)
         {
         }
      };

      new Thread(enumerator).start();
      for (int i = 1; i <= SEARCH_THREADS; i++) {
         Runnable searcher = () -> {
            try
            {
               boolean done = false;
               while (!done)
               {
                  Path file = queue.take();
                  if (file == DUMMY)
                  {
                     queue.put(file);
                     done = true;
                  }
                  else search(file, keyword);
               }
            }
            catch (IOException e)
```

```
               {
                  e.printStackTrace();
               }
               catch (InterruptedException e)
               {
               }
            };
            new Thread(searcher).start();
         }
      }
   }

   /**
    * Recursively enumerates all files in a given directory and its subdirectories.
    * See Chapters 1 and 2 of Volume II for the stream and file operations.
    * @param directory the directory in which to start
    */
   public static void enumerate(Path directory) throws IOException, InterruptedException
   {
      try (Stream<Path> children = Files.list(directory))
      {
         for (Path child : children.toList())
         {
            if (Files.isDirectory(child))
               enumerate(child);
            else
               queue.put(child);
         }
      }
   }

   /**
    * Searches a file for a given keyword and prints all matching lines.
    * @param file the file to search
    * @param keyword the keyword to search for
```

```java
     */
    public static void search(Path file, String keyword) throws IOException
    {
       try (var in = new Scanner(file, StandardCharsets.UTF_8))
       {
          int lineNumber = 0;
          while (in.hasNextLine())
          {
             lineNumber++;
             String line = in.nextLine();
             if (line.contains(keyword))
                System.out.printf("%s:%d:%s%n", file, lineNumber, line);
          }
       }
    }
}
```

---

java.util.concurrent.ArrayBlockingQueue<E> 5

- ArrayBlockingQueue(int capacity)
- ArrayBlockingQueue(int capacity, boolean fair)

  constructs a blocking queue with the given capacity and fairness settings. The queue is implemented as a circular array.

java.util.concurrent.LinkedBlockingQueue<E> 5

java.util.concurrent.LinkedBlockingDeque<E> 6

- LinkedBlockingQueue()
- LinkedBlockingDeque()

constructs an unbounded blocking queue or deque, implemented as a linked list.

- `LinkedBlockingQueue(int capacity)`
- `LinkedBlockingDeque(int capacity)`

constructs a bounded blocking queue or deque with the given capacity, implemented as a linked list.

`java.util.concurrent.DelayQueue<E extends Delayed>` 5

- `DelayQueue()`

constructs an unbounded blocking queue of `Delayed` elements. Only elements whose delay has expired can be removed from the queue.

`java.util.concurrent.Delayed` 5

- `long getDelay(TimeUnit unit)`

gets the delay for this object, measured in the given time unit.

`java.util.concurrent.PriorityBlockingQueue<E>` 5

- `PriorityBlockingQueue()`
- `PriorityBlockingQueue(int initialCapacity)`
- `PriorityBlockingQueue(int initialCapacity, Comparator<? super E> comparator)`

constructs an unbounded blocking priority queue implemented as a heap. The default for the initial capacity is `11`. If the comparator is not specified, the elements must implement the `Comparable` interface.

java.util.concurrent.BlockingQueue<E> 5

* `void put(E element)`

  adds the element, blocking if necessary.

* `E take()`

  removes and returns the head element, blocking if necessary.

* `boolean offer(E element, long time, TimeUnit unit)`

  adds the given element and returns `true` if successful, blocking if necessary until the element has been added or the time has elapsed.

* `E poll(long time, TimeUnit unit)`

  removes and returns the head element, blocking if necessary until an element is available or the time has elapsed. Returns `null` upon failure.

java.util.concurrent.BlockingDeque<E> 6

* `void putFirst(E element)`
* `void putLast(E element)`

  adds the element, blocking if necessary.

* `E takeFirst()`
* `E takeLast()`

  removes and returns the head or tail element, blocking if necessary.

* `boolean offerFirst(E element, long time, TimeUnit unit)`
* `boolean offerLast(E element, long time, TimeUnit unit)`

adds the given element and returns `true` if successful, blocking if necessary until the element has been added or the time has elapsed.

- `E pollFirst(long time, TimeUnit unit)`
- `E pollLast(long time, TimeUnit unit)`

removes and returns the head or tail element, blocking if necessary until an element is available or the time has elapsed. Returns `null` upon failure.

java.util.concurrent.TransferQueue<E> 7

- `void transfer(E element)`
- `boolean tryTransfer(E element, long time, TimeUnit unit)`

transfers a value, or tries transferring it with a given timeout, blocking until another thread has removed the item. The second method returns `true` if successful.

12.5.2 Efficient Maps, Sets, and Queues

The `java.util.concurrent` package supplies efficient implementations for maps, sorted sets, and queues: `ConcurrentHashMap`, `ConcurrentSkipListMap`, `ConcurrentSkipListSet`, and `ConcurrentLinkedQueue`.

These collections use sophisticated algorithms that minimize contention by allowing concurrent access to different parts of the data structure.

Unlike most collections, the `size` method of these classes does not necessarily operate in constant time. Determining the current size of one of these collections usually requires traversal.

NOTE:

Some applications use humongous concurrent hash maps, so large that the `size` method is insufficient because it returns an `int`. What is one to do with a map that has over two billion entries? The `mappingCount` method returns the size as a `long`.

The collections return *weakly consistent* iterators. That means that the iterators may or may not reflect all modifications that are made after they were constructed, but they will not return a value twice and they will not throw a `ConcurrentModificationException`.

NOTE:

In contrast, an iterator of a collection in the `java.util` package throws a `ConcurrentModificationException` when the collection has been modified after construction of the iterator.

The concurrent hash map can efficiently support a large number of readers and a bounded number of writers.

NOTE:

A hash map keeps all entries with the same hash code in the same "bucket." Some applications use poor hash functions, and as a result all entries end up in a small number of buckets, severely degrading performance. Even generally reasonable hash functions, such as that of the `String` class, can be problematic. For example, an attacker can slow down a program by crafting a large number of strings that hash to the same value. In recent Java versions, the concurrent hash map organizes the buckets as trees, not lists, when the key type implements `Comparable`, guaranteeing $O(\log n)$ performance.

java.util.concurrent.ConcurrentLinkedQueue<E> 5

- `ConcurrentLinkedQueue<E>()`

  constructs an unbounded, nonblocking queue that can be safely accessed by multiple threads.

java.util.concurrent.ConcurrentSkipListSet<E> 6

- `ConcurrentSkipListSet<E>()`
- `ConcurrentSkipListSet<E>(Comparator<? super E> comp)`

  constructs a sorted set that can be safely accessed by multiple threads. The first constructor requires that the elements implement the `Comparable` interface.

java.util.concurrent.ConcurrentHashMap<K, V> 5

java.util.concurrent.ConcurrentSkipListMap<K, V> 6

- `ConcurrentHashMap<K, V>()`
- `ConcurrentHashMap<K, V>(int initialCapacity)`
- `ConcurrentHashMap<K, V>(int initialCapacity, float loadFactor, int concurrencyLevel)`

  constructs a hash map that can be safely accessed by multiple threads. The default for the initial capacity is `16`. If the average load per bucket exceeds the load factor, the table is resized. The default is `0.75`. The concurrency level is the estimated number of concurrent writer threads.

- `ConcurrentSkipListMap<K, V>()`
- `ConcurrentSkipListSet<K, V>(Comparator<? super K> comp)`

constructs a sorted map that can be safely accessed by multiple threads. The first constructor requires that the keys implement the Comparable interface.

12.5.3 Atomic Update of Map Entries

The original version of ConcurrentHashMap only had a few methods for atomic updates, which made for somewhat awkward programming. Suppose we want to count how often certain features are observed. As a simple example, suppose multiple threads encounter words, and we want to count their frequencies.

Can we use a ConcurrentHashMap<String, Long>? Consider the code for incrementing a count. Obviously, the following is not thread-safe:

```
Long oldValue = map.get(word);
Long newValue = oldValue == null ? 1 : oldValue + 1;
map.put(word, newValue); // ERROR--might not replace oldValue
```

Another thread might be updating the exact same count at the same time.

NOTE:

Some programmers are surprised that a supposedly thread-safe data structure permits operations that are not thread-safe. But there are two entirely different considerations. If multiple threads modify a plain HashMap, they can destroy the internal structure (an array of linked lists). Some of the links may go missing, or even go in circles, rendering the data structure unusable. That will never happen with a ConcurrentHashMap. In the example above, the code for get and put will never corrupt the data structure. But, since the sequence of operations is not atomic, the result is not predictable.

In old versions of Java, it was necessary to use the `replace` method, which atomically replaces an old value with a new one, provided that no other thread has come before and replaced the old value with something else. You had to keep doing it until the attempt succeeded:

```
do
{
   oldValue = map.get(word);
   newValue = oldValue == null ? 1 : oldValue + 1;
}
while (!map.replace(word, oldValue, newValue));
```

An alternative was to use a `ConcurrentHashMap<String, AtomicLong>` and the following update code:

```
map.putIfAbsent(word, new AtomicLong());
map.get(word).incrementAndGet();
```

Unfortunately, a new `AtomicLong` is constructed for each increment, whether or not it is needed.

Nowadays, the Java API provides methods that make atomic updates more convenient. The `compute` method is called with a key and a function to compute the new value. That function receives the key and the associated value, or `null` if there is none, and it computes the new value. For example, here is how we can update a map of integer counters:

```
map.compute(word, (k, v) -> v == null ? 1 : v + 1);
```

NOTE:

You cannot have `null` values in a `ConcurrentHashMap`. There are many methods that use a `null` value as an indication that a given key is not present in the map.

There are also variants `computeIfPresent` and `computeIfAbsent` that only compute a new value when there is already an old one, or when there isn't yet one. A map of `LongAdder` counters can be updated with

```
map.computeIfAbsent(word, k -> new LongAdder()).increment();
```

That is almost like the call to `putIfAbsent` that you saw before, but the `LongAdder` constructor is only called when a new counter is actually needed.

You often need to do something special when a key is added for the first time. The `merge` method makes this particularly convenient. It has a parameter for the initial value that is used when the key is not yet present. Otherwise, the function that you supplied is called, combining the existing value and the initial value. (Unlike `compute`, the function does *not* process the key.)

```
map.merge(word, 1L, (existingValue, newValue) -> existingValue
+ newValue);
```

or simply

```
map.merge(word, 1L, Long::sum);
```

It doesn't get more concise than that.

NOTE:

If the function that is passed to `compute` or `merge` returns `null`, the existing entry is removed from the map.

CAUTION:

When you use `compute` or `merge`, keep in mind that the function that you supply should not do a lot of work. While that function runs, some other updates to the map may be blocked. Of course, that function should also not update other parts of the map.

The program in Listing 12.7 uses a concurrent hash map to count all words in the Java files of a directory tree.

Listing 12.7 `concurrentHashMap/CHMDemo.java`

```
package concurrentHashMap;

import java.io.*;
import java.nio.file.*;
import java.util.*;
import java.util.concurrent.*;
import java.util.stream.*;

/**
 * This program demonstrates concurrent hash maps.
 * @version 1.0 2018-01-04
 * @author Cay Horstmann
 */
public class CHMDemo
{
   public static ConcurrentHashMap<String, Long> map = new ConcurrentHashMap<>();

   /**
    * Adds all words in the given file to the concurrent hash map.
    * @param file a file
    */
   public static void process(Path file)
   {
      try (var in = new Scanner(file))
      {
         while (in.hasNext())
```

```
         {
            String word = in.next();
            map.merge(word, 1L, Long::sum);
         }
      }
      catch (IOException e)
      {
         e.printStackTrace();
      }
   }

   /**
    * Returns all descendants of a given directory--see Chapters 1 and 2 of Volume II
    * @param rootDir the root directory
    * @return a set of all descendants of the root directory
    */
   public static Set<Path> descendants(Path rootDir) throws IOException
   {
      try (Stream<Path> entries = Files.walk(rootDir))
      {
         return entries.collect(Collectors.toSet());
      }
   }

   public static void main(String[] args)
      throws InterruptedException, ExecutionException, IOException
   {
      int processors = Runtime.getRuntime().availableProcessors();
      ExecutorService executor = Executors.newFixedThreadPool(processors);
      Path pathToRoot = Path.of(".");
      for (Path p : descendants(pathToRoot))
      {
         if (p.getFileName().toString().endsWith(".java"))
            executor.execute(() -> process(p));
```

```
        }
        executor.shutdown();
        executor.awaitTermination(10, TimeUnit.MINUTES);
        map.forEach((k, v) ->
           {
              if (v >= 10)
                 System.out.println(k + " occurs " + v + " times");
           });
    }
}
```

12.5.4 Bulk Operations on Concurrent Hash Maps

The Java API provides bulk operations on concurrent hash maps that can safely execute even while other threads operate on the map. The bulk operations traverse the map and operate on the elements they find as they go along. No effort is made to freeze a snapshot of the map in time. Unless you happen to know that the map is not being modified while a bulk operation runs, you should treat its result as an approximation of the map's state.

There are three kinds of operations:

- `search` applies a function to each key and/or value, until the function yields a non-null result. Then the search terminates and the function's result is returned.
- `reduce` combines all keys and/or values, using a provided accumulation function.
- `forEach` applies a function to all keys and/or values.

Each operation has four versions:

- *operation*`Keys`: operates on keys.
- *operation*`Values`: operates on values.
- *operation*: operates on keys and values.
- *operation*`Entries`: operates on `Map.Entry` objects.

With each of the operations, you need to specify a *parallelism threshold*. If the map contains more elements than the threshold, the bulk operation is parallelized. If you want the bulk operation to run in a single thread, use a threshold of `Long.MAX_VALUE`. If you want the maximum number of threads to be made available for the bulk operation, use a threshold of `1`.

Let's look at the `search` methods first. Here are the versions:

```
U searchKeys(long threshold, BiFunction<? super K, ? extends U>
f)
U searchValues(long threshold, BiFunction<? super V, ? extends
U> f)
U search(long threshold, BiFunction<? super K, ? super V,?
extends U> f)
U searchEntries(long threshold, BiFunction<Map.Entry<K, V>, ?
extends U> f)
```

For example, suppose we want to find the first word that occurs more than 1,000 times. We need to search keys and values:

```
String result = map.search(threshold, (k, v) -> v > 1000 ? k :
null);
```

Then `result` is set to the first match, or to `null` if the search function returns `null` for all inputs.

The `forEach` methods have two variants. The first one simply applies a *consumer* function for each map entry, for example

```
map.forEach(threshold,
   (k, v) -> System.out.println(k + " -> " + v));
```

The second variant takes an additional *transformer* function, which is applied first, and its result is passed to the consumer:

```
map.forEach(threshold,
   (k, v) -> k + " -> " + v, // transformer
```

```
   System.out::println); // consumer
```

The transformer can be used as a filter. Whenever the transformer returns `null`, the value is silently skipped. For example, here we only print the entries with large values:

```
map.forEach(threshold,
   (k, v) -> v > 1000 ? k + " -> " + v : null, // filter and
transformer
   System.out::println); // the nulls are not passed to the
consumer
```

The `reduce` operations combine their inputs with an accumulation function. For example, here is how you can compute the sum of all values:

```
Long sum = map.reduceValues(threshold, Long::sum);
```

As with `forEach`, you can also supply a transformer function. Here we compute the length of the longest key:

```
Integer maxlength = map.reduceKeys(threshold,
   String::length, // transformer
   Integer::max); // accumulator
```

The transformer can act as a filter, by returning `null` to exclude unwanted inputs. Here, we count how many entries have value > 1000:

```
Long count = map.reduceValues(threshold,
   v -> v > 1000 ? 1L : null,
   Long::sum);
```

NOTE:

If the map is empty, or all entries have been filtered out, the reduce operation returns null. If there is only one element, its transformation is returned, and the accumulator is not applied.

There are specializations for int, long, and double outputs with suffixes ToInt, ToLong, and ToDouble. You need to transform the input to a primitive value and specify a default value and an accumulator function. The default value is returned when the map is empty.

```
long sum = map.reduceValuesToLong(threshold,
   Long::longValue, // transformer to primitive type
   0, // default value for empty map
   Long::sum); // primitive type accumulator
```

CAUTION:

These specializations act differently from the object versions where there is only one element to be considered. Instead of returning the transformed element, it is accumulated with the default. Therefore, the default must be the neutral element of the accumulator.

12.5.5 Concurrent Set Views

Suppose you want a large, thread-safe set instead of a map. There is no ConcurrentHashSet class, and you know better than trying to create your own. Of course, you can use a ConcurrentHashMap with bogus values, but then you get a map, not a set, and you can't apply operations of the Set interface.

The static newKeySet method yields a Set<K> that is actually a wrapper around a ConcurrentHashMap<K, Boolean>. (All map values are Boolean.TRUE, but you don't actually care since you just use it as a set.)

```
Set<String> words = ConcurrentHashMap.<String>newKeySet();
```

Of course, if you have an existing map, the `keySet` method yields the set of keys. That set is mutable. If you remove the set's elements, the keys (and their values) are removed from the map. But it doesn't make sense to add elements to the key set, because there would be no corresponding values to add. There is a second `keySet` method to `ConcurrentHashMap`, with a default value, to be used when adding elements to the set:

```
Set<String> words = map.keySet(1L);
words.add("Java");
```

If `"Java"` wasn't already present in `words`, it now has a value of one.

12.5.6 Copy on Write Arrays

The `CopyOnWriteArrayList` and `CopyOnWriteArraySet` are thread-safe collections in which all mutators make a copy of the underlying array. This arrangement is useful if the threads that iterate over the collection greatly outnumber the threads that mutate it. When you construct an iterator, it contains a reference to the current array. If the array is later mutated, the iterator still has the old array, but the collection's array is replaced. As a consequence, the older iterator has a consistent (but potentially outdated) view that it can access without any synchronization expense.

12.5.7 Parallel Array Algorithms

The `Arrays` class has a number of parallelized operations. The static `Arrays.parallelSort` method can sort an array of primitive values or objects. For example,

```
var contents = new String(Files.readAllBytes(
   Path.of("alice.txt")), StandardCharsets.UTF_8); // read file
into string
String[] words = contents.split("[\\P{L}]+"); // split along
```

```
nonletters
Arrays.parallelSort(words);
```

When you sort objects, you can supply a `Comparator`.

```
Arrays.parallelSort(words,
Comparator.comparing(String::length));
```

With all methods, you can supply the bounds of a range, such as

```
Arrays.parallelSort(words.length / 2, words.length); // sort
the upper half
```

NOTE:

At first glance, it seems a bit odd that these methods have `parallel` in their name, since the user shouldn't care how the sorting happens. However, the API designers wanted to make it clear that the sorting is parallelized. That way, users are on notice to avoid comparators with side effects.

The `parallelSetAll` method fills an array with values that are computed from a function. The function receives the element index and computes the value at that location.

```
Arrays.parallelSetAll(values, i -> i % 10);
   // fills values with 0 1 2 3 4 5 6 7 8 9 0 1 2 . . .
```

Clearly, this operation benefits from being parallelized. There are versions for all primitive type arrays and for object arrays.

Finally, there is a `parallelPrefix` method that replaces each array element with the accumulation of the prefix for a given associative operation. Huh? Here is an example. Consider the array `[1, 2, 3, 4, . . .]` and the ×

operation. After executing `Arrays.parallelPrefix(values, (x, y) -> x * y)`, the array contains

```
[1, 1 × 2, 1 × 2 × 3, 1 × 2 × 3 × 4, . . .]
```

Perhaps surprisingly, this computation can be parallelized. First, join neighboring elements, as indicated here:

```
[1, 1 × 2, 3, 3 × 4, 5, 5 × 6, 7, 7 × 8]
```

The gray values are left alone. Clearly, one can make this computation in parallel in separate regions of the array. In the next step, update the indicated elements by multiplying them with elements that are one or two positions below:

```
[1, 1 × 2, 1 × 2 × 3, 1 × 2 × 3 × 4, 5, 5 × 6, 5 × 6 × 7, 5 × 6
× 7 × 8]
```

This, again, can be done in parallel. After log n steps, the process is complete. This is a win over the straightforward linear computation if sufficient processors are available. On special-purpose hardware, this algorithm is commonly used, and users of such hardware are quite ingenious in adapting it to a variety of problems.

12.5.8 Older Thread-Safe Collections

Ever since the initial release of Java, the `Vector` and `Hashtable` classes provided thread-safe implementations of a dynamic array and a hash table. These classes are now considered obsolete, having been replaced by the `ArrayList` and `HashMap` classes. Those classes are not thread-safe. Instead, a different mechanism is supplied in the collections library. Any collection class can be made thread-safe by means of a *synchronization wrapper*:

```
List<E> synchArrayList = Collections.synchronizedList(new
ArrayList<E>());
```

```
Map<K, V> synchHashMap = Collections.synchronizedMap(new
HashMap<K, V>());
```

The methods of the resulting collections are protected by a lock, providing thread-safe access.

You should make sure that no thread accesses the data structure through the original unsynchronized methods. The easiest way to ensure this is not to save any reference to the original object. Simply construct a collection and immediately pass it to the wrapper, as we did in our examples.

You still need to use "client-side" locking if you want to *iterate* over the collection while another thread has the opportunity to mutate it:

```
synchronized (synchHashMap)
{
   Iterator<K> iter = synchHashMap.keySet().iterator();
   while (iter.hasNext()) . . .;
}
```

You must use the same code if you use a "for each" loop because the loop uses an iterator. Note that the iterator actually fails with a `ConcurrentModificationException` if another thread mutates the collection while the iteration is in progress. The synchronization is still required so that the concurrent modification can be reliably detected.

You are usually better off using the collections defined in the `java.util.concurrent` package instead of the synchronization wrappers. In particular, the `ConcurrentHashMap` has been carefully implemented so that multiple threads can access it without blocking each other, provided they access different buckets. One exception is an array list that is frequently mutated. In that case, a synchronized `ArrayList` can outperform a `CopyOnWriteArrayList`.

`java.util.Collections` 1.2

- static <E> Collection<E> synchronizedCollection(Collection<E> c)
- static <E> List synchronizedList(List<E> c)
- static <E> Set synchronizedSet(Set<E> c)
- static <E> SortedSet synchronizedSortedSet(SortedSet<E> c)
- static <K, V> Map<K, V> synchronizedMap(Map<K, V> c)
- static <K, V> SortedMap<K, V> synchronizedSortedMap(SortedMap<K, V> c)

  constructs a view of the collection whose methods are synchronized.

12.6 Tasks and Thread Pools

Constructing a new thread is somewhat expensive because it involves interaction with the operating system. If your program creates a large number of short-lived threads, you should not map each task to a separate thread, but use a *thread pool* instead. A thread pool contains a number of threads that are ready to run. You give a Runnable to the pool, and one of the threads calls the run method. When the run method exits, the thread doesn't die but stays around to serve the next request.

In the following sections, you will see the tools that the Java concurrency framework provides for coordinating concurrent tasks.

12.6.1 Callables and Futures

A Runnable encapsulates a task that runs asynchronously; you can think of it as an asynchronous method with no parameters and no return value. A Callable is similar to a Runnable, but it returns a value. The Callable interface is a parameterized type, with a single method call.

```
public interface Callable<V>
{
   V call() throws Exception;
}
```

The type parameter is the type of the returned value. For example, a `Callable<Integer>` represents an asynchronous computation that eventually returns an `Integer` object.

A `Future` holds the *result* of an asynchronous computation. You start a computation, give someone the `Future` object, and forget about it. The owner of the `Future` object can obtain the result when it is ready.

The `Future<V>` interface has the following methods:

```
V get()
V get(long timeout, TimeUnit unit)
void cancel(boolean mayInterrupt)
boolean isCancelled()
boolean isDone()
```

A call to the first `get` method blocks until the computation is finished. The second `get` method also blocks, but it throws a `TimeoutException` if the call timed out before the computation finished. If the thread running the computation is interrupted, both methods throw an `InterruptedException`. If the computation has already finished, `get` returns immediately.

The `isDone` method returns `false` if the computation is still in progress, `true` if it is finished.

You can cancel the computation with the `cancel` method. If the computation has not yet started, it is canceled and will never start. If the computation is currently in progress, it is interrupted if the `mayInterrupt` parameter is `true`.

CAUTION:

Canceling a task involves two steps. The underlying thread must be located and interrupted. And the task implementation (in the `call` method) must sense the interruption and abandon its work. If a `Future` object does not know on which thread the task is executed, or if the task does not monitor the interrupted status of the thread on which it executes, cancellation will have no effect.

One way to execute a `Callable` is to use a `FutureTask`, which implements both the `Future` and `Runnable` interfaces, so that you can construct a thread for running it:

```
Callable<Integer> task = . . .;
var futureTask = new FutureTask<Integer>(task);
var t = new Thread(futureTask); // it's a Runnable t.start();
. . .
Integer result = futureTask.get(); // it's a Future
```

More commonly, you will pass a `Callable` to an executor. That is the topic of the next section.

java.util.concurrent.Callable<V> 5

- `V call()`

  runs a task that yields a result.

java.util.concurrent.Future<V> 5

- `V get()`
- `V get(long time, TimeUnit unit)`

  gets the result, blocking until it is available or the given time has elapsed. The second method throws a `TimeoutException` if it was unsuccessful.

- `boolean cancel(boolean mayInterrupt)` attempts to cancel the execution of this task. If the task has already started and the `mayInterrupt` parameter is `true`, it is interrupted. Returns `true` if the cancellation was successful.

- `boolean isCancelled()`

  returns `true` if the task was canceled before it completed.

- `boolean isDone()`

  returns `true` if the task completed, through normal completion, cancellation, or an exception.

`java.util.concurrent.FutureTask<V>` 5

- `FutureTask(Callable<V> task)`
- `FutureTask(Runnable task, V result)`

  constructs an object that is both a `Future<V>` and a `Runnable`.

12.6.2 Executors

The `Executors` class has a number of static factory methods for constructing thread pools; see Table 12.2 for a summary.

Table 12.2 Executors Factory Methods

Method	Description
`newCachedThreadPool`	New threads are created as needed; idle threads are kept for 60 seconds.
`newFixedThreadPool`	The pool contains a fixed set of threads; idle threads are kept indefinitely.
`newWorkStealingPool`	A pool suitable for "fork-join" tasks (see Section 12.6.4) in which complex tasks are broken up into simpler tasks and idle threads "steal" simpler tasks.
`newSingleThreadExecutor`	A "pool" with a single thread that executes the submitted tasks sequentially.
`newScheduledThreadPool`	A fixed-thread pool for scheduled execution.
`newSingleThreadScheduledExecutor`	A single-thread "pool" for scheduled execution.

The `newCachedThreadPool` method constructs a thread pool that executes each task immediately, using an existing idle thread when available and creating a new thread otherwise. The `newFixedThreadPool` method constructs a thread pool with a fixed size. If more tasks are submitted than there are idle threads, the un-served tasks are placed on a queue. They are run when other tasks have completed. The `newSingleThreadExecutor` is a degenerate pool of size 1 where a single thread executes the submitted tasks, one after another. These three methods return an object of the `ThreadPoolExecutor` class that implements the `ExecutorService` interface.

Use a cached thread pool when you have threads that are short-lived or spend a lot of time blocking. However, if you have threads that are working hard without blocking, you don't want to run a large number of them together. For optimum speed, the number of concurrent threads is the number of processor cores. In such a situation, you should use a fixed thread pool that bounds the total number of concurrent threads.

The single-thread executor is useful for performance analysis. If you temporarily replace a cached or fixed thread pool with a single-thread pool, you can measure how much slower your application runs without the benefit of concurrency.

NOTE:

Java EE provides a `ManagedExecutorService` subclass that is suitable for concurrent tasks in a Java EE environment. Similarly, web frameworks such as Play provide executor services that are intended for tasks within the framework.

You can submit a `Runnable` or `Callable` to an `ExecutorService` with one of the following methods:

```
Future<T> submit(Callable<T> task)
Future<?> submit(Runnable task)
Future<T> submit(Runnable task, T result)
```

The pool will run the submitted task at its earliest convenience. When you call `submit`, you get back a `Future` object that you can use to get the result or cancel the task.

The second `submit` method returns an odd-looking `Future<?>`. You can use such an object to call `isDone`, `cancel`, or `isCancelled`, but the `get` method simply returns `null` upon completion.

The third version of `submit` yields a `Future` whose `get` method returns the given `result` object upon completion.

When you are done with a thread pool, call `shutdown`. This method initiates the shutdown sequence for the pool. An executor that is shut down accepts no new tasks. When all tasks are finished, the threads in the pool die. Alternatively, you can call `shutdownNow`. The pool then cancels all tasks that have not yet begun.

Here, in summary, is what you do to use a thread pool:

1. Call the static `newCachedThreadPool` or `newFixedThreadPool` method of the `Executors` class.
2. Call `submit` to submit `Callable` or `Runnable` objects.
3. Hang on to the returned `Future` objects so that you can get the results or cancel the tasks.
4. Call `shutdown` when you no longer want to submit any tasks.

The `ScheduledExecutorService` interface has methods for scheduled or repeated execution of tasks. It is a generalization of `java.util.Timer` that allows for thread pooling. The `newScheduledThreadPool` and `newSingleThreadScheduledExecutor` methods of the `Executors` class return objects that implement the `ScheduledExecutorService`

interface.

You can schedule a `Runnable` or `Callable` to run once, after an initial delay. You can also schedule a `Runnable` to run periodically. See the API notes for details.

java.util.concurrent.Executors 5

- `ExecutorService newCachedThreadPool()`

  returns a cached thread pool that creates threads as needed and terminates threads that have been idle for 60 seconds.

- `ExecutorService newFixedThreadPool(int threads)`

  returns a thread pool that uses the given number of threads to execute tasks.

- `ExecutorService newSingleThreadExecutor()`

  returns an executor that executes tasks sequentially in a single thread.

- `ScheduledExecutorService newScheduledThreadPool(int threads)` returns a thread pool that uses the given number of threads to schedule tasks.

- ScheduledExecutorService newSingleThreadScheduledExecutor()

  returns an executor that schedules tasks in a single thread.

java.util.concurrent.ExecutorService 5

- Future<T> submit(Callable<T> task)
- Future<T> submit(Runnable task, T result)
- Future<?> submit(Runnable task)

  submits the given task for execution.

- void shutdown()

  shuts down the service, completing the already submitted tasks but not accepting new submissions.

java.util.concurrent.ThreadPoolExecutor 5

- int getLargestPoolSize()

  returns the largest size of the thread pool during the life of this executor.

java.util.concurrent.ScheduledExecutorService 5

- ScheduledFuture<V> schedule(Callable<V> task, long time, TimeUnit unit)

- `ScheduledFuture<?> schedule(Runnable task, long time, TimeUnit unit)`

  schedules the given task after the given time has elapsed.

- `ScheduledFuture<?> scheduleAtFixedRate(Runnable task, long initialDelay, long period, TimeUnit unit)`

  schedules the given task to run periodically, every `period` units, after the initial delay has elapsed.

- `ScheduledFuture<?> scheduleWithFixedDelay(Runnable task, long initialDelay, long delay, TimeUnit unit)`

  schedules the given task to run periodically, with `delay` units between completion of one invocation and the start of the next, after the initial delay has elapsed.

12.6.3 Controlling Groups of Tasks

You have seen how to use an executor service as a thread pool to increase the efficiency of task execution. Sometimes, an executor is used for a more tactical reason—simply to control a group of related tasks. For example, you can cancel all tasks in an executor with the `shutdownNow` method.

The `invokeAny` method submits all objects in a collection of `Callable` objects and returns the result of a completed task. You don't know which task that is—presumably, it is the one that finished most quickly. Use this method for a search problem in which you are willing to accept any solution. For example, suppose that you need to factor a large integer—a computation that is required for breaking the RSA cipher. You could submit a number of tasks, each attempting a factorization with numbers in a different range. As soon as one of these tasks has an answer, your computation can stop.

The `invokeAll` method submits all objects in a collection of `Callable` objects, blocks until all of them complete, and returns a list of `Future` objects that represent the solutions to all tasks. You can process the results of the computation, when they are available, like this:

```
List<Callable<T>> tasks = . . .;
List<Future<T>> results = executor.invokeAll(tasks);
for (Future<T> result : results)
   processFurther(result.get());
```

In the `for` loop, the first call `result.get()` blocks until the first result is available. That is not a problem if all tasks finish in about the same time. However, it may be worth obtaining the results in the order in which they are available. This can be arranged with the `ExecutorCompletionService`.

Start with an executor, obtained in the usual way. Then construct an `ExecutorCompletionService`. Submit tasks to the completion service. The service manages a blocking queue of `Future` objects, containing the results of the submitted tasks as they become available. Thus, a more efficient organization for the preceding computation is the following:

```
var service = new ExecutorCompletionService<T>(executor);
for (Callable<T> task : tasks) service.submit(task);
for (int i = 0; i < tasks.size(); i++)
   processFurther(service.take().get());
```

The program in Listing 12.8 shows how to use callables and executors. In the first computation, we count how many files in a directory tree contain a given word. We make a separate task for each file:

```
Set<Path> files = descendants(Path.of(start));
var tasks = new ArrayList<Callable<Long>>();
for (Path file : files)
{
   Callable<Long> task = () -> occurrences(word, file);
   tasks.add(task);
}
```

Then we pass the tasks to an executor service:

```
ExecutorService executor = Executors.newCachedThreadPool();
List<Future<Long>> results = executor.invokeAll(tasks);
```

To get the combined count, we add all results, blocking until they are available:

```
long total = 0;
for (Future<Long> result : results)
   total += result.get();
```

The program also displays the time spent during the search. Unzip the source code for the JDK somewhere and run the search. Then replace the executor service with a single-thread executor and try again to see whether the concurrent computation was faster.

In the second part of the program, we search for the first file that contains the given word. We use `invokeAny` to parallelize the search. Here, we have to be more careful about formulating the tasks. The `invokeAny` method terminates as soon as any task *returns*. So we cannot have the search tasks return a `boolean` to indicate success or failure. We don't want to stop searching when a task failed. Instead, a failing task throws a `NoSuchElementException`. Also, when one task has succeeded, the others are canceled. Therefore, we monitor the interrupted status. If the underlying thread is interrupted, the search task prints a message before terminating, so that you can see that the cancellation is effective.

```
public static Callable<Path> searchForTask(String word, Path
path)
{
   return () ->
      {
         try (var in = new Scanner(path))
         {
            while (in.hasNext())
            {
               if (in.next().equals(word)) return path;
               if (Thread.currentThread().isInterrupted())
```

```
                {
                    System.out.println("Search in " + path + "
canceled.");
                    return null;
                }
            }
            throw new NoSuchElementException();
        }
    };
}
```

For informational purposes, this program prints out the largest pool size during execution. This information is not available through the `ExecutorService` interface. For that reason, we had to cast the pool object to the `ThreadPoolExecutor` class.

TIP:

As you read through this program, you can appreciate how useful executor services are. In your own programs, you should use executor services to manage threads instead of launching threads individually.

Listing 12.8 `executors/ExecutorDemo.java`

```
package executors;

import java.io.*;
import java.nio.file.*;
import java.time.*;
import java.util.*;
import java.util.concurrent.*;
import java.util.stream.*;

/**
 * This program demonstrates the Callable interface and
```

```
executors.
 * @version 1.01 2021-05-30
 * @author Cay Horstmann
 */
public class ExecutorDemo
{
   /**
    * Counts occurrences of a given word in a file.
    * @return the number of times the word occurs in the given word
    */
   public static long occurrences(String word, Path path)
   {
      try (var in = new Scanner(path))
      {
         int count = 0;
         while (in.hasNext())
            if (in.next().equals(word)) count++;
         return count;
      }
      catch (IOException ex)
      {
         return 0;
      }
   }

   /**
    * Returns all descendants of a given directory--see Chapters 1 and 2 of Volume II.
    * @param rootDir the root directory
    * @return a set of all descendants of the root directory
    */
   public static Set<Path> descendants(Path rootDir) throws IOException
   {
      try (Stream<Path> entries = Files.walk(rootDir))
      {
         return entries.filter(Files::isRegularFile)
            .collect(Collectors.toSet());
      }
```

```
   }

   /**
    * Yields a task that searches for a word in a file.
    * @param word the word to search
    * @param path the file in which to search
    * @return the search task that yields the path upon success
    */
   public static Callable<Path> searchForTask(String word, Path path)
   {
      return () -> {
         try (var in = new Scanner(path))
         {
            while (in.hasNext())
         {
            if (in.next().equals(word)) return path;
            if (Thread.currentThread().isInterrupted())
            {
               System.out.println("Search in " + path + " canceled.");
               return null;
            }
          }
          throw new NoSuchElementException();
        }
     };
  }

  public static void main(String[] args)
        throws InterruptedException, ExecutionException, IOException
  {
     try (var in = new Scanner(System.in))
     {
        System.out.print("Enter base directory (e.g. /opt/jdk-9-src): ");
        String start = in.nextLine();
        System.out.print("Enter keyword (e.g. volatile): ");
```

```
      String word = in.nextLine();

      Set<Path> files = descendants(Path.of(start));
      var tasks = new ArrayList<Callable<Long>>();
      for (Path file : files)
      {
         Callable<Long> task = () -> occurrences(word, file);
         tasks.add(task);
      }
      ExecutorService executor = Executors.newCachedThreadPool();
      // use a single thread executor instead to see if multiple threads
      // speed up the search
      // ExecutorService executor = Executors.newSingleThreadExecutor();

      Instant startTime = Instant.now();
      List<Future<Long>> results = executor.invokeAll(tasks);
      long total = 0;
      for (Future<Long> result : results)
         total += result.get();
      Instant endTime = Instant.now();
      System.out.println("Occurrences of " + word + ": " + total);
      System.out.println("Time elapsed: "
         + Duration.between(startTime, endTime).toMillis() + " ms");

      var searchTasks = new ArrayList<Callable<Path>>();
      for (Path file : files)
         searchTasks.add(searchForTask(word, file));
      Path found = executor.invokeAny(searchTasks);
      System.out.println(word + " occurs in: " + found);

      if (executor instanceof ThreadPoolExecutor tpExecutor)
         // the single thread executor isn't
         System.out.println("Largest pool size: "
            + tpExecutor.getLargestPoolSize());
```

```
            executor.shutdown();
        }
    }
}
```

java.util.concurrent.ExecutorService 5

- T invokeAny(Collection<Callable<T>> tasks)
- T invokeAny(Collection<Callable<T>> tasks, long timeout, TimeUnit unit)

  executes the given tasks and returns the result of one of them. The second method throws a TimeoutException if a timeout occurs.

- List<Future<T>> invokeAll(Collection<Callable<T>> tasks)
- List<Future<T>> invokeAll(Collection<Callable<T>> tasks, long timeout, TimeUnit unit)

  executes the given tasks and returns the results of all of them. The second method throws a TimeoutException if a timeout occurs.

java.util.concurrent.ExecutorCompletionService<V> 5

- ExecutorCompletionService(Executor e)

  constructs an executor completion service that collects the results of the given executor.

- Future<V> submit(Callable<V> task)
- Future<V> submit(Runnable task, V result)

  submits a task to the underlying executor.

- Future<V> take()

removes the next completed result, blocking if no completed results are available.

- `Future<V> poll()`
- `Future<V> poll(long time, TimeUnit unit)`

removes and returns the next completed result, or returns `null` if no completed results are available. The second method waits for the given time.

12.6.4 The Fork-Join Framework

Some applications use a large number of threads that are mostly idle. An example would be a web server that uses one thread per connection. Other applications use one thread per processor core, in order to carry out computationally intensive tasks, such as image or video processing. The fork-join framework, which appeared in Java 7, is designed to support the latter. Suppose you have a processing task that naturally decomposes into subtasks, like this:

```
if (problemSize < threshold)
solve problem directly
else
{
break problem into subproblems
recursively solve each subproblem
combine the results
}
```

One example is image processing. To enhance an image, you can transform the top half and the bottom half. If you have enough idle processors, those operations can run in parallel. (You will need to do a bit of extra work along the strip that separates the two halves, but that's a technical detail.)

Here, we discuss a simpler example. Suppose we want to count how many elements of an array fulfill a particular property. We cut the array in half, compute the counts of each half, and add them up.

To put the recursive computation in a form that is usable by the framework, supply a class that extends `RecursiveTask<T>` (if the computation produces a result of type `T`) or `RecursiveAction` (if it doesn't produce a result). Override the `compute` method to generate and invoke subtasks, and to combine their results.

```
class Counter extends RecursiveTask<Integer>
{
   . . .
   protected Integer compute()
   {
      if (to - from < THRESHOLD)
      {
         solve problem directly
      }
      else
      {
         int mid = from + (to - from) / 2;
         var first = new Counter(values, from, mid, filter);
         var second = new Counter(values, mid, to,
filter);         invokeAll(first, second);
         return first.join() + second.join();
      }
   }
}
```

Here, the `invokeAll` method receives a number of tasks and blocks until all of them have completed. The `join` method yields the result. Here, we apply `join`

to each subtask and return the sum.

NOTE:

There is also a `get` method for getting the current result, but it is less attractive since it can throw checked exceptions that we are not allowed to throw in the `compute` method.

Listing 12.9 shows the complete example.

Behind the scenes, the fork-join framework uses an effective heuristic, called *work stealing*, for balancing the workload among available threads. Each worker thread has a deque (double-ended queue) for tasks. A worker thread pushes subtasks onto the head of its own deque. (Only one thread accesses the head, so no locking is required.) When a worker thread is idle, it “steals” a task from the tail of another deque. Since large subtasks are at the tail, such stealing is rare.

CAUTION:

Fork-join pools are optimized for nonblocking workloads. If you add many blocking tasks into a fork-join pool, you can starve it. It is possible to overcome this by having tasks implement the `ForkJoinPool.ManagedBlocker` interface, but this is an advanced technique that we won’t discuss.

Listing 12.9 `forkJoin/ForkJoinTest.java`

```
package forkJoin;

import java.util.concurrent.*;
import java.util.function.*;

/**
 * This program demonstrates the fork-join framework.
 * @version 1.02 2021-06-17
 * @author Cay Horstmann
 */
public class ForkJoinTest
{
    public static void main(String[] args)
   {
```

```
      final int SIZE = 10000000;
      var numbers = new double[SIZE];
      for (int i = 0; i < SIZE; i++) numbers[i] = Math.random();
      var counter = new Counter(numbers, 0, numbers.length, x -> x > 0.5);
      var pool = new ForkJoinPool();
      pool.invoke(counter);
      System.out.println(counter.join());
   }
}

class Counter extends RecursiveTask<Integer>
{
   public static final int THRESHOLD = 1000;
   private double[] values;
   private int from;
   private int to;
   private DoublePredicate filter;

   public Counter(double[] values, int from, int to, DoublePredicate filter)
   {
      this.values = values;
      this.from = from;
      this.to = to;
      this.filter = filter;
   }

   protected Integer compute()
   {
      if (to - from < THRESHOLD)
      {
         int count = 0;
         for (int i = from; i < to; i++)
         {
            if (filter.test(values[i])) count++;
         }
         return count;
```

```
         }
         else
         {
            int mid = from + (to - from) / 2;
            var first = new Counter(values, from, mid, filter);
            var second = new Counter(values, mid, to, filter);
            invokeAll(first, second);
            return first.join() + second.join();
         }
      }
   }
```

12.7 Asynchronous Computations

So far, our approach to concurrent computation has been to break up a task, and then wait until all pieces have completed. But waiting is not always a good idea. In the following sections, you will see how to implement wait-free, or *asynchronous*, computations.

12.7.1 Completable Futures

When you have a `Future` object, you need to call `get` to obtain the value, blocking until the value is available. The `CompletableFuture` class implements the `Future` interface, and it provides a second mechanism for obtaining the result. You register a *callback* that will be invoked (in some thread) with the result once it is available.

```
CompletableFuture<String> f = . . .;
f.thenAccept(s -> Process the result string s);
```

In this way, you can process the result without blocking once it is available.

There are a few API methods that return `CompletableFuture` objects. For example, you can fetch a web page asynchronously with the `HttpClient` class that you will encounter in Chapter 4 of Volume II:

```
HttpClient client = HttpClient.newHttpClient();
HttpRequest request =
HttpRequest.newBuilder(URI.create(urlString)).GET().build();
CompletableFuture<HttpResponse<String>> f = client.sendAsync(
   request, BodyHandlers.ofString());
```

It is nice if there is a method that produces a ready-made `CompletableFuture`, but most of the time, you need to make your own. To run a task asynchronously and obtain a `CompletableFuture`, you don't submit it directly to an executor service. Instead, you call the static method `CompletableFuture.supplyAsync`. Here is how to read the web page without the benefit of the `HttpClient` class:

```
public CompletableFuture<String> readPage(URL url)
{
   return CompletableFuture.supplyAsync(() ->
      {
         try
         {
            return new String(url.openStream().readAllBytes(),
"UTF-8");
         }
         catch (IOException e)
         {
            throw new UncheckedIOException(e);
         }      }, executor);
}
```

If you omit the executor, the task is run on a default executor (namely the executor returned by `ForkJoinPool.commonPool()`). You usually don't want to do that.

CAUTION:

Note that the first argument of the `supplyAsync` method is a `Supplier<T>`, not a `Callable<T>`. Both interfaces describe functions with no arguments and a return value of type `T`, but a `Supplier` function cannot throw a checked exception. As you can see from the code above, that was not an inspired choice.

A `CompletableFuture` can complete in two ways: either with a result, or with an uncaught exception. In order to handle both cases, use the `whenComplete` method. The supplied function is called with the result (or `null` if none) and the exception (or `null` if none).

```
f.whenComplete((s, t) ->
  {
  if (t == null)
  {
Process the result s;
  }
  else
  {
Process the Throwable t;
  }
  });
```

The `CompletableFuture` is called completable because you can manually set a completion value. (In other concurrency libraries, such an object is called a *promise*.) Of course, when you create a `CompletableFuture` with `supplyAsync`, the completion value is implicitly set when the task has finished. But setting the result explicitly gives you additional flexibility. For example, two tasks can work simultaneously on computing an answer:

```
var f = new CompletableFuture<Integer>();
executor.execute(() ->
   {
      int n = workHard(arg);
      f.complete(n);
   });
```

```
executor.execute(() ->
   {
      int n = workSmart(arg);
      f.complete(n);
   });
```

To instead complete a future with an exception, call

```
Throwable t = . . .;
f.completeExceptionally(t);
```

NOTE:

It is safe to call `complete` or `completeExceptionally` on the same future in multiple threads. If the future is already completed, these calls have no effect.

The `isDone` method tells you whether a `Future` object has been completed (normally or with an exception). In the preceding example, the `workHard` and `workSmart` methods can use that information to stop working when the result has been determined by the other method.

CAUTION:

Unlike a plain `Future`, the computation of a `CompletableFuture` is not interrupted when you invoke its `cancel` method. Canceling simply sets the `Future` object to be completed exceptionally, with a `CancellationException`. In general, this makes sense since a `CompletableFuture` may not have a single thread that is responsible for its completion. However, this restriction also applies to `CompletableFuture` instances returned by methods such as `supplyAsync`, which could in principle be interrupted.

12.7.2 Composing Completable Futures

Nonblocking calls are implemented through callbacks. The programmer registers a callback for the action that should occur after a task completes. Of course, if the next action is also asynchronous, the next action after that is in a different callback. Even though the programmer thinks in terms of "first do step 1, then step 2, then step 3," the program logic can become dispersed in "callback hell." It gets even worse when one has to add error handling. Suppose step 2 is "the user logs in." You may need to repeat that step since the user can mistype the credentials. Trying to implement such a control flow in a set of callbacks, or to understand it once it has been implemented, can be quite challenging.

The `CompletableFuture` class solves this problem by providing a mechanism for *composing* asynchronous tasks into a processing pipeline.

For example, suppose we want to extract all images from a web page. Let's say we have a method

```
public CompletableFuture<String> readPage(URL url)
```

that yields the text of a web page when it becomes available. If the method

```
public List<URL> getImageURLs(String page)
```

yields the URLs of images in an HTML page, you can schedule it to be called when the page is available:

```
CompletableFuture<String> contents = readPage(url);
CompletableFuture<List<URL>> imageURLs =
contents.thenApply(this::getLinks);
```

The `thenApply` method doesn't block either. It returns another future. When the first future has completed, its result is fed to the `getImageURLs` method, and the return value of that method becomes the final result.

With completable futures, you just specify what you want to have done and in which order. It won't all happen right away, of course, but what is important is that all the code is in one place.

Conceptually, `CompletableFuture` is a simple API, but there are many variants of methods for composing completable futures. Let us first look at those that deal with a single future (see Table 12.3). In the table, I use a shorthand notation for the ponderous functional interfaces, writing `T -> U` instead of `Function<? super T, U>`. These aren't actual Java types, of course.

For each method shown, there are also two `Async` variants that I don't show. One of them uses the common `ForkJoinPool`, and the other has an `Executor` parameter.

You have already seen the `thenApply` method. Suppose `f` is a function that receives values of type `T` and returns values of type `U`. The calls

```
CompletableFuture<U> future.thenApply(f);
CompletableFuture<U> future.thenApplyAsync(f, executor);
```

return a future that applies the function `f` to the result of `future` when it is available. The second call runs `f` with yet another executor.

The `thenCompose` method, instead of taking a function mapping the type `T` to the type `U`, receives a function mapping `T` to `CompletableFuture<U>`. That sounds rather abstract, but it can be quite natural. Consider the action of reading a web page from a given URL. Instead of supplying a method

```
public String blockingReadPage(URL url)
```

it is more elegant to have that method return a future:

```
public CompletableFuture<String> readPage(URL url)
```

Now, suppose we have another method that gets the URL from user input, perhaps from a dialog that won't reveal the answer until the user has clicked the OK button. That, too, is an event in the future:

```
public CompletableFuture<URL> getURLInput(String prompt)
```

Here we have two functions T -> CompletableFuture<U> and U -> CompletableFuture<V>. Clearly, they compose to a function T -> CompletableFuture<V> if the second function is called when the first one has completed. That is exactly what thenCompose does.

In the preceding section, you saw the whenComplete method for handling exceptions. There is also a handle method that requires a function processing the result or exception and computing a new result. In many cases, it is simpler to call the exceptionally method instead. That method computes a dummy value when an exception occurs:

```
CompletableFuture<List<URL>> imageURLs = readPage(url)
   .exceptionally(ex -> "<html></html>")
   .thenApply(this::getImageURLs)
```

You can handle a timeout in the same way:

```
CompletableFuture<List<URL>> imageURLs = readPage(url)
   .completeOnTimeout("<html></html>", 30, TimeUnit.SECONDS)
   .thenApply(this::getImageURLs)
```

Alternatively, you can throw an exception on timeout:

```
CompletableFuture<String> = readPage(url).orTimeout(30,
TimeUnit.SECONDS)
```

The methods in Table 12.3 with void result are normally used at the end of a processing pipeline.

Now let us turn to methods that combine multiple futures (see Table 12.4).

The first three methods run a CompletableFuture<T> and a CompletableFuture<U> action concurrently and combine the results.

The next three methods run two CompletableFuture<T> actions concurrently. As soon as one of them finishes, its result is passed on, and the other result is ignored.

Finally, the static allOf and anyOf methods take a variable number of completable futures and yield a CompletableFuture<Void> that completes when all of them, or any one of them, completes. The allOf method does not yield a result. The anyOf method does *not* terminate the remaining tasks.

Table 12.3 Adding an Action to a CompletableFuture<T> Object

Method	Parameter	Description
thenApply	T -> U	Apply a function to the result.
thenAccept	T -> void	Like thenApply, but with void result.
thenCompose	T -> CompletableFuture<U>	Invoke the function on the result and execute the returned future.
thenRun	Runnable	Execute the Runnable with void result.
handle	(T, Throwable) -> U	Process the result or error and yield a new result.
whenComplete	(T, Throwable) -> void	Like handle, but with void result.
exceptionally	Throwable -> U	Compute a result from the error.
exceptionallyCompose	Throwable -> CompletableFuture<U>	Invoke the function on the exception and execute the returned future.
completeOnTimeout	T, long, TimeUnit	Yield the given value as the result in case of timeout.
orTimeout	long, TimeUnit	Yield a TimeoutException in case of timeout.

NOTE:

Technically speaking, the methods in this section accept parameters of type `CompletionStage`, not `CompletableFuture`. The `CompletionStage` interface describes how to compose asynchronous computations, whereas the `Future` interface focuses on the result of a computation. A `CompletableFuture` is both a `CompletionStage` and a `Future`.

Listing 12.10 shows a complete program that reads a web page, scans it for images, loads the images and saves them locally. Note how all time-consuming methods return a `CompletableFuture`. To kick off the asynchronous computation, we use a little trick. Rather than calling the `readPage` method directly, we make a completed future with the URL argument, and then compose that future with `this::readPage`. That way, the pipeline has a very uniform appearance:

```
CompletableFuture.completedFuture(url)
   .thenComposeAsync(this::readPage, executor)
   .thenApply(this::getImageURLs)
   .thenCompose(this::getImages)
   .thenAccept(this::saveImages);
```

Table 12.4 Combining Multiple Composition Objects

Method	Parameters	Description
thenCombine	CompletableFuture<U>, (T, U) -> V	Execute both and combine the results with the given function.
thenAcceptBoth	CompletableFuture<U>, (T, U) -> void	Like thenCombine, but with void result.
runAfterBoth	CompletableFuture<?>, Runnable	Execute the runnable after both complete.
applyToEither	CompletableFuture<T>, T -> V	When a result is available from one or the other, pass it to the given function.
acceptEither	CompletableFuture<T>, T -> void	Like applyToEither, but with void result.
runAfterEither	CompletableFuture<?>, Runnable	Execute the runnable after one or the other completes.
static allOf	CompletableFuture<?>...	Complete with void result after all given futures complete.
static anyOf	CompletableFuture<?>...	Complete after any of the given futures completes, yielding its result.

Listing 12.10 completableFutures/CompletableFutureDemo.java

```
package completableFutures;

import java.awt.image.*;
import java.io.*;
import java.net.*;
import java.nio.charset.*;
import java.util.*;
import java.util.concurrent.*;
import java.util.regex.*;

import javax.imageio.*;

```

```
public class CompletableFutureDemo
{
   private static final Pattern IMG_PATTERN = Pattern.compile(
      "[<]\\s*[iI][mM][gG]\\s*[^>]*[sS][rR][cC]\\s*[=]\\s*['\"]([^'\"]*)['\"][^>]*[>]");
   private ExecutorService executor = Executors.newCachedThreadPool();
   private URL urlToProcess;

   public CompletableFuture<String> readPage(URL url)
   {
      return CompletableFuture.supplyAsync(() ->
      {
         try
         {
            var contents = new String(url.openStream().readAllBytes(),
               StandardCharsets.UTF_8);
            System.out.println("Read page from " + url);
            return contents;
      }
      catch (IOException e)
      {
         throw new UncheckedIOException(e);
      }
   }, executor);
  }

  public List<URL> getImageURLs(String webpage) // not time-consuming
  {
     try
     {
        var result = new ArrayList<URL>();
        Matcher matcher = IMG_PATTERN.matcher(webpage);
        while (matcher.find())
        {
           var url = new URL(urlToProcess, matcher.group(1));
           result.add(url);
        }
```

```
      System.out.println("Found URLs: " + result);
      return result;
   }
   catch (IOException e)
   {
      throw new UncheckedIOException(e);
   }
}

public CompletableFuture<List<BufferedImage>> getImages(List<URL> urls)
{
   return CompletableFuture.supplyAsync(() ->
      {
         try
         {
            var result = new ArrayList<BufferedImage>();
            for (URL url : urls)
            {
               result.add(ImageIO.read(url));
               System.out.println("Loaded " + url);
            }
            return result;
         }
         catch (IOException e)
         {
            throw new UncheckedIOException(e);
         }
      }, executor);
}

public void saveImages(List<BufferedImage> images)
{
   System.out.println("Saving " + images.size() + " images");
   try
   {
      for (int i = 0; i < images.size(); i++)
      {
         String filename = "/tmp/image" + (i + 1) + ".png";
         ImageIO.write(images.get(i), "PNG", new
```

```
File(filename));
         }
      }
      catch (IOException e)
      {
         throw new UncheckedIOException(e);
      }
      executor.shutdown();
   }

   public void run(URL url)
         throws IOException, InterruptedException
   {
      urlToProcess = url;
      CompletableFuture.completedFuture(url)
         .thenComposeAsync(this::readPage, executor)
         .thenApply(this::getImageURLs)
         .thenCompose(this::getImages)
         .thenAccept(this::saveImages);

      /*
      // or use the HTTP client:

      HttpClient client = HttpClient.newBuilder().build();
      HttpRequest request =
HttpRequest.newBuilder(urlToProcess.toURI()).GET()
         .build();
      client.sendAsync(request, BodyProcessors.ofString())
         .thenApply(HttpResponse::body)
         .thenApply(this::getImageURLs)
         .thenCompose(this::getImages)
         .thenAccept(this::saveImages);
      */
   }

   public static void main(String[] args)
         throws IOException, InterruptedException
   {
   new CompletableFutureDemo().run(new
URL("http://horstmann.com/index.html"));
```

```
  }
}
```

12.7.3 Long-Running Tasks in User Interface Callbacks

One of the reasons to use threads is to make your programs more responsive. This is particularly important in an application with a user interface. When your program needs to do something time-consuming, you cannot do the work in the user-interface thread, or the user interface will be frozen. Instead, fire up another worker thread.

For example, if you want to read a file when the user clicks a button, don’t do this:

```
var open = new JButton("Open");
open.addActionListener(event ->
   { // BAD--long-running action is executed on UI thread
      var in = new Scanner(file);
      while (in.hasNextLine())
      {
         String line = in.nextLine();
         . . .
      }
   });
```

Instead, do the work in a separate thread.

```
open.addActionListener(event ->
   { // GOOD--long-running action in separate thread
      Runnable task = () ->
         {
            var in = new Scanner(file);
            while (in.hasNextLine())
            {
               String line = in.nextLine();
               . . .
            }
```

```
        };
      executor.execute(task);
    });
```

However, you cannot directly update the user interface from the worker thread that executes the long-running task. User interfaces such as Swing, JavaFX, or Android are not thread-safe. You cannot manipulate user interface elements from multiple threads, or they risk becoming corrupted. In fact, JavaFX and Android check for this, and throw an exception if you try to access the user interface from a thread other than the UI thread.

Therefore, you need to schedule any UI updates to happen on the UI thread. Each user interface library provides some mechanism to schedule a `Runnable` for execution on the UI thread. For example, in Swing, you call

```
EventQueue.invokeLater(() -> label.setText(percentage + "%
complete"));
```

It is tedious to implement user feedback in a worker thread, so each user interface library provides some kind of helper class for managing the details, such as `SwingWorker` in Swing, `Task` in JavaFX, and `AsyncTask` in Android. You specify actions for the long-running task (which is run on a separate thread), as well as progress updates and the final disposition (which are run on the UI thread).

The program in Listing 12.11 has commands for loading a text file and for canceling the file loading process. You should try the program with a long file, such as the full text of *The Count of Monte Cristo*, supplied in the `gutenberg` directory of the book's companion code. The file is loaded in a separate thread. While the file is being read, the Open menu item is disabled and the Cancel item is enabled (see Figure 12.6). After each line is read, a line counter in the status bar is updated. After the reading process is complete, the Open menu item is reenabled, the Cancel item is disabled, and the status line text is set to Done.

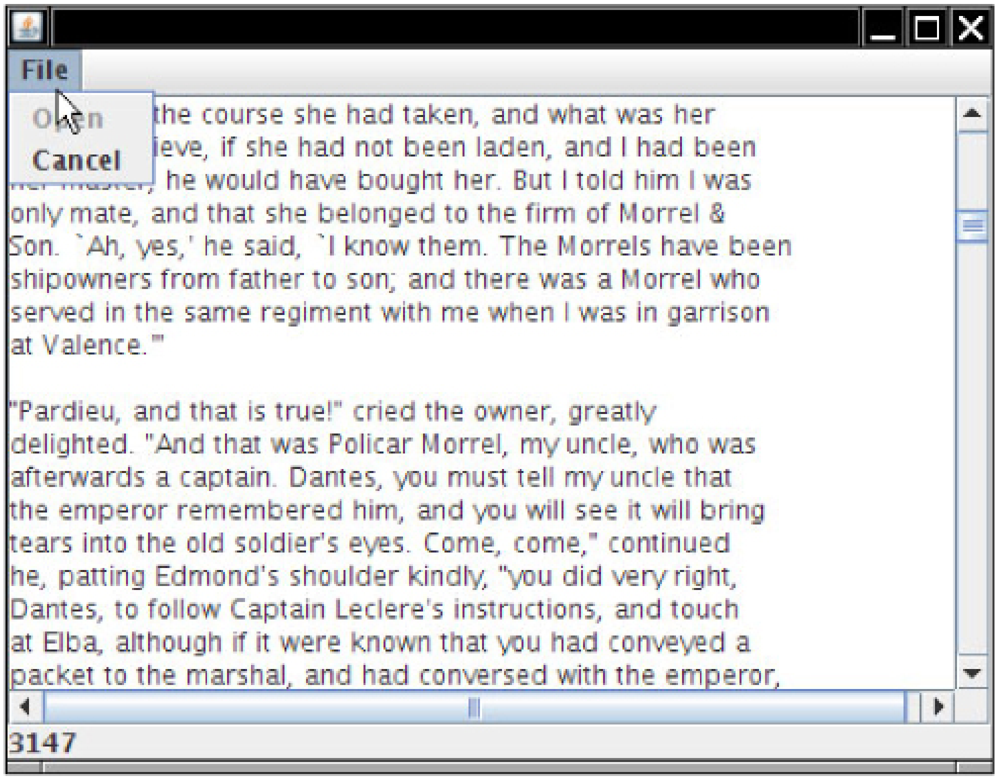


Figure 12.6 Loading a file in a separate thread

This example shows the typical UI activities of a background task:

- After each work unit, update the UI to show progress.
- After the work is finished, make a final change to the UI.

The `SwingWorker` class makes it easy to implement such a task. Override the `doInBackground` method to do the time-consuming work and occasionally call `publish` to communicate work progress. This method is executed in a worker thread. The `publish` method causes a `process` method to execute in the event dispatch thread to deal with the progress data. When the work is complete, the `done` method is called in the event dispatch thread so that you can finish updating the UI.

Whenever you want to do some work in the worker thread, construct a new worker. (Each worker object is meant to be used only once.) Then call the `execute` method. You will typically call `execute` on the event dispatch thread, but that is not a requirement.

It is assumed that a worker produces a result of some kind; therefore, `SwingWorker<T, V>` implements `Future<T>`. This result can be obtained by the `get` method of the `Future` interface. Since the `get` method blocks until the result is available, you don't want to call it immediately after calling `execute`. It is a good idea to call it only when you know that the work has been completed. Typically, you call `get` from the `done` method. (There is no requirement to call `get`. Sometimes, processing the progress data is all you need.)

Both the intermediate progress data and the final result can have arbitrary types. The `SwingWorker` class has these types as type parameters. A `SwingWorker<T, V>` produces a result of type `T` and progress data of type `V`.

To cancel the work in progress, use the `cancel` method of the `Future` interface. When the work is canceled, the `get` method throws a `CancellationException`.

As already mentioned, the worker thread's call to `publish` will cause calls to `process` on the event dispatch thread. For efficiency, the results of several calls to `publish` may be batched up in a single call to `process`. The `process` method receives a `List<V>` containing all intermediate results.

Let us put this mechanism to work for reading in a text file. As it turns out, a `JTextArea` is quite slow. Appending lines from a long text file (such as all lines in *The Count of Monte Cristo*) takes considerable time.

To show the user that progress is being made, we want to display the number of lines read in a status line. Thus, the progress data consist of the current line number and the current line of text. We package these into a trivial inner class:

```
private class ProgressData
{
   public int number;
   public String line;
}
```

The final result is the text that has been read into a `StringBuilder`. Thus, we need a `SwingWorker<StringBuilder, ProgressData>`.

In the `doInBackground` method, we read a file, a line at a time. After each line, we call `publish` to publish the line number and the text of the current line.

```
@Override public StringBuilder doInBackground() throws
IOException, InterruptedException
{
   int lineNumber = 0;
   var in = new Scanner(new FileInputStream(file),
StandardCharsets.UTF_8);
   while (in.hasNextLine())
   {
      String line = in.nextLine();
      lineNumber++;
      text.append(line).append("\n");
      var data = new ProgressData();
      data.number = lineNumber;
      data.line = line;
      publish(data);
      Thread.sleep(1); // to test cancellation; no need to do
this in your programs
   }
   return text;
}
```

We also sleep for a millisecond after every line so that you can test cancellation without getting stressed out, but you wouldn't want to slow down your own programs by sleeping. If you comment out this line, you will find that *The Count of Monte Cristo* loads quite quickly, with only a few batched user interface updates.

In the `process` method, we ignore all line numbers but the last one, and we concatenate all lines for a single update of the text area.

```
@Override public void process(List<ProgressData> data)
{
   if (isCancelled()) return;
   var b = new StringBuilder();
   statusLine.setText("" + data.get(data.size() - 1).number);
   for (ProgressData d : data) b.append(d.line).append("\n");
   textArea.append(b.toString());
}
```

In the `done` method, the text area is updated with the complete text, and the Cancel menu item is disabled.

Note how the worker is started in the event listener for the Open menu item.

This simple technique allows you to execute time-consuming tasks while keeping the user interface responsive.

Listing 12.11 `swingWorker/SwingWorkerTest.java`

```
package swingWorker;

import java.awt.*;
import java.io.*;
import java.nio.charset.*;
import java.util.*;
import java.util.List;
import java.util.concurrent.*;

import javax.swing.*;

/**
 * This program demonstrates a worker thread that runs a potentially time-consuming task.
 * @version 1.12 2018-03-17
 * @author Cay Horstmann
 */
public class SwingWorkerTest
{
```

```
   public static void main(String[] args) throws Exception
   {
      EventQueue.invokeLater(() ->
         {
            var frame = new SwingWorkerFrame();
            frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
            frame.setVisible(true);
         });
   }
}

/**
 * This frame has a text area to show the contents of a text file, a menu to open a file and
 * cancel the opening process, and a status line to show the file loading progress.
 */
class SwingWorkerFrame extends JFrame
{
   private JFileChooser chooser;
   private JTextArea textArea;
   private JLabel statusLine;
   private JMenuItem openItem;
   private JMenuItem cancelItem;
   private SwingWorker<StringBuilder, ProgressData> textReader;
   public static final int TEXT_ROWS = 20;
   public static final int TEXT_COLUMNS = 60;

   public SwingWorkerFrame()
   {
      chooser = new JFileChooser();
      chooser.setCurrentDirectory(new File("."));

      textArea = new JTextArea(TEXT_ROWS, TEXT_COLUMNS);
      add(new JScrollPane(textArea));

      statusLine = new JLabel(" ");
      add(statusLine, BorderLayout.SOUTH);
```

```java

         var menuBar = new JMenuBar();
         setJMenuBar(menuBar);

         var menu = new JMenu("File");
         menuBar.add(menu);

         openItem = new JMenuItem("Open");
         menu.add(openItem);
         openItem.addActionListener(event -> {
            // show file chooser dialog
            int result = chooser.showOpenDialog(null);

            // if file selected, set it as icon of the label
            if (result == JFileChooser.APPROVE_OPTION)
            {
               textArea.setText("");
               openItem.setEnabled(false);
               textReader = new TextReader(chooser.getSelectedFile());
               textReader.execute();
               cancelItem.setEnabled(true);
            }
         });

         cancelItem = new JMenuItem("Cancel");
         menu.add(cancelItem);
         cancelItem.setEnabled(false);
         cancelItem.addActionListener(event -> textReader.cancel(true));
         pack();
      }

   private class ProgressData
   {
      public int number;
      public String line;
   }

```

```java
private class TextReader extends SwingWorker<StringBuilder, ProgressData>
{
   private File file;
   private StringBuilder text = new StringBuilder();

   public TextReader(File file)
   {
      this.file = file;
    }

    // the following method executes in the worker thread; it doesn't touch Swing components

    public StringBuilder doInBackground() throws IOException, InterruptedException
    {
       int lineNumber = 0;
       try (var in = new Scanner(new FileInputStream(file), StandardCharsets.UTF_8))
       {
          while (in.hasNextLine())
          {
             String line = in.nextLine();
             lineNumber++;
             text.append(line).append("\n");
             var data = new ProgressData();
             data.number = lineNumber;
             data.line = line;
             publish(data);
             Thread.sleep(1); // to test cancellation; no need to do this in your programs
          }
       }
       return text;
    }

    // the following methods execute in the event dispatch thread
```

```
      public void process(List<ProgressData> data)
      {
         if (isCancelled()) return;
         var builder = new StringBuilder();
         statusLine.setText("" + data.get(data.size() - 1).number);
         for (ProgressData d : data) builder.append(d.line).append("\n");
         textArea.append(builder.toString());
      }

      public void done()
      {
         try
         {
            StringBuilder result = get();
            textArea.setText(result.toString());
            statusLine.setText("Done");
         }
         catch (InterruptedException ex)
         {
         }
         catch (CancellationException ex)
         {
            textArea.setText("");
            statusLine.setText("Cancelled");
         }
         catch (ExecutionException ex)
         {
            statusLine.setText("" + ex.getCause());
         }

         cancelItem.setEnabled(false);
         openItem.setEnabled(true);
      }
   };
}
```

javax.swing.SwingWorker<T, V> 6

- abstract T doInBackground()

  is the method to override to carry out the background task and to return the result of the work.

- void process(List<V> data)

  is the method to override to process intermediate progress data in the event dispatch thread.

- void publish(V... data)

  forwards intermediate progress data to the event dispatch thread. Call this method from doInBackground.

- void execute()

  schedules this worker for execution on a worker thread.

- SwingWorker.StateValue getState()

  gets the state of this worker, one of PENDING, STARTED, or DONE.

12.8 Processes

Up to now, you have seen how to execute Java code in separate threads within the same program. Sometimes, you need to execute another program. For this, use the ProcessBuilder and Process classes. The Process class executes a command in a separate operating system process and lets you interact with its standard input, output, and error streams. The ProcessBuilder class lets you configure a Process object.

NOTE:

The ProcessBuilder class is a more flexible replacement for the Runtime.exec calls.

12.8.1 Building a Process

Start by specifying the command that you want to execute. You can supply a `List<String>` or simply the strings that make up the command.

```
var builder = new ProcessBuilder("gcc", "myapp.c");
```

CAUTION:

The first string must be an executable command, not a shell builtin. For example, to run the `dir` command in Windows, you need to build a process with strings `"cmd.exe"`, `"/C"`, and `"dir"`.

Each process has a *working directory*, which is used to resolve relative directory names. By default, a process has the same working directory as the virtual machine, which is typically the directory from which you launched the `java`

program. You can change it with the `directory` method:

```
builder = builder.directory(path.toFile());
```

NOTE:

Each of the methods for configuring a `ProcessBuilder` returns itself, so that you can chain commands. Ultimately, you will call

```
Process p = new ProcessBuilder(command).directory(file)....
start();
```

Next, you will want to specify what should happen to the standard input, output, and error streams of the process. By default, each of them is a pipe that you can access with

```
OutputStream processIn = p.getOutputStream();
InputStream processOut = p.getInputStream();
InputStream processErr = p.getErrorStream();
```

Note that the input stream of the process is an output stream in the JVM! You write to that stream, and whatever you write becomes the input of the process. Conversely, you read what the process writes to the output and error streams. For you, they are input streams.

You can specify that the input, output, and error streams of the new process should be the same as the JVM. If the user runs the JVM in a console, any user input is forwarded to the process, and the process output shows up in the console. Call

```
builder.inheritIO()
```

to make this setting for all three streams. If you only want to inherit some of the streams, pass the value

```
ProcessBuilder.Redirect.INHERIT
```

to the `redirectInput`, `redirectOutput`, or `redirectError` methods. For example,

```
builder.redirectOutput(ProcessBuilder.Redirect.INHERIT);
```

You can redirect the process streams to files by supplying `File` objects:

```
builder.redirectInput(inputFile)
   .redirectOutput(outputFile)
   .redirectError(errorFile)
```

The files for output and error are created or truncated when the process starts. To append to existing files, use

```
builder.redirectOutput(ProcessBuilder.Redirect.appendTo(outputF
ile));
```

It is often useful to merge the output and error streams, so you see the outputs and error messages in the sequence in which the process generates them. Call

```
builder.redirectErrorStream(true)
```

to activate the merging. If you do that, you can no longer call `redirectError` on the `ProcessBuilder` or `getErrorStream` on the `Process`.

You may also want to modify the environment variables of the process. Here, the builder chain syntax breaks down. You need to get the builder's environment (which is initialized by the environment variables of the process running the JVM), then put or remove entries.

```
Map<String, String> env = builder.environment();
env.put("LANG", "fr_FR");
env.remove("JAVA_HOME");
Process p = builder.start();
```

If you want to pipe the output of one process into the input of another (as with the `|` operator in a shell), Java 9 offers a `startPipeline` method. Pass a list of process builders and read the result from the last process. Here is an example, enumerating the unique extensions in a directory tree:

```
List<Process> processes = ProcessBuilder.startPipeline(List.of(
   new ProcessBuilder("find", "/opt/jdk-17"),
   new ProcessBuilder("grep", "-o", "\\.[^./]*$"),
   new ProcessBuilder("sort"),
   new ProcessBuilder("uniq")
));
```

```
Process last = processes.get(processes.size() - 1);
var result = new String(last.getInputStream().readAllBytes());
```

Of course, this particular task would be more efficiently solved by making the directory walk in Java instead of running four processes. Chapter 2 of Volume II will show you how to do that.

12.8.2 Running a Process

After you have configured the builder, invoke its `start` method to start the process. If you configured the input, output, and error streams as pipes, you can now write to the input stream and read the output and error streams. For example,

```
Process process = new ProcessBuilder("/bin/ls", "-l")
   .directory(Path.of("/tmp").toFile())
   .start();
try (var in = new Scanner(process.getInputStream()))
{
   while (in.hasNextLine())
      System.out.println(in.nextLine());
}
```

CAUTION:

There is limited buffer space for the process streams. You should not flood the input, and you should read the output promptly. If there is a lot of input and output, you may need to produce and consume it in separate threads.

To wait for the process to finish, call

```
int result = process.waitFor();
```

or, if you don't want to wait indefinitely,

```
long delay = . . .;
if (process.waitFor(delay, TimeUnit.SECONDS))
{
   int result = process.exitValue();   . . .
}
else
{
   process.destroyForcibly();
}
```

The first call to `waitFor` returns the exit value of the process (by convention, `0` for success or a nonzero error code). The second call returns `true` if the process didn't time out. Then you need to retrieve the exit value by calling the `exitValue` method.

Instead of waiting for the process to finish, you can just leave it running and occasionally call `isAlive` to see whether it is still alive. To kill the process, call `destroy` or `destroyForcibly`. The difference between these calls is platform-dependent. On UNIX, the former terminates the process with `SIGTERM`, the latter with `SIGKILL`. (The `supportsNormalTermination` method returns `true` if the `destroy` method can terminate the process normally.)

Finally, you can receive an asynchronous notification when the process has completed. The call `process.onExit()` yields a `CompletableFuture<Process>` that you can use to schedule any action.

```
process.onExit().thenAccept(
   p -> System.out.println("Exit value: " + p.exitValue()));
```

12.8.3 Process Handles

To get more information about a process that your program started, or any other process that is currently running on your machine, use the `ProcessHandle` interface. You can obtain a `ProcessHandle` in four ways:

1. Given a `Process` object `p`, `p.toHandle()` yields its `ProcessHandle`.

2. Given a long operating system process ID, ProcessHandle.of(id) yields the handle of that process.
3. ProcessHandle.current() is the handle of the process that runs this Java virtual machine.
4. ProcessHandle.allProcesses() yields a Stream<ProcessHandle> of all operating system processes that are visible to the current process.

Given a process handle, you can get its process ID, its parent process, its children, and descendants:

```
long pid = handle.pid();
Optional<ProcessHandle> parent = handle.parent();
Stream<ProcessHandle> children = handle.children();
Stream<ProcessHandle> descendants = handle.descendants();
```

NOTE:

The Stream<ProcessHandle> instances that are returned by the allProcesses, children, and descendants methods are just snapshots in time. Any of the processes in the stream might be terminated by the time you get around to seeing them, and other processes may have started that are not in the stream.

The info method yields a ProcessHandle.Info object with methods for obtaining information about the process.

```
Optional<String[]> arguments()
Optional<String> command()
Optional<String> commandLine()
Optional<String> startInstant()
Optional<String> totalCpuDuration()
Optional<String> user()
```

All of these methods return Optional values since it is possible that a particular operating system may not be able to report the information.

For monitoring or forcing process termination, the ProcessHandle interface has the same isAlive, supportsNormalTermination, destroy, destroyForcibly, and onExit methods as the Process class. However, there is no equivalent to the waitFor method.

java.lang.ProcessBuilder 5

- ProcessBuilder(String... command)
- ProcessBuilder(List<String> command)

  constructs a process builder with the given command and arguments.

- ProcessBuilder directory(File directory)

  sets the working directory for the process.

- ProcessBuilder inheritIO() 9

  makes the process use the standard input, output, and error of the virtual machine.

- ProcessBuilder redirectErrorStream(boolean redirectErrorStream)

  if redirectErrorStream is true, the standard error of the process is merged into the standard output.

- ProcessBuilder redirectInput(File file) 7
- ProcessBuilder redirectOutput(File file) 7
- ProcessBuilder redirectError(File file) 7

  redirects the standard input, output, or error of the process to the given file.

- ProcessBuilder redirectInput(ProcessBuilder.Redirect source) 7
- ProcessBuilder redirectOutput(ProcessBuilder.Redirect destination) 7
- ProcessBuilder redirectError(ProcessBuilder.Redirect destination) 7

redirects the standard input, output, or error of the process, where `destination` is one of:

- `Redirect.PIPE`—the default behavior, access via the `Process` object
- `Redirect.INHERIT`—the stream from the virtual machine
- `Redirect.DISCARD`
- `Redirect.from(file)`
- `Redirect.to(file)`
- `Redirect.appendTo(file)`

- `Map<String,String> environment()`

  yields a mutable map for setting environment variables for the process.

- `Process start()`

  starts the process and yields its `Process` object.

- `static List<Process> startPipeline(List<ProcessBuilder> builders)` 9

  starts a pipeline of processes, connecting the standard output of each process to the standard input of the next one.

`java.lang.Process` 1.0

- `abstract OutputStream getOutputStream()`

  gets a stream for writing to the input stream of the process.

- `abstract InputStream getInputStream()`
- `abstract InputStream getErrorStream()`

  gets an input stream for reading the output or error stream of the process.

- `abstract int waitFor()`

waits for the process to finish and yields the exit value.

- `boolean waitFor(long timeout, TimeUnit unit)` 8

  waits for the process to finish, but no longer than the given timeout. Returns `true` if the process exited.

- `abstract int exitValue()`

  returns the exit value of the process. By convention, a non-zero exit value indicates an error.

- `boolean isAlive()` 8

  checks whether this process is still alive.

- `abstract void destroy()`
- `Process destroyForcibly()` 8

  terminates this process, either normally or forcefully.

- `boolean supportsNormalTermination()` 9

  checks whether this process can be terminated normally or must be destroyed forcefully.

- `ProcessHandle toHandle()` 9

  yields the `ProcessHandle` describing this process.

- `CompletableFuture<Process> onExit()` 9

  yields a `CompletableFuture` that is executed when this process exits.

java.lang.ProcessHandle 9

- `static Optional<ProcessHandle> of(long pid)`
- `static Stream<ProcessHandle> allProcesses()`
- `static ProcessHandle current()`

  yields the process handle(s) of the process with the given PID, of all processes, or the process of the virtual machine.

- `Stream<ProcessHandle> children()`
- `Stream<ProcessHandle> descendants()`

  yields the process handles of the children or descendants of this process.

- `long pid()`

  yields the PID of this process.

- `ProcessHandle.Info info()`

  yields detail information about this process.

`java.lang.ProcessHandle.Info` 9

- `Optional<String[]> arguments()`
- `Optional<String> command()`
- `Optional<String> commandLine()`
- `Optional<Instant> startInstant()`
- `Optional<Instant> totalCpuDuration()`
- `Optional<String> user()`

  yield the given detail information if available.

You have now reached the end of Volume I of *Core Java*. This volume covered the fundamentals of the Java programming language and the parts of the standard library that you need for most programming projects. I hope that you enjoyed your tour through the Java fundamentals and that you found useful information along the way. For advanced topics, such as the Java platform module system, networking, advanced user interface and graphics programming, security, and internationalization, please turn to Volume II.

Appendix A

This appendix lists all keywords and keyword-like words of the Java language. A "restricted keyword" is a keyword only in a module declaration, and otherwise an identfiier. A "restricted identifier" is an identifier unless it is used in certain positions. For example, `var` is always an identifier unless it is used where a type is expected. The symbols `null`, `false`, and `true` are not keywords but literals.

Table A.1 Java Keywords

Keyword	Meaning	Type	See Chapter
`abstract`	An abstract class or method	Keyword	5
`assert`	Used to locate internal program error	Keyword	7
`boolean`	The Boolean type	Keyword	3
`break`	Breaks out of a switch or loop	Keyword	3
`byte`	The 8-bit integer type	Keyword	3
`case`	A case of a `switch`	Keyword	3
`catch`	The clause of a `try` block catching an exception	Keyword	7
`char`	The Unicode character type	Keyword	3
`class`	Defines a class type	Keyword	4

const	Not used	Keyword	
continue	Continues at the end of a loop	Keyword	3
default	The default clause of a switch, or a default method in an interface	Keyword	3, 6
do	The top of a do/while loop	Keyword	3
double	The double-precision floating-number type	Keyword	3
else	The else clause of an if statement	Keyword	3
enum	An enumerated type	Keyword	3
exports	Exports a package of a module	Restricted keyword	9 (Vol. II)
extends	Defines the parent class of a class, or an upper bound of a wildcard	Keyword	4
false	One of the two Boolean values	Literal	3
final	A constant, or a class or method that cannot be overridden	Keyword	5
finally	The part of a try block that is always executed	Keyword	7
float	The single-precision floating-point type	Keyword	3
for	A loop type	Keyword	3
goto	Not used	Keyword	
if	A conditional statement	Keyword	3
implements	Defines the interface(s) that a class implements	Keyword	6
import	Imports a package	Keyword	4
instanceof	Tests if an object is an instance of a class	Keyword	5
int	The 32-bit integer type	Keyword	3

`interface`	An abstract type with methods that a class can implement	Keyword	6
`long`	The 64-bit long integer type	Keyword	3
`native`	A method implemented by the host system	Keyword	12 (Vol. II)
`new`	Allocates a new object or array	Keyword	3
`non-sealed`	A subtype of a sealed type of which arbitrary subtypes may be formed	Keyword	5
`null`	A null reference	Literal	3
`module`	Declares a module	Restricted keyword	9 (Vol. II)
`open`	Modifies a `module` declaration	Restricted keyword	9 (Vol. II)
`opens`	Opens a package of a module	Restricted keyword	9 (Vol. II)
`package`	A package of classes	Keyword	4
`permits`	Introduces a list of permitted subtypes of a sealed type	Restricted identifier	3
`private`	A feature that is accessible only by methods of this class	Keyword	4
`protected`	A feature that is accessible only by methods of this class, its children, and other classes in the same package	Keyword	5
`provides`	Indicates that a module uses a service	Restricted keyword	9 (Vol. II)
`public`	A feature that is accessible by methods of all classes	Keyword	4
`record`	Declares a class with a given set of final instance variables	Restricted identifier	4

`return`	Returns from a method	Keyword	3
`sealed`	A type with a controlled set of direct subtypes	Restricted identifier	5
`short`	The 16-bit integer type	Keyword	3
`static`	A feature that is unique to a class or interface, not to instances of a class	Keyword	3, 6
`strictfp`	Use strict rules for floating-point computations (obsolete)	Keyword	2
`super`	The superclass object or constructor, or a lower bound in a wildcard	Keyword	5
`switch`	A selection statement or expression	Keyword	3
`synchronized`	A method or code block that is atomic to a thread	Keyword	12
`this`	The implicit argument of a method, or a constructor of this class	Keyword	4
`throw`	Throws an exception	Keyword	7
`throws`	The exceptions that a method can throw	Keyword	7
`to`	A part of an `exports` or `opens` declaration	Restricted keyword	9 (Vol. II)
`transient`	Marks data that should not be persistent	Keyword	2 (Vol. II)
`transitive`	Modifies a `requires` declaration	Restricted keyword	9 (Vol. II)
`true`	One of the two Boolean values	Literal	3
`try`	A block of code that traps exceptions	Keyword	7
`uses`	Indicates that a module uses a service	Restricted keyword	9 (Vol. II)

`var`	Declares a variable whose type is inferred	Restricted identifier	3
`void`	Denotes a method that returns no value	Keyword	3
`volatile`	Ensures that a field is coherently accessed by multiple threads	Keyword	12
`while`	A loop	Keyword	3
`with`	Defines the service class in a `provides` statement	Restricted keyword	9 (Vol. II)
`yield`	Yields the value of a `switch` expression	Restricted identifier	3
`_` (underscore)	Currently unused	Keyword	