



Chapter 11

Exception Handling: A Deeper Look

Java™ How to Program, 10/e



OBJECTIVES

In this chapter you'll:

- Learn what exceptions are and how they're handled.
- Learn when to use exception handling.
- Use `try` blocks to delimit code in which exceptions might occur.
- Use `throw` to indicate a problem.
- Use `catch` blocks to specify exception handlers.
- Use the `finally` block to release resources.
- Understand the exception class hierarchy.
- Create user-defined exceptions.



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- 11.1 Introduction
 - 11.2 Example: Divide by Zero without Exception Handling
 - 11.3 Example: Handling **ArithmeticExceptions** and **InputMismatchExceptions**
 - 11.4 When to Use Exception Handling
 - 11.5 Java Exception Hierarchy
 - 11.6 **finally** Block
 - 11.7 Stack Unwinding and Obtaining Information from an Exception Object
 - 11.8 Chained Exceptions
 - 11.9 Declaring New Exception Types
 - 11.10 Preconditions and Postconditions
 - 11.11 Assertions
 - 11.12 **try-with-Resources**: Automatic Resource Deallocation
 - 11.13 Wrap-Up
-



11.1 Introduction

- ▶ **Exception handling**
- ▶ **Exception**—an indication of a problem that occurs during a program’s execution.
 - The name “exception” implies that the problem occurs infrequently.
- ▶ With exception handling, a program can continue executing (rather than terminating) after dealing with a problem.
 - Mission-critical or business-critical computing.
 - **Robust** and **fault-tolerant programs** (i.e., programs that can deal with problems as they arise and continue executing).



11.1 Introduction (Cont.)

- ▶ `ArrayIndexOutOfBoundsException` occurs when an attempt is made to access an element past either end of an array.
- ▶ `ClassCastException` occurs when an attempt is made to cast an object that does not have an *is-a* relationship with the type specified in the cast operator.
- ▶ A `NullPointerException` occurs when a `null` reference is used where an object is expected.
- ▶ Only classes that extend `Throwable` (package `java.lang`) directly or indirectly can be used with exception handling.



Chapter	Sample of exceptions used
Chapter 7	<code>ArrayIndexOutOfBoundsException</code>
Chapters 8–10	<code>IllegalArgumentException</code>
Chapter 11	<code>ArithmeticException</code> , <code>InputMismatchException</code>
Chapter 15	<code>SecurityException</code> , <code>FileNotFoundException</code> , <code>IOException</code> , <code>ClassNotFoundException</code> , <code>IllegalStateException</code> , <code>FormatterClosedException</code> , <code>NoSuchElementException</code>
Chapter 16	<code>ClassCastException</code> , <code>UnsupportedOperationException</code> , <code>NullPointerException</code> , custom exception types
Chapter 20	<code>ClassCastException</code> , custom exception types
Chapter 21	<code>IllegalArgumentException</code> , custom exception types
Chapter 23	<code>InterruptedException</code> , <code>IllegalMonitorStateException</code> , <code>ExecutionException</code> , <code>CancellationException</code>
Chapter 28	<code>MalformedURLException</code> , <code>EOFException</code> , <code>SocketException</code> , <code>InterruptedException</code> , <code>UnknownHostException</code>
Chapter 24	<code>SQLException</code> , <code>IllegalStateException</code> , <code>PatternSyntaxException</code>
Chapter 31	<code>SQLException</code>

Fig. 11.1 | Various exception types that you'll see throughout this book



11.2 Example: Divide by Zero without Exception Handling

- ▶ Exceptions are **thrown** (i.e., the exception occurs) by a method detects a problem and is unable to handle it.
- ▶ **Stack trace**—information displayed when an exception occurs and is not handled.
- ▶ Information includes:
 - The name of the exception in a descriptive message that indicates the problem that occurred
 - The method-call stack (i.e., the call chain) at the time it occurred. Represents the path of execution that led to the exception method by method.
- ▶ This information helps you debug the program.



11.2 Example: Divide by Zero without Exception Handling (Cont.)

- ▶ Java does not allow division by zero in integer arithmetic.
 - Throws an `ArithmeticException`.
 - Can arise from a several problems, so an error message (e.g., “/ by zero”) provides more specific information.
- ▶ Java *does* allow division by zero with floating-point values.
 - Such a calculation results in the value positive or negative infinity
 - Floating-point value that displays as `Infinity` or `-Infinity`.
 - If 0.0 is divided by 0.0, the result is NaN (not a number), which is represented as a floating-point value that displays as `NaN`.



```
1 // Fig. 11.2: DivideByZeroNoExceptionHandling.java
2 // Integer division without exception handling.
3 import java.util.Scanner;
4
5 public class DivideByZeroNoExceptionHandling
6 {
7     // demonstrates throwing an exception when a divide-by-zero occurs
8     public static int quotient(int numerator, int denominator)
9     {
10         return numerator / denominator; // possible division by zero
11     }
12
13     public static void main(String[] args)
14     {
15         Scanner scanner = new Scanner(System.in);
```

Fig. 11.2 | Integer division without exception handling. (Part 1 of 3.)



```
16
17     System.out.print("Please enter an integer numerator: ");
18     int numerator = scanner.nextInt();
19     System.out.print("Please enter an integer denominator: ");
20     int denominator = scanner.nextInt();
21
22     int result = quotient(numerator, denominator);
23     System.out.printf(
24         "%nResult: %d / %d = %d%n", numerator, denominator, result);
25 }
26 } // end class DivideByZeroNoExceptionHandling
```

```
Please enter an integer numerator: 100
Please enter an integer denominator: 7

Result: 100 / 7 = 14
```

Fig. 11.2 | Integer division without exception handling. (Part 2 of 3.)



```
Please enter an integer numerator: 100
Please enter an integer denominator: 0
Exception in thread "main" java.lang.ArithmeticException: / by zero
    at DivideByZeroNoExceptionHandling.quotient(
        DivideByZeroNoExceptionHandling.java:10)
    at DivideByZeroNoExceptionHandling.main(
        DivideByZeroNoExceptionHandling.java:22)
```

```
Please enter an integer numerator: 100
Please enter an integer denominator: hello
Exception in thread "main" java.util.InputMismatchException
    at java.util.Scanner.throwFor(Unknown Source)
    at java.util.Scanner.next(Unknown Source)
    at java.util.Scanner.nextInt(Unknown Source)
    at java.util.Scanner.nextInt(Unknown Source)
    at DivideByZeroNoExceptionHandling.main(
        DivideByZeroNoExceptionHandling.java:20)
```

Fig. 11.2 | Integer division without exception handling. (Part 3 of 3.)



11.2 Example: Divide by Zero without Exception Handling (Cont.)

- ▶ Last line of the stack trace started the call chain.
- ▶ Each line contains the class name and method followed by the filename and line number.
- ▶ The top row of the call chain indicates the **throw point**—the initial point at which the exception occurred.



11.2 Example: Divide by Zero without Exception Handling (Cont.)

- ▶ Prior examples that input numeric values assumed that the user would input a proper integer value.
- ▶ Users sometimes make mistakes and input noninteger values.
- ▶ An `InputMismatchException` occurs when `Scanner` method `nextInt` receives a `String` that does not represent a valid integer.
- ▶ If a stack trace contains “Unknown Source” for a particular method, the debugging symbols for that method’s class were not available to the JVM—this is typically the case for the classes of the Java API.



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions

- ▶ The application in Fig. 11.2 uses exception handling to process any ArithmeticExceptions and InputMismatchExceptions that arise.
- ▶ If the user makes a mistake, the program catches and handles (i.e., deals with) the exception—in this case, allowing the user to try to enter the input.



```
1 // Fig. 11.3: DivideByZeroWithExceptionHandling.java
2 // Handling ArithmeticExceptions and InputMismatchExceptions.
3 import java.util.InputMismatchException;
4 import java.util.Scanner;
5
6 public class DivideByZeroWithExceptionHandling
7 {
8     // demonstrates throwing an exception when a divide-by-zero occurs
9     public static int quotient(int numerator, int denominator)
10        throws ArithmeticException
11    {
12        return numerator / denominator; // possible division by zero
13    }
14
15    public static void main(String[] args)
16    {
17        Scanner scanner = new Scanner(System.in);
18        boolean continueLoop = true; // determines if more input is needed
19    }
```

Fig. 11.3 | Handling ArithmeticExceptions and InputMismatchExceptions.
(Part I of 4.)



```
20 do
21 {
22     try // read two numbers and calculate quotient
23     {
24         System.out.print("Please enter an integer numerator: ");
25         int numerator = scanner.nextInt();
26         System.out.print("Please enter an integer denominator: ");
27         int denominator = scanner.nextInt();
28
29         int result = quotient(numerator, denominator);
30         System.out.printf("%nResult: %d / %d = %d%n", numerator,
31             denominator, result);
32         continueLoop = false; // input successful; end looping
33     }
34     catch (InputMismatchException inputMismatchException)
35     {
36         System.err.printf("%nException: %s%n",
37             inputMismatchException);
38         scanner.nextLine(); // discard input so user can try again
39         System.out.printf(
40             "You must enter integers. Please try again.%n%n");
41     }
```

Fig. 11.3 | Handling ArithmeticExceptions and InputMismatchExceptions.
(Part 2 of 4.)



```
42     catch (ArithmeticException arithmeticException)
43     {
44         System.err.printf("%nException: %s%n", arithmeticException);
45         System.out.printf(
46             "Zero is an invalid denominator. Please try again.%n%n");
47     }
48 } while (continueLoop);
49 }
50 } // end class DivideByZeroWithExceptionHandling
```

```
Please enter an integer numerator: 100
Please enter an integer denominator: 7

Result: 100 / 7 = 14
```

Fig. 11.3 | Handling ArithmeticExceptions and InputMismatchExceptions.
(Part 3 of 4.)



```
Please enter an integer numerator: 100
Please enter an integer denominator: 0

Exception: java.lang.ArithmeticException: / by zero
Zero is an invalid denominator. Please try again.

Please enter an integer numerator: 100
Please enter an integer denominator: 7

Result: 100 / 7 = 14
```

```
Please enter an integer numerator: 100
Please enter an integer denominator: hello

Exception: java.util.InputMismatchException
You must enter integers. Please try again.

Please enter an integer numerator: 100
Please enter an integer denominator: 7

Result: 100 / 7 = 14
```

Fig. 11.3 | Handling `ArithmeticExceptions` and `InputMismatchExceptions`.
(Part 4 of 4.)



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions (Cont.)

- ▶ **try block** encloses
 - code that might **throw** an exception
 - code that should not execute if an exception occurs.
- ▶ Consists of the keyword **try** followed by a block of code enclosed in curly braces.



Software Engineering Observation 11.1

Exceptions may surface through explicitly mentioned code in a `try` block, through deeply nested method calls initiated by code in a `try` block or from the Java Virtual Machine as it executes Java bytecodes.



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions (Cont.)

- ▶ **catch block** (also called a **catch clause** or **exception handler**) *catches* and *handles* an exception.
 - Begins with the keyword **catch** followed by an exception parameter in parentheses and a block of code enclosed in curly braces.
- ▶ At least one **catch block** or a **finally block** (Section 11.6) *must* immediately follow the **try** block.
- ▶ The **exception parameter** identifies the exception type the handler can process.
 - The parameter's name enables the **catch** block to interact with a caught exception object.



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions (Cont.)

- ▶ When an exception occurs in a `try` block, the `catch` block that executes is the first one whose type matches the type of the exception that occurred.
- ▶ Use the `System.err` (standard error stream) object to output error messages.
 - By default, displays data to the *command prompt*.



Common Programming Error 11.1

It's a syntax error to place code between a `try` block and its corresponding `catch` blocks.



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions (Cont.)

Multi-catch

- ▶ If the bodies of several `catch` blocks are identical, you can use the multi-`catch` feature (introduced in Java SE 7) to catch those exception types in a *single* `catch` handler and perform the same task.
- ▶ The syntax for a *multi-catch* is:
 - `catch (Type1 | Type2 | Type3 e)`
- ▶ Each exception type is separated from the next with a vertical bar (`|`).
- ▶ The preceding line of code indicates that *any* of the types (or their subclasses) can be caught in the exception handler.
- ▶ Any number of `Throwable` types can be specified in a multi-catch.



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions (Cont.)

- ▶ **Uncaught exception**—one for which there are no matching catch blocks.
- ▶ Recall that previous uncaught exceptions caused the application to terminate early.
 - This does not always occur as a result of uncaught exceptions.
- ▶ Java uses a multithreaded model of program execution.
 - Each **thread** is a *concurrent activity*.
 - One program can have many threads.
 - If a program has only *one* thread, an uncaught exception will cause the program to terminate.
 - If a program has multiple threads, an uncaught exception will terminate *only* the thread in which the exception occurred.



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions (Cont.)

- ▶ If an exception occurs in a `try` block, the `try` block terminates immediately and program control transfers to the first matching `catch` block.
- ▶ After the exception is handled, control resumes after the last `catch` block.
- ▶ Known as the **termination model of exception handling**.
 - Some languages use the **resumption model of exception handling**, in which, after an exception is handled, control resumes just after the throw point.



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions (Cont.)

- ▶ If no exceptions are thrown in a `try` block, the `catch` blocks are *skipped* and control continues with the first statement after the `catch` blocks
 - We'll learn about another possibility when we discuss the `finally` block in Section 11.6.
- ▶ The `try` block and its corresponding `catch` and/or `finally` blocks form a **try statement**.



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions (Cont.)

- ▶ When a `try` block terminates, local variables declared in the block go out of scope.
 - The *local variables* of a `try` block are not accessible in the corresponding `catch` blocks.
- ▶ When a `catch` block *terminates*, *local variables* declared within the `catch` block (including the exception parameter) also *go out of scope*.
- ▶ Any remaining `catch` blocks in the `try` statement are *ignored*, and execution resumes at the first line of code after the `try...catch` sequence.
 - A `finally` block, if one is present.



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions (Cont.)

- ▶ **throws clause**—specifies the exceptions a method *might* throw if problems occur.
 - Must appear after the method's parameter list and before the body.
 - Contains a comma-separated list of the exception types.
 - May be thrown by statements in the method's body or by methods called from there.
 - Clients of a method with a **throws** clause are thus informed that the method might throw exceptions.



Error-Prevention Tip 11.1

Read the online API documentation for a method before using it in a program. The documentation specifies the exceptions thrown by the method (if any) and indicates reasons why such exceptions may occur. Next, read the online API documentation for the specified exception classes. The documentation for an exception class typically contains potential reasons that such exceptions occur. Finally, provide for handling those exceptions in your program.



11.3 Example: Handling ArithmeticExceptions and InputMismatchExceptions (Cont.)

- ▶ When a method throws an exception, the method terminates and does not return a value, and its *local variables go out of scope*.
 - If the local variables were references to objects and there were no other references to those objects, the objects would be available for *garbage collection*.



11.4 When to Use Exception Handling

- ▶ Exception handling is designed to process **synchronous errors**, which occur when a statement executes.
- ▶ Common examples in this book:
 - out-of-range array indices
 - arithmetic overflow
 - division by zero
 - invalid method parameters
 - thread interruption



11.4 When to Use Exception Handling (Cont.)

- ▶ Exception handling is not designed to process problems associated with **asynchronous events**
 - disk I/O completions
 - network message arrivals
 - mouse clicks and keystrokes



Software Engineering Observation 11.2

Incorporate your exception-handling and error-recovery strategy into your system from the inception of the design process—including these after a system has been implemented can be difficult.



Software Engineering Observation 11.3

Exception handling provides a single, uniform technique for documenting, detecting and recovering from errors. This helps programmers working on large projects understand each other's error-processing code.



Software Engineering Observation 11.4

There's a great variety of situations that generate exceptions—some exceptions are easier to recover from than others.



11.5 Java Exception Hierarchy

- ▶ Exception classes inherit directly or indirectly from class **Exception**, forming an *inheritance hierarchy*.
 - Can extend this hierarchy with your own exception classes.
- ▶ Figure 11.3 shows a small portion of the inheritance hierarchy for class **Throwable** (a subclass of **Object**), which is the superclass of class **Exception**.
 - Only **Throwable** objects can be used with the exception-handling mechanism.
- ▶ Class **Throwable** has two subclasses: **Exception** and **Error**.



11.5 Java Exception Hierarchy (Cont.)

- ▶ Class **Exception** and its subclasses represent exceptional situations that can occur in a Java program
 - These can be caught and handled by the application.
- ▶ Class **Error** and its subclasses represent abnormal situations that happen in the JVM.
 - **Errors** happen infrequently.
 - These should not be caught by applications.
 - Applications usually cannot recover from **Errors**.

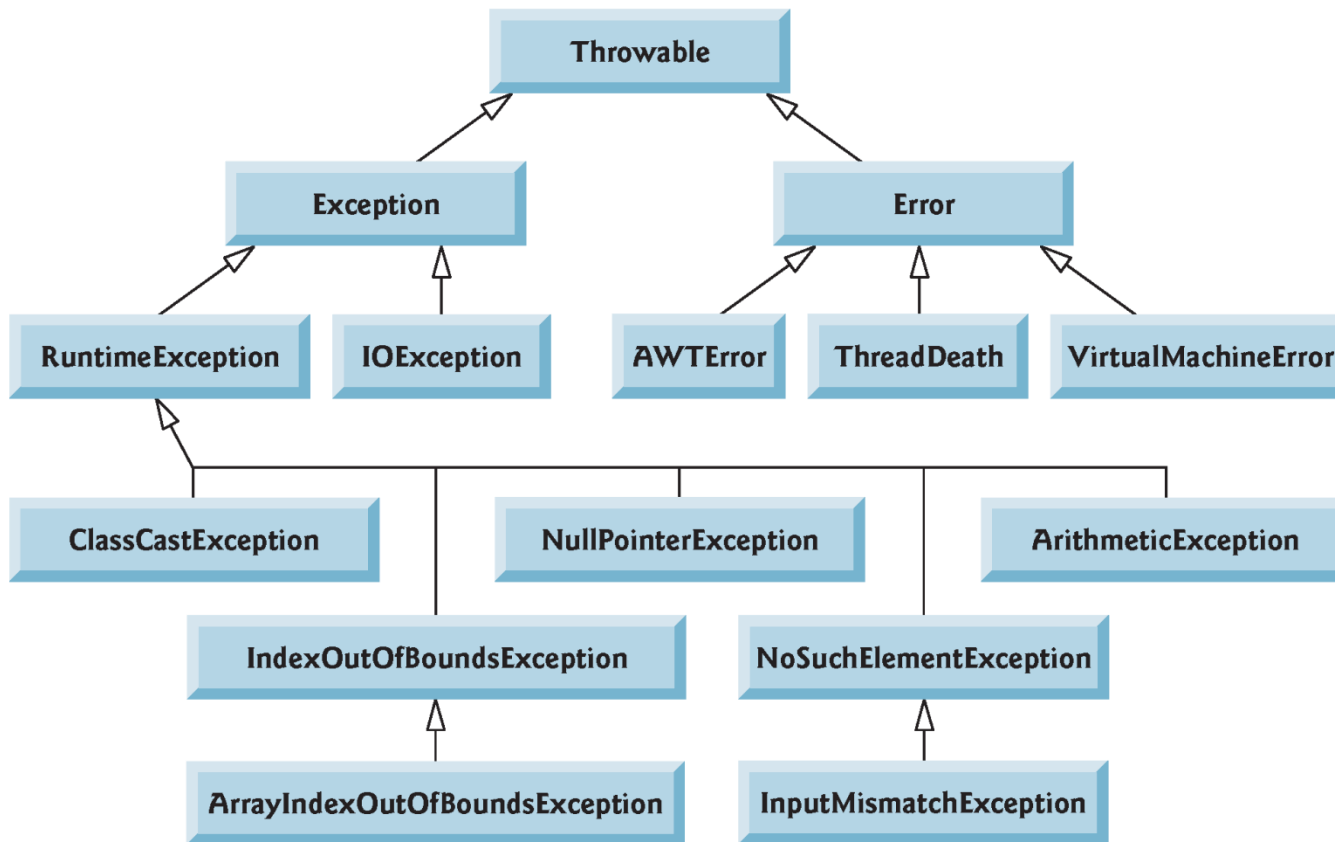


Fig. 11.4 | Portion of class Throwable's inheritance hierarchy.



11.5 Java Exception Hierarchy (Cont.)

- ▶ **Checked exceptions** vs. **unchecked exceptions**.
 - Compiler enforces a **catch-or-declare requirement** for *checked* exceptions.
- ▶ An exception's type determines whether it is checked or unchecked.
- ▶ Direct or indirect subclasses of class **RuntimeException** (package `java.lang`) are *unchecked* exceptions.
- ▶ Typically caused by defects in your program's code, e.g.:
- ▶ **ArrayIndexOutOfBoundsException**
- ▶ **ArithmeticExceptions**
- ▶ Subclasses of **Exception** but not **RuntimeException** are *checked* exceptions.
 - Caused by conditions that are not in the control of the program—e.g., in file processing, the program can't open a file if it does not exist.



11.5 Java Exception Hierarchy (Cont.)

- ▶ The compiler *checks* each method call and method declaration to determine whether the method throws a checked exception.
 - If so, the compiler verifies that the checked exception is *caught* or is *declared* in a `throws` clause—this is known as the **catch-or-declare** requirement.
- ▶ `throws` clause specifies the exceptions a method throws.
 - Such exceptions are typically not caught in the method's body.



11.5 Java Exception Hierarchy (Cont.)

- ▶ To satisfy the *catch* part of the *catch-or-declare requirement*, the code that generates the exception must be wrapped in a `try` block and must provide a `catch` handler for the checked-exception type (or one of its superclasses).
- ▶ To satisfy the *declare* part of the *catch-or-declare requirement*, the method must provide a `throws` clause containing the checked-exception type after its parameter list and before its method body.
- ▶ If the catch-or-declare requirement is not satisfied, the compiler will issue an error message.



Error-Prevention Tip 11.2

You must deal with checked exceptions. This results in more robust code than would be created if you were able to simply ignore them.



Common Programming Error 11.2

*If a subclass method overrides a superclass method, it's an error for the subclass method to list more exceptions in its **throws** clause than the superclass method does. However, a subclass's **throws** clause can contain a subset of a superclass's **throws** clause.*



Software Engineering Observation 11.5

If your method calls other methods that throw checked exceptions, those exceptions must be caught or declared. If an exception can be handled meaningfully in a method, the method should catch the exception rather than declare it.



11.5 Java Exception Hierarchy (Cont.)

- ▶ The compiler does *not* examine the code to determine whether an unchecked exception is caught or declared.
 - These typically can be *prevented* by proper coding.
 - For example, an `ArithmeticException` can be avoided if a method ensures that the denominator is not zero *before* performing.
- ▶ Unchecked exceptions are not required to be listed in a method's **throws** clause.
 - Even if they are, it's not required that such exceptions be caught by an application.



Software Engineering Observation 11.6

Although the compiler does not enforce the catch-or-declare requirement for unchecked exceptions, provide appropriate exception-handling code when it's known that such exceptions might occur. For example, a program should process the `NumberFormatException` from `Integer` method `parseInt`, even though `NumberFormatException` is an indirect subclass of `RuntimeException` (and thus an unchecked exception). This makes your programs more robust.



11.5 Java Exception Hierarchy (Cont.)

- ▶ If a **catch** handler is written to catch *superclass* exception objects, it can also catch all objects of that class's *subclasses*.
- ▶ This enables catch to handle related exceptions *polymorphically*.
- ▶ You can catch each subclass individually if those exceptions require different processing.



11.5 Java Exception Hierarchy (Cont.)

- ▶ If *multiple* `catch` blocks match a particular exception type, only the *first* matching `catch` block executes.
- ▶ It's a compilation error to catch the *exact same type* in two different `catch` blocks associated with a particular `try` block.



Common Programming Error 11.3

Placing a catch block for a superclass exception type before other catch blocks that catch subclass exception types would prevent those catch blocks from executing, so a compilation error occurs.



Error-Prevention Tip 11.3

Catching subclass types individually is subject to error if you forget to test for one or more of the subclass types explicitly; catching the superclass guarantees that objects of all subclasses will be caught. Positioning a catch block for the superclass type after all other subclass catch blocks ensures that all subclass exceptions are eventually caught.



Software Engineering Observation 11.7

In industry, throwing or catching type Exception is discouraged—we use it here simply to demonstrate exception-handling mechanics. In subsequent chapters, we generally throw and catch more specific exception types.



11.6 finally Block

- ▶ Programs that obtain certain resources must return them to the system to avoid so-called **resource leaks**.
 - In programming languages such as C and C++, the most common resource leak is a *memory leak*.
 - Java automatically garbage collects memory no longer used by programs, thus avoiding most memory leaks.
 - Other types of resource leaks can occur.
 - Files, database connections and network connections that are not closed properly might not be available for use in other programs.
- ▶ The **finally** block (which consists of the **finally** keyword, followed by code enclosed in curly braces), sometimes referred to as the **finally clause**, is optional.



Error-Prevention Tip 11.4

A subtle issue is that Java does not entirely eliminate memory leaks. Java will not garbage-collect an object until there are no remaining references to it. Thus, if you erroneously keep references to unwanted objects, memory leaks can occur.



11.6 finally Block (Cont.)

- ▶ `finally` block will execute *whether or not* an exception is thrown in the corresponding `try` block.
- ▶ `finally` block will execute if a `try` block exits by using a `return`, `break` or `continue` statement or simply by reaching its closing right brace.
- ▶ `finally` block will *not* execute if the application *exits early* from a `try` block by calling method `System.exit`.



Error-Prevention Tip 11.5

The finally block is an ideal place to release resources acquired in a try block (such as opened files), which helps eliminate resource leaks.



Performance Tip 11.1

Always release a resource explicitly and at the earliest possible moment at which it's no longer needed. This makes resources available for reuse as early as possible, thus improving resource utilization and program performance.



11.6 finally Block (Cont.)

- ▶ If an exception that occurs in a `try` block cannot be caught by one of that `try` block's `catch` handlers, control proceeds to the `finally` block.
- ▶ Then the program passes the exception to the next outer `try` block—normally in the calling method—where an associated `catch` block might catch it.
 - This process can occur through many levels of `try` blocks.
 - The exception could go *uncaught*.
- ▶ If a `catch` block throws an exception, the `finally` block still executes.
 - Then the exception is passed to the next outer `try` block—again, normally in the calling method.



11.6 finally Block (Cont.)

- ▶ Because a `finally` block always executes, it typically contains *resource-release code*.
- ▶ Suppose a resource is allocated in a `try` block.
 - If no exception occurs, control proceeds to the `finally` block, which frees the resource. Control then proceeds to the first statement after the `finally` block.
 - If an exception occurs, the `try` block *terminates*. The program catches and processes the exception in one of the corresponding `catch` blocks, then the `finally` block *releases the resource* and control proceeds to the first statement after the `finally` block.
 - If the program doesn't catch the exception, the `finally` block *still* releases the resource and an attempt is made to catch the exception in a calling method.



```
1 // Fig. 11.5: UsingExceptions.java
2 // try...catch...finally exception handling mechanism.
3
4 public class UsingExceptions
5 {
6     public static void main(String[] args)
7     {
8         try
9         {
10            throwException();
11        }
12        catch (Exception exception) // exception thrown by throwException
13        {
14            System.err.println("Exception handled in main");
15        }
16
17        doesNotThrowException();
18    }
19
```

Fig. 11.5 | try...catch...finally exception-handling mechanism. (Part 1 of 4.)



```
20 // demonstrate try...catch...finally
21 public static void throwException() throws Exception
22 {
23     try // throw an exception and immediately catch it
24     {
25         System.out.println("Method throwException");
26         throw new Exception(); // generate exception
27     }
28     catch (Exception exception) // catch exception thrown in try
29     {
30         System.err.println(
31             "Exception handled in method throwException");
32         throw exception; // rethrow for further processing
33
34         // code here would not be reached; would cause compilation errors
35     }
36 }
37 finally // executes regardless of what occurs in try...catch
38 {
39     System.err.println("Finally executed in throwException");
40 }
41
42 // code here would not be reached; would cause compilation errors
43
44 }
```

Fig. 11.5 | try...catch...finally exception-handling mechanism. (Part 2 of 4.)



```
45
46 // demonstrate finally when no exception occurs
47 public static void doesNotThrowException()
48 {
49     try // try block does not throw an exception
50     {
51         System.out.println("Method doesNotThrowException");
52     }
53     catch (Exception exception) // does not execute
54     {
55         System.err.println(exception);
56     }
57     finally // executes regardless of what occurs in try...catch
58     {
59         System.err.println(
60             "Finally executed in doesNotThrowException");
61     }
62
63     System.out.println("End of method doesNotThrowException");
64 }
65 } // end class UsingExceptions
```

Fig. 11.5 | try...catch...finally exception-handling mechanism. (Part 3 of 4.)



```
Method throwException  
Exception handled in method throwException  
Finally executed in throwException  
Exception handled in main  
Method doesNotThrowException  
Finally executed in doesNotThrowException  
End of method doesNotThrowException
```

Fig. 11.5 | try...catch...finally exception-handling mechanism. (Part 4 of 4.)



11.6 finally Block (Cont.)

- ▶ `System.out` and `System.err` are **streams**—a sequence of bytes.
 - `System.out` (the **standard output stream**) displays output
 - `System.err` (the **standard error stream**) displays errors
- ▶ Output from these streams can be redirected (e.g., to a file).
- ▶ Using two different streams enables you to easily separate error messages from other output.
 - Data output from `System.err` could be sent to a log file
 - Data output from `System.out` can be displayed on the screen



11.6 finally Block (Cont.)

- ▶ **throw statement**—indicates that an exception has occurred.
 - Used to throw exceptions.
 - Indicates to client code that an error has occurred.
 - Specifies an object to be thrown.
 - The operand of a **throw** can be of any class derived from class **Throwable**.



Software Engineering Observation 11.8

When `toString` is invoked on any `Throwable` object, its resulting `String` includes the descriptive string that was supplied to the constructor, or simply the class name if no string was supplied.



Software Engineering Observation 11.9

An exception can be thrown without containing information about the problem that occurred. In this case, simply knowing that an exception of a particular type occurred may provide sufficient information for the handler to process the problem correctly.



Software Engineering Observation 11.10

Throw exceptions from constructors to indicate that the constructor parameters are not valid—this prevents an object from being created in an invalid state.



11.6 finally Block (Cont.)

- ▶ **Rethrow an exception**
 - Done when a `catch` block, cannot process that exception or can only partially process it.
 - Defers the exception handling (or perhaps a portion of it) to another `catch` block associated with an outer `try` statement.
- ▶ Rethrow by using the **throw keyword**, followed by a reference to the exception object that was just caught.
- ▶ When a rethrow occurs, the *next enclosing try block* detects the exception, and that `try` block's `catch` blocks attempt to handle it.



Common Programming Error 11.4

If an exception has not been caught when control enters a `finally` block and the `finally` block throws an exception that's not caught in the `finally` block, the first exception will be lost and the exception from the `finally` block will be returned to the calling method.



Error-Prevention Tip 11.6

Avoid placing in a `finally` block code that can throw an exception. If such code is required, enclose the code in a `try...catch` within the `finally` block.



Common Programming Error 11.5

Assuming that an exception thrown from a catch block will be processed by that catch block or any other catch block associated with the same try statement can lead to logic errors.



Good Programming Practice I I. I

Exception handling removes error-processing code from the main line of a program's code to improve program clarity. Do not place `try...catch...finally` around every statement that may throw an exception. This decreases readability. Rather, place one `try` block around a significant portion of your code, follow the `try` with `catch` blocks that handle each possible exception and follow the `catch` blocks with a single `finally` block (if one is required).



11.7 Stack Unwinding and Obtaining Information from an Exception Object

- ▶ **Stack unwinding**—When an exception is thrown but not caught in a particular scope, the method-call stack is “unwound”
- ▶ An attempt is made to **catch** the exception in the next outer **try** block.
- ▶ All local variables in the unwound method go out of scope and control returns to the statement that originally invoked that method.
- ▶ If a **try** block encloses that statement, an attempt is made to **catch** the exception.
- ▶ If a **try** block does not enclose that statement or if the exception is not caught, stack unwinding occurs again.



```
1 // Fig. 11.6: UsingExceptions.java
2 // Stack unwinding and obtaining data from an exception object.
3
4 public class UsingExceptions
5 {
6     public static void main(String[] args)
7     {
8         try
9         {
10            method1();
11        }
12        catch (Exception exception) // catch exception thrown in method1
13        {
14            System.err.printf("%s%n%n", exception.getMessage());
15            exception.printStackTrace();
16
17            // obtain the stack-trace information
18            StackTraceElement[] traceElements = exception.getStackTrace();
19
20            System.out.printf("%nStack trace from getStackTrace:%n");
21            System.out.println("Class\t\tFile\t\t\tLine\tMethod");
22
```

Fig. 11.6 | Stack unwinding and obtaining data from an exception object. (Part I of 4.)



```
23     // loop through traceElements to get exception description
24     for (StackTraceElement element : traceElements)
25     {
26         System.out.printf("%s\t", element.getClassName());
27         System.out.printf("%s\t", element.getFileName());
28         System.out.printf("%s\t", element.getLineNumber());
29         System.out.printf("%s%n", element.getMethodName());
30     }
31 }
32 } // end main
33
34 // call method2; throw exceptions back to main
35 public static void method1() throws Exception
36 {
37     method2();
38 }
39
40 // call method3; throw exceptions back to method1
41 public static void method2() throws Exception
42 {
43     method3();
44 }
```

Fig. 11.6 | Stack unwinding and obtaining data from an exception object. (Part 2 of 4.)



```
45
46 // throw Exception back to method2
47 public static void method3() throws Exception
48 {
49     throw new Exception("Exception thrown in method3");
50 }
51 } // end class UsingExceptions
```

Fig. 11.6 | Stack unwinding and obtaining data from an exception object. (Part 3 of 4.)



Exception thrown in method3

```
java.lang.Exception: Exception thrown in method3
    at UsingExceptions.method3(UsingExceptions.java:49)
    at UsingExceptions.method2(UsingExceptions.java:43)
    at UsingExceptions.method1(UsingExceptions.java:37)
    at UsingExceptions.main(UsingExceptions.java:10)
```

Stack trace from `getStackTrace`:

Class	File	Line	Method
UsingExceptions	UsingExceptions.java	49	method3
UsingExceptions	UsingExceptions.java	43	method2
UsingExceptions	UsingExceptions.java	37	method1
UsingExceptions	UsingExceptions.java	10	main

Fig. 11.6 | Stack unwinding and obtaining data from an exception object. (Part 4 of 4.)



Error-Prevention Tip 11.7

An exception that's not caught in an application causes Java's default exception handler to run. This displays the name of the exception, a descriptive message that indicates the problem that occurred and a complete execution stack trace. In an application with a single thread of execution, the application terminates. In an application with multiple threads, the thread that caused the exception terminates. We discuss multithreading in Chapter 23.



Error-Prevention Tip 11.8

Throwable method `toString` (inherited by all *Throwable* subclasses) returns a `String` containing the name of the exception's class and a descriptive message.



Software Engineering Observation 11.11

Occasionally, you might want to ignore an exception by writing a `catch` handler with an empty body. Before doing so, ensure that the exception doesn't indicate a condition that code higher up the stack might want to know about or recover from.



11.8 Chained Exceptions

- ▶ Sometimes a method responds to an exception by throwing a different exception type that is specific to the current application.
- ▶ If a `catch` block throws a new exception, the original exception's information and stack trace are *lost*.
- ▶ Earlier Java versions provided no mechanism to wrap the original exception information with the new exception's information.
 - This made debugging such problems particularly difficult.
- ▶ **Chained exceptions** enable an exception object to maintain the complete stack-trace information from the original exception.



```
1 // Fig. 11.7: UsingChainedExceptions.java
2 // Chained exceptions.
3
4 public class UsingChainedExceptions
5 {
6     public static void main(String[] args)
7     {
8         try
9         {
10            method1();
11        }
12        catch (Exception exception) // exceptions thrown from method1
13        {
14            exception.printStackTrace();
15        }
16    }
17
```

Fig. 11.7 | Chained exceptions. (Part 1 of 3.)



```
18 // call method2; throw exceptions back to main
19 public static void method1() throws Exception
20 {
21     try
22     {
23         method2();
24     } // end try
25     catch (Exception exception) // exception thrown from method2
26     {
27         throw new Exception("Exception thrown in method1", exception);
28     }
29 }
30
31 // call method3; throw exceptions back to method1
32 public static void method2() throws Exception
33 {
34     try
35     {
36         method3();
37     }
38     catch (Exception exception) // exception thrown from method3
39     {
40         throw new Exception("Exception thrown in method2", exception);
41     }
42 }
```

Fig. 11.7 | Chained exceptions. (Part 2 of 3.)



```
43
44 // throw Exception back to method2
45 public static void method3() throws Exception
46 {
47     throw new Exception("Exception thrown in method3");
48 }
49 } // end class UsingChainedExceptions
```

```
java.lang.Exception: Exception thrown in method1
    at UsingChainedExceptions.method1(UsingChainedExceptions.java:27)
    at UsingChainedExceptions.main(UsingChainedExceptions.java:10)
Caused by: java.lang.Exception: Exception thrown in method2
    at UsingChainedExceptions.method2(UsingChainedExceptions.java:40)
    at UsingChainedExceptions.method1(UsingChainedExceptions.java:23)
    ... 1 more
Caused by: java.lang.Exception: Exception thrown in method3
    at UsingChainedExceptions.method3(UsingChainedExceptions.java:47)
    at UsingChainedExceptions.method2(UsingChainedExceptions.java:36)
    ... 2 more
```

Fig. 11.7 | Chained exceptions. (Part 3 of 3.)



11.9 Declaring New Exception Types

- ▶ Sometimes it's useful to declare your own exception classes that are specific to the problems that can occur when another programmer uses your reusable classes.
- ▶ A new exception class must extend an existing exception class to ensure that the class can be used with the exception-handling mechanism.



11.9 Declaring New Exception Types (cont.)

- ▶ A typical new exception class contains only four constructors:
 - one that takes no arguments and passes a default error message `String` to the superclass constructor;
 - one that receives a customized error message as a `String` and passes it to the superclass constructor;
 - one that receives a customized error message as a `String` and a `Throwable` (for chaining exceptions) and passes both to the superclass constructor;
 - and one that receives a `Throwable` (for chaining exceptions) and passes it to the superclass constructor.



Good Programming Practice 11.2

Associating each type of serious execution-time malfunction with an appropriately named `Exception` class improves program clarity.



Software Engineering Observation 11.12

When defining your own exception type, study the existing exception classes in the Java API and try to extend a related exception class. For example, if you're creating a new class to represent when a method attempts a division by zero, you might extend class `ArithmeticException` because division by zero occurs during arithmetic. If the existing classes are not appropriate superclasses for your new exception class, decide whether your new class should be a checked or an unchecked exception class. If clients should be required to handle the exception, the new exception class should be a checked exception (i.e., extend `Exception` but not `RuntimeException`). The client application should be able to reasonably recover from such an exception. If the client code should be able to ignore the exception (i.e., the exception is an unchecked one), the new exception class should extend `RuntimeException`.



Good Programming Practice 11.3

*By convention, all exception-class names should end with the word **Exception**.*



11.10 Preconditions and Postconditions

- ▶ Programmers spend significant amounts of time maintaining and debugging code.
- ▶ To facilitate these tasks and to improve the overall design, they can specify the expected states before and after a method's execution.
- ▶ These states are called preconditions and postconditions, respectively.



11.10 Preconditions and Postconditions (Cont.)

- ▶ A **precondition** must be true when a method is invoked.
 - Describes constraints on method parameters and any other expectations the method has about the current state of a program just before it begins executing.
 - If the preconditions are not met, the method's behavior is undefined.
 - You should never expect consistent behavior if the preconditions are not satisfied.



11.10 Preconditions and Postconditions (Cont.)

- ▶ A **postcondition** is true after the method successfully returns.
 - Describes constraints on the return value and any other side effects the method may have.
 - When calling a method, you may assume that a method fulfills all of its postconditions.
 - If writing your own method, document all postconditions so that others know what to expect when they call your method, and you should make certain that your method honors all its postconditions if its preconditions are met.
- ▶ When preconditions or postconditions are not met, methods typically throw exceptions.



11.10 Preconditions and Postconditions (Cont.)

- ▶ As an example, examine `String` method `charAt`, which has one `int` parameter—an index in the `String`.
 - For a precondition, method `charAt` assumes that `index` is greater than or equal to zero and less than the length of the `String`.
 - If the precondition is met, the postcondition states that the method will return the character at the position in the `String` specified by the parameter `index`.
 - Otherwise, the method throws an `IndexOutOfBoundsException`.
 - We trust that method `charAt` satisfies its postcondition, provided that we meet the precondition.
 - We need not be concerned with the details of how the method actually retrieves the character at the index.



11.10 Preconditions and Postconditions (Cont.)

- ▶ Some programmers state preconditions and postconditions informally as part of the general method specification, while others prefer a more formal approach by explicitly defining them.
- ▶ State the preconditions and postconditions in a comment before the method declaration.
- ▶ Stating the preconditions and postconditions before writing a method will also help guide you as you implement the method.



11.11 Assertions

- ▶ When implementing and debugging a class, it's sometimes useful to state conditions that should be true at a particular point in a method.
- ▶ **Assertions** help ensure a program's validity by catching potential bugs and identifying possible logic errors during development.
- ▶ Preconditions and postconditions are two types of assertions.



11.11 Assertions (Cont.)

- ▶ Java includes two versions of the `assert` statement for validating assertions programmatically.
- ▶ `assert` evaluates a `boolean` expression and, if `false`, throws an `AssertionError` (a subclass of `Error`).
 - `assert expression;`
 - throws an `AssertionError` if *expression is false*.
 - `assert expression1 : expression2;`
 - evaluates *expression1* and throws an `AssertionError` with *expression2* as the error message if *expression1* is `false`.
- ▶ Can be used to programmatically implement preconditions and postconditions or to verify any other *intermediate* states that help you ensure your code is working correctly.



11.11 Assertions (Cont.)

- ▶ You use assertions primarily for debugging and identifying logic errors in an application.
- ▶ You must explicitly enable assertions when executing a program
 - They reduce performance.
 - They are unnecessary for the program's user.
- ▶ To enable assertions, use the `java` command's `-ea` command-line option, as in

```
java -ea AssertTest
```



```
1 // Fig. 11.8: AssertTest.java
2 // Checking with assert that a value is within range
3 import java.util.Scanner;
4
5 public class AssertTest
6 {
7     public static void main(String[] args)
8     {
9         Scanner input = new Scanner(System.in);
10
11         System.out.print("Enter a number between 0 and 10: ");
12         int number = input.nextInt();
13
14         // assert that the value is >= 0 and <= 10
15         assert (number >= 0 && number <= 10) : "bad number: " + number;
16
17         System.out.printf("You entered %d\n", number);
18     }
19 } // end class AssertTest
```

```
Enter a number between 0 and 10: 5
You entered 5
```

Fig. 11.8 | Checking with assert that a value is within range. (Part 1 of 2.)



```
Enter a number between 0 and 10: 50  
Exception in thread "main" java.lang.AssertionError: bad number: 50  
    at AssertTest.main(AssertTest.java:15)
```

Fig. 11.8 | Checking with assert that a value is within range. (Part 2 of 2.)



11.12 try-with-Resources: Automatic Resource Deallocation

- ▶ Typically resource-release code should be placed in a `finally` block to ensure that a resource is released, regardless of whether there were exceptions when the resource was used in the corresponding `try` block.
- ▶ An alternative notation—the `try-with-resources` statement (introduced in Java SE 7)—simplifies writing code in which you obtain one or more resources, use them in a `try` block and release them in a corresponding `finally` block.



11.12 try-with-Resources: Automatic Resource Deallocation (cont.)

- ▶ For example, a file-processing application could process a file with a `try-with-resources` statement to ensure that the file is closed properly when it's no longer needed.
- ▶ Each resource must be an object of a class that implements the `AutoCloseable` interface—and thus provides a `close` method.



11.12 try-with-Resources: Automatic Resource Deallocation (cont.)

- ▶ The general form of a `try-with-resources` statement is

```
try ( ClassName theObject = new ClassName() )
{
    // use theObject here
}
catch ( Exception e )
{
    // catch exceptions that occur while using the resource
}
```

- ▶ *ClassName* is a class that implements the `AutoCloseable` interface.



Software Engineering Observation 11.13

Users shouldn't encounter `AssertionErrors`—these should be used only during program development. For this reason, you shouldn't catch `AssertionErrors`. Instead, allow the program to terminate, so you can see the error message, then locate and fix the source of the problem. You should not use `assert` to indicate runtime problems in production code (as we did in Fig. 11.8 for demonstration purposes)—use the exception mechanism for this purpose.

11.13 (New in Java SE 7) try-with-Resources: Automatic Resource Deallocation (cont.)



- ▶ This code creates an object of type *ClassName* and uses it in the `try` block, then calls its `close` method to release any resources used by the object.
- ▶ The `try-with-resources` statement *implicitly* calls the Object's `close` method *at the end of the try block*.
- ▶ You can allocate multiple resources in the parentheses following `try` by separating them with a semicolon (`;`).