Chapter 9

Exception Handling

Key Skills & Concepts

- Know the exception hierarchy
- Use **try** and **catch**
- Understand the effects of an uncaught exception
- Use multiple **catch** statements
- Catch subclass exceptions
- Nest **try** blocks

- Throw an exception
- Know the members of **Throwable**
- Use **finally**
- Use **throws**
- Know Java's built-in exceptions
- Create custom exception classes

This chapter discusses exception handling. An exception is an error that occurs at run time. Using Java's exception handling subsystem you can, in a structured and controlled manner, handle run-time errors. Although most modern programming languages offer some form of exception handling, Java's support for it is both easy-to-use and flexible.

A principal advantage of exception handling is that it automates much of the error handling code that previously had to be entered "by hand" into any large program. For example, in some older computer languages, error codes are returned when a method fails, and these values must be checked manually, each time the method is called. This approach is both tedious and error-prone. Exception handling streamlines error handling by allowing your program to define a block of code, called an *exception handler,* that is executed automatically when an error occurs. It is not necessary to manually check the success or failure of each specific operation or method call. If an error occurs, it will be processed by the exception handler.

Another reason that exception handling is important is that Java defines standard exceptions for common program errors, such as divide-by-zero or file-not-found. To respond to these errors, your program must watch for and handle these exceptions. Also, Java's API library makes extensive use of exceptions.

In the final analysis, to be a successful Java programmer means that you are fully capable of navigating Java's exception handling subsystem.

The Exception Hierarchy

In Java, all exceptions are represented by classes. All exception classes are derived from a class called **Throwable**. Thus, when an exception occurs in a program, an object of some type of exception class is generated. There are two direct subclasses of **Throwable**: **Exception** and **Error**. Exceptions of type **Error** are related to errors that occur in the Java Virtual Machine itself, and not in your program. These types of exceptions are beyond your control, and your program will not usually deal with them. Thus, these types of exceptions are not described here.

Errors that result from program activity are represented by subclasses of **Exception**. For example, divide-by-zero, array boundary, and file errors fall into this category. In general, your program should handle exceptions of these types. An important subclass of **Exception** is **RuntimeException**, which is used to represent various common types of run-time errors.

Exception Handling Fundamentals

Java exception handling is managed via five keywords: **try**, **catch**, **throw**, **throws**, and **finally**. They form an interrelated subsystem in which the use of one implies the use of another. Throughout the course of this chapter, each keyword is examined in detail. However, it is useful at the outset to have a general understanding of the role each plays in exception handling. Briefly, here is how they work.

Program statements that you want to monitor for exceptions are contained within a **try** block. If an exception occurs within the **try** block, it is *thrown*. Your code can catch this exception using **catch** and handle it in some rational manner. System-generated exceptions are automatically thrown by the Java run-time system. To manually throw an exception, use the keyword **throw**. In some cases, an exception that is thrown out of a method must be specified as such by a **throws** clause. Any code that absolutely must be executed upon exiting from a **try** block is put in a **finally** block.

Ask the Expert

Q: **Just to be sure, could you review the conditions that cause an exception to be generated?**

A: Exceptions are generated in three different ways. First, the Java Virtual Machine can generate an exception in response to some internal error which is beyond your control. Normally, your program won't handle these types of exceptions. Second, standard exceptions, such as those corresponding to divide-by-zero or array index out-of-bounds, are generated by errors in program code. You need to handle these exceptions. Third, you can manually generate an exception by using the **throw** statement. No matter how an exception is generated, it is handled in the same way.

Using try and catch

At the core of exception handling are **try** and **catch**. These keywords work together; you can't have a **catch** without a **try**. Here is the general form of the **try**/**catch** exception handling blocks:

```
try {
  // block of code to monitor for errors
}
catch (ExcepType1 exOb) {
  // handler for ExcepType1
}
catch (ExcepType2 exOb) {
  // handler for ExcepType2
}
.
.
.
```

Here, *ExcepType* is the type of exception that has occurred. When an exception is thrown, it is caught by its corresponding **catch** statement, which then processes the exception. As the general form shows, there can be more than one **catch** statement associated with a **try**. The type of the exception determines which **catch** statement is executed. That is, if the exception type specified by a **catch** statement matches that of the exception, then that **catch** statement is executed (and all others are bypassed). When an exception is caught, *exOb* will receive its value.

Here is an important point: If no exception is thrown, then a **try** block ends normally, and all of its **catch** statements are bypassed. Execution resumes with the first statement following the last **catch**. Thus, **catch** statements are executed only if an exception is thrown.

NOTE

There is another form of the **try** statement that supports *automatic resource management.* This form of **try** is called *try-with-resources.* It is described in Chapter 10, in the context of managing I/O streams (such as those connected to a file) because I/O streams are some of the most commonly used resources.

A Simple Exception Example

Here is a simple example that illustrates how to watch for and catch an exception. As you know, it is an error to attempt to index an array beyond its boundaries. When this occurs, the JVM throws an **ArrayIndexOutOfBoundsException**. The following program purposely generates such an exception and then catches it:

```
// Demonstrate exception handling.
class ExcDemo1 {
  public static void main(String[] args) {
    int[] nums = new int[4];
    try {  ← Create a try block.
      System.out.println("Before exception is generated.");

      // Generate an index out-of-bounds exception.
      nums[7] = 10;  ← Attempt to index past nums boundary.
      System.out.println("this won't be displayed");
    }
    catch (ArrayIndexOutOfBoundsException exc) {  ← Catch array boundary errors.
      // catch the exception
      System.out.println("Index out-of-bounds!");
    }
    System.out.println("After catch statement.");
  }
}
```

This program displays the following output:

```
Before exception is generated.
Index out-of-bounds!
After catch statement.
```

Although quite short, the preceding program illustrates several key points about exception handling. First, the code that you want to monitor for errors is contained within a **try** block. Second, when an exception occurs (in this case, because of the attempt to index **nums** beyond its bounds), the exception is thrown out of the **try** block and caught by the **catch** statement. At this point, control passes to the **catch**, and the **try** block is terminated. That is, **catch** is *not* called. Rather, program execution is transferred to it. Thus, the **println( )** statement following the out-of-bounds index will never execute. After the **catch** statement executes, program control continues with the statements following the **catch**. Thus, it is the job of your exception handler to remedy the problem that caused the exception so that program execution can continue normally.

Remember, if no exception is thrown by a **try** block, no **catch** statements will be executed and program control resumes after the **catch** statement. To confirm this, in the preceding program, change the line

```
nums[7] = 10;
```

to

```
nums[0] = 10;
```

Now, no exception is generated, and the **catch** block is not executed.

It is important to understand that all code within a **try** block is monitored for exceptions. This includes exceptions that might be generated by a method called from within the **try** block. An exception thrown by a method called from within a **try** block can be caught by the **catch** statements associated with that **try** block—assuming, of course, that the method did not catch the exception itself. For example, this is a valid program:

```
/* An exception can be generated by one
   method and caught by another. */

class ExcTest {
  // Generate an exception.
  static void genException() {
    int[] nums = new int[4];

    System.out.println("Before exception is generated.");

    // generate an index out-of-bounds exception
    nums[7] = 10;                                        Exception generated here.
    System.out.println("this won't be displayed");
  }
}

class ExcDemo2 {
  public static void main(String[] args) {

    try {                                                  Exception caught here.
      ExcTest.genException();
    } catch (ArrayIndexOutOfBoundsException exc) {
      // catch the exception
      System.out.println("Index out-of-bounds!");
    }
    System.out.println("After catch statement.");
  }
}
```

This program produces the following output, which is the same as that produced by the first version of the program shown earlier:

```
Before exception is generated.
Index out-of-bounds!
After catch statement.
```

Since **genException( )** is called from within a **try** block, the exception that it generates (and does not catch) is caught by the **catch** in **main( )**. Understand, however, that if **genException( )** had caught the exception itself, it never would have been passed back to **main( )**.

The Consequences of an Uncaught Exception

Catching one of Java's standard exceptions, as the preceding program does, has a side benefit: It prevents abnormal program termination. When an exception is thrown, it must be caught by some piece of code, somewhere. In general, if your program does not catch an exception, then it will be caught by the JVM. The trouble is that the JVM's default exception handler terminates execution and displays a stack trace and error message. For example, in this version of the preceding example, the index out-of-bounds exception is not caught by the program.

```
// Let JVM handle the error.
class NotHandled {
  public static void main(String[] args) {

    int[] nums = new int[4];

    System.out.println("Before exception is generated.");

    // generate an index out-of-bounds exception
    nums[7] = 10;
  }
}
```

When the array index error occurs, execution is halted, and the following error message is displayed. (The exact output you see may vary because of differences between JDKs.)

```
Exception in thread "main" java.lang.ArrayIndexOutOfBoundsException:
        Index 7 out of bounds for length 4
        at NotHandled.main(NotHandled.java:9)
```

While such a message is useful for you while debugging, it would not be something that you would want others to see, to say the least! This is why it is important for your program to handle exceptions itself, rather than rely upon the JVM.

As mentioned earlier, the type of the exception must match the type specified in a **catch** statement. If it doesn't, the exception won't be caught. For example, the following program tries to catch an array boundary error with a **catch** statement for an **ArithmeticException** (another of Java's built-in exceptions). When the array boundary is overrun, an **ArrayIndexOutOfBoundsException** is generated, but it won't be caught by the **catch** statement. This results in abnormal program termination.

```
// This won't work!
class ExcTypeMismatch {
  public static void main(String[] args) {
    int[] nums = new int[4];

    try {
      System.out.println("Before exception is generated.");

      //generate an index out-of-bounds exception
      nums[7] = 10;
      System.out.println("this won't be displayed");
    }

    /* Can't catch an array boundary error with an
       ArithmeticException. */
    catch (ArithmeticException exc) {
      // catch the exception
      System.out.println("Index out-of-bounds!");
    }
    System.out.println("After catch statement.");
  }
}
```

This throws an **ArrayIndexOutOfBoundsException**.

This tries to catch it with an **ArithmeticException**.

The output is shown here. (Again, your output may vary based on differences between JDKs.)

```
Before exception is generated.
Exception in thread "main" java.lang.ArrayIndexOutOfBoundsException:
        Index 7 out of bounds for length 4
        at ExcTypeMismatch.main(ExcTypeMismatch.java:10)
```

As the output demonstrates, a **catch** for **ArithmeticException** won't catch an **ArrayIndexOutOfBoundsException**.

Exceptions Enable You to Handle Errors Gracefully

One of the key benefits of exception handling is that it enables your program to respond to an error and then continue running. For example, consider the following example that divides the elements of one array by the elements of another. If a division by zero occurs, an **ArithmeticException** is generated. In the program, this exception is handled by reporting the error and then continuing with execution. Thus, attempting to divide by zero does not cause an abrupt run-time error resulting in the termination of the program. Instead, it is handled gracefully, allowing program execution to continue.

```
// Handle error gracefully and continue.
class ExcDemo3 {
  public static void main(String[] args) {
    int[] numer = { 4, 8, 16, 32, 64, 128 };
    int[] denum = { 2, 0, 4, 4, 0, 8 };

    for(int i=0; i<numer.length; i++) {
      try {
        System.out.println(numer[i] + " / " +
                           denom[i] + " is " +
                           numer[i]/denom[i]);
      }
      catch (ArithmeticException exc) {
        // catch the exception
        System.out.println("Can't divide by Zero!");
      }
    }
  }
}
```

The output from the program is shown here:

```
4 / 2 is 2
Can't divide by Zero!
16 / 4 is 4
32 / 4 is 8
Can't divide by Zero!
128 / 8 is 16
```

This example makes another important point: Once an exception has been handled, it is removed from the system. Therefore, in the program, each pass through the loop enters the **try** block anew; any prior exceptions have been handled. This enables your program to handle repeated errors.

Using Multiple catch Statements

As stated earlier, you can associate more than one **catch** statement with a **try**. In fact, it is common to do so. However, each **catch** must catch a different type of exception. For example, the program shown here catches both array boundary and divide-by-zero errors:

```
// Use multiple catch statements.
class ExcDemo4 {
  public static void main(String[] args) {
    // Here, numer is longer than denom.
    int[] numer = { 4, 8, 16, 32, 64, 128, 256, 512 };
    int[] denom = { 2, 0, 4, 4, 0, 8 };

    for(int i=0; i<numer.length; i++) {
      try {
        System.out.println(numer[i] + " / " +
                           denom[i] + " is " +
                           numer[i]/denom[i]);
      }
      catch (ArithmeticException exc) {
        // catch the exception
        System.out.println("Can't divide by Zero!");
      }
      catch (ArrayIndexOutOfBoundsException exc) {
        // catch the exception
        System.out.println("No matching element found.");
      }
    }
  }
}
```

Multiple **catch** statements

This program produces the following output:

```
4 / 2 is 2
Can't divide by Zero!
16 / 4 is 4
32 / 4 is 8
Can't divide by Zero!
128 / 8 is 16
No matching element found.
No matching element found.
```

As the output confirms, each **catch** statement responds only to its own type of exception.

In general, **catch** expressions are checked in the order in which they occur in a program. Only a matching statement is executed. All other **catch** blocks are ignored.

Catching Subclass Exceptions

There is one important point about multiple **catch** statements that relates to subclasses. A **catch** clause for a superclass will also match any of its subclasses. For example, since the superclass of all exceptions is **Throwable**, to catch all possible exceptions, catch **Throwable**. If you want to catch exceptions of both a superclass type and a subclass type, put the subclass first in the **catch** sequence. If you don't, then the superclass **catch** will also catch all derived classes. This rule is self-enforcing because putting the superclass first causes unreachable code to be created, since the subclass **catch** clause can never execute. In Java, unreachable code is an error.

For example, consider the following program:

```
// Subclasses must precede superclasses in catch statements.
class ExcDemo5 {
  public static void main(String[] args) {
    // Here, numer is longer than denom.
    int[] numer = { 4, 8, 16, 32, 64, 128, 256, 512 };
    int[] denom = { 2, 0, 4, 4, 0, 8 };

    for(int i=0; i<numer.length; i++) {
      try {
        System.out.println(numer[i] + " / " +
                           denom[i] + " is " +
                           numer[i]/denom[i]);
      }
      catch (ArrayIndexOutOfBoundsException exc) {  ← Catch subclass
        // catch the exception
        System.out.println("No matching element found.");
      }
      catch (Throwable exc) {  ←──────────────────────── Catch superclass
        System.out.println("Some exception occurred.");
      }
    }
  }
}
```

The output from the program is shown here:

```
4 / 2 is 2
Some exception occurred.
16 / 4 is 4
32 / 4 is 8
Some exception occurred.
128 / 8 is 16
No matching element found.
No matching element found.
```

Ask the Expert

Q: Why would I want to catch superclass exceptions?

A: There are, of course, a variety of reasons. Here are a couple. First, if you add a **catch** clause that catches exceptions of type **Exception**, then you have effectively added a “catch all” clause to your exception handler that deals with all program-related exceptions. Such a “catch all” clause might be useful in a situation in which abnormal program termination must be avoided no matter what occurs. Second, in some situations, an entire category of exceptions can be handled by the same clause. Catching the superclass of these exceptions allows you to handle all without duplicated code.

In this case, **catch(Throwable)** catches all exceptions except for **ArrayIndexOutOfBounds-Exception**. The issue of catching subclass exceptions becomes more important when you create exceptions of your own.

Try Blocks Can Be Nested

One **try** block can be nested within another. An exception generated within the inner **try** block that is not caught by a **catch** associated with that **try** is propagated to the outer **try** block. For example, here the **ArrayIndexOutOfBoundsException** is not caught by the inner **catch**, but by the outer **catch**:

```
// Use a nested try block.
class NestTrys {
  public static void main(String[] args) {
    // Here, numer is longer than denom.
    int[] numer = { 4, 8, 16, 32, 64, 128, 256, 512 };
    int[] denom = { 2, 0, 4, 4, 0, 8 };

    try { // outer try  <------------------ Nested try blocks
      for(int i=0; i<numer.length; i++) {        |
        try { // nested try  <-------------------
          System.out.println(numer[i] + " / " +
                             denom[i] + " is " +
                             numer[i]/denom[i]);
        }
        catch (ArithmeticException exc) {
          // catch the exception
          System.out.println("Can't divide by Zero!");
        }
      }
    }
    catch (ArrayIndexOutOfBoundsException exc) {
      // catch the exception
      System.out.println("No matching element found.");
      System.out.println("Fatal error - program terminated.");
    }
  }
}
```

The output from the program is shown here:

```
4 / 2 is 2
Can't divide by Zero!
16 / 4 is 4
32 / 4 is 8
Can't divide by Zero!
128 / 8 is 16
No matching element found.
Fatal error - program terminated.
```

In this example, an exception that can be handled by the inner **try**—in this case, a divide-by-zero error—allows the program to continue. However, an array boundary error is caught by the outer **try**, which causes the program to terminate.

Although certainly not the only reason for nested **try** statements, the preceding program makes an important point that can be generalized. Often nested **try** blocks are used to allow different categories of errors to be handled in different ways. Some types of errors are catastrophic and cannot be fixed. Some are minor and can be handled immediately. You might use an outer **try** block to catch the most severe errors, allowing inner **try** blocks to handle less serious ones.

Throwing an Exception

The preceding examples have been catching exceptions generated automatically by the JVM. However, it is possible to manually throw an exception by using the **throw** statement. Its general form is shown here:

```
throw exceptOb;
```

Here, *exceptOb* must be an object of an exception class derived from **Throwable**.

Here is an example that illustrates the **throw** statement by manually throwing an **ArithmeticException**:

```
// Manually throw an exception.
class ThrowDemo {
  public static void main(String[] args) {
    try {
      System.out.println("Before throw.");
      throw new ArithmeticException();  ◄——— Throw an exception.

    }
    catch (ArithmeticException exc) {
      // catch the exception
      System.out.println("Exception caught.");
    }
    System.out.println("After try/catch block.");
  }
}
```

The output from the program is shown here:

```
Before throw.
Exception caught.
After try/catch block.
```

Notice how the **ArithmeticException** was created using **new** in the **throw** statement. Remember, **throw** throws an object. Thus, you must create an object for it to throw. That is, you can't just throw a type.

Rethrowing an Exception

An exception caught by one **catch** statement can be rethrown so that it can be caught by an outer **catch**. The most likely reason for rethrowing this way is to allow multiple handlers access to the exception. For example, perhaps one exception handler manages one aspect of an exception, and a second handler copes with another aspect. Remember, when you rethrow an exception, it will not be recaught by the same **catch** statement. It will propagate to the next **catch** statement. The following program illustrates rethrowing an exception:

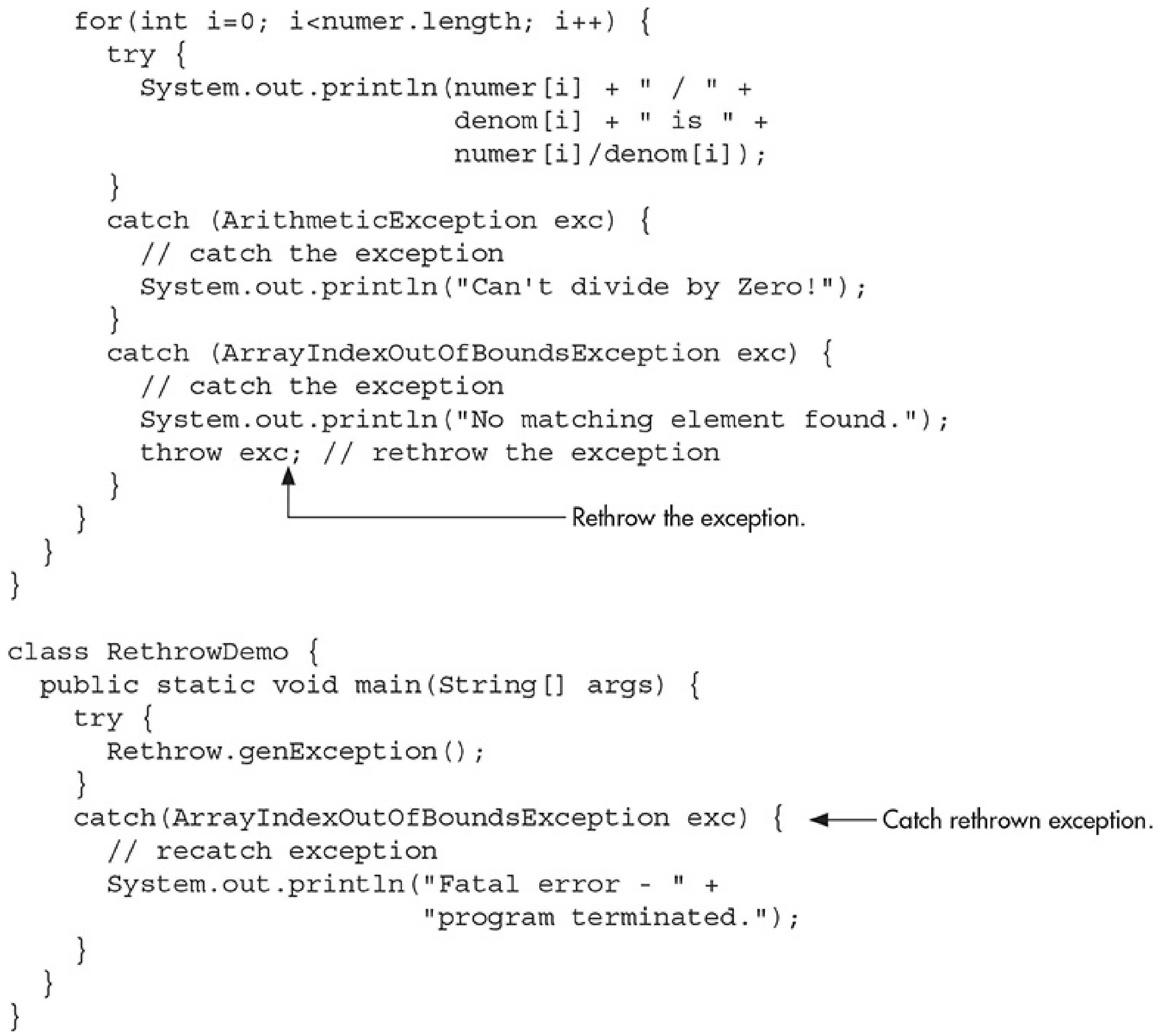
```
// Rethrow an exception.
class Rethrow {
  public static void genException() {
    // here, numer is longer than denom
    int[] numer = { 4, 8, 16, 32, 64, 128, 256, 512 };
    int[] denom = { 2, 0, 4, 4, 0, 8 };
```

In this program, divide-by-zero errors are handled locally, by **genException( )**, but an array boundary error is rethrown. In this case, it is caught by **main( )**.

Ask the Expert

Q: Why would I want to manually throw an exception?

A: Most often, the exceptions that you will throw will be instances of exception classes that you created. As you will see later in this chapter, creating your own exception classes allows you to handle errors in your code as part of your program's overall exception handling strategy.



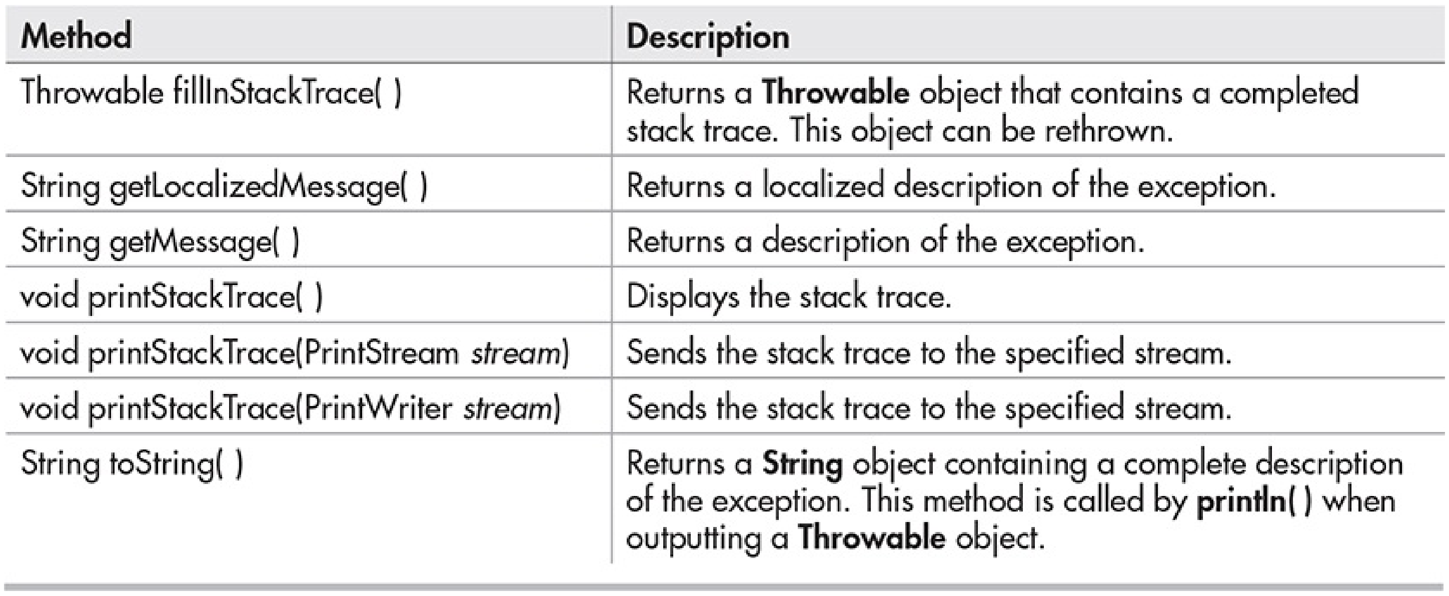
```
    for(int i=0; i<numer.length; i++) {
      try {
        System.out.println(numer[i] + " / " +
                           denom[i] + " is " +
                           numer[i]/denom[i]);
      }
      catch (ArithmeticException exc) {
        // catch the exception
        System.out.println("Can't divide by Zero!");
      }
      catch (ArrayIndexOutOfBoundsException exc) {
        // catch the exception
        System.out.println("No matching element found.");
        throw exc; // rethrow the exception
      }
    }
  }
}

class RethrowDemo {
  public static void main(String[] args) {
    try {
      Rethrow.genException();
    }
    catch(ArrayIndexOutOfBoundsException exc) {
      // recatch exception
      System.out.println("Fatal error - " +
                         "program terminated.");
    }
  }
}
```

In this program, divide-by-zero errors are handled locally, by **genException( )**, but an array boundary error is rethrown. In this case, it is caught by **main( )**.

A Closer Look at Throwable

Up to this point, we have been catching exceptions, but we haven't been doing anything with the exception object itself. As the preceding examples all show, a **catch** clause specifies an exception type and a parameter. The parameter receives the exception object. Since all exceptions are subclasses of **Throwable**, all exceptions support the methods defined by **Throwable**. Several commonly used ones are shown in Table 9-1.

Of the methods defined by **Throwable**, two of the most interesting are **printStackTrace( )** and **toString( )**. You can display the standard error message plus a record of the method calls that lead up to the exception by calling **printStackTrace( )**. You can use **toString( )** to retrieve the standard error message. The **toString( )** method is also called when an exception is used as an argument to **println( )**. The following program demonstrates these methods:



Method	Description
Throwable fillInStackTrace( )	Returns a **Throwable** object that contains a completed stack trace. This object can be rethrown.
String getLocalizedMessage( )	Returns a localized description of the exception.
String getMessage( )	Returns a description of the exception.
void printStackTrace( )	Displays the stack trace.
void printStackTrace(PrintStream *stream*)	Sends the stack trace to the specified stream.
void printStackTrace(PrintWriter *stream*)	Sends the stack trace to the specified stream.
String toString( )	Returns a **String** object containing a complete description of the exception. This method is called by **println( )** when outputting a **Throwable** object.

Table 9-1 Commonly Used Methods Defined by **Throwable**

```
// Using the Throwable methods.

class ExcTest {
  static void genException() {
    int[] nums = new int[4];

    System.out.println("Before exception is generated.");

    // generate an index out-of-bounds exception
    nums[7] = 10;
    System.out.println("this won't be displayed");
  }
}

class UseThrowableMethods {
  public static void main(String[] args) {

    try {
      ExcTest.genException();
    }
    catch (ArrayIndexOutOfBoundsException exc) {
      // catch the exception
      System.out.println("Standard message is: ");
      System.out.println(exc);
      System.out.println("\nStack trace: ");

      exc.printStackTrace();
    }
    System.out.println("After catch statement.");
  }
}
```

The output from this program is shown here. (Your output may vary because of differences between JDKs.)

```
Before exception is generated.
Standard message is:
java.lang.ArrayIndexOutOfBoundsException: Index 7 out of bounds for length 4

Stack trace:
java.lang.ArrayIndexOutOfBoundsException: Index 7 out of bounds for length 4
    at ExcTest.genException(UseThrowableMethods.java:10)
    at UseThrowableMethods.main(UseThrowableMethods.java:19)
After catch statement.
```

Using finally

Sometimes you will want to define a block of code that will execute when a **try/catch** block is left. For example, an exception might cause an error that terminates the current method, causing its premature return. However, that method may have opened a file or a network connection that needs to be closed. Such types of circumstances are common in programming, and Java provides a convenient way to handle them: **finally**.

To specify a block of code to execute when a **try/catch** block is exited, include a **finally** block at the end of a **try**/**catch** sequence. The general form of a **try**/**catch** that includes **finally** is shown here.

```
try {
  // block of code to monitor for errors
}
catch (ExcepType1 exOb) {
  // handler for ExcepType1
}
catch (ExcepType2 exOb) {
  // handler for ExcepType2
}
//...
finally {
  // finally code
}
```

The **finally** block will be executed whenever execution leaves a **try/catch** block, no matter what conditions cause it. That is, whether the **try** block ends normally, or because of an exception, the last code executed is that defined by **finally**. The **finally** block is also executed if any code within the **try** block or any of its **catch** statements return from the method.

Here is an example of **finally**:

```
// Use finally.
class UseFinally {
  public static void genException(int what) {
    int t;
    int[] nums = new int[2];

    System.out.println("Receiving " + what);
    try {
      switch(what) {
        case 0:
          t = 10 / what; // generate div-by-zero error
          break;
        case 1:
          nums[4] = 4; // generate array index error.
          break;
        case 2:
          return; // return from try block
      }
    }
    catch (ArithmeticException exc) {
      // catch the exception
      System.out.println("Can't divide by Zero!");
      return; // return from catch
    }
    catch (ArrayIndexOutOfBoundsException exc) {
      // catch the exception
      System.out.println("No matching element found.");
    }
    finally {
      System.out.println("Leaving try.");
    }
  }
}

class FinallyDemo {
  public static void main(String[] args) {

    for(int i=0; i < 3; i++) {
      UseFinally.genException(i);
      System.out.println();
    }
  }
}
```

This is executed on the way out of **try/catch** blocks.

Here is the output produced by the program:

```
Receiving 0
Can't divide by Zero!
Leaving try.

Receiving 1
No matching element found.
Leaving try.

Receiving 2
Leaving try.
```

As the output shows, no matter how the **try** block is exited, the **finally** block is executed.

Using throws

In some cases, if a method generates an exception that it does not handle, it must declare that exception in a **throws** clause. Here is the general form of a method that includes a **throws** clause:

```
ret-type methName(param-list) throws except-list {
  // body
}
```

Here, *except-list* is a comma-separated list of exceptions that the method might throw outside of itself.

You might be wondering why you did not need to specify a **throws** clause for some of the preceding examples, which threw exceptions outside of methods. The answer is that exceptions that are subclasses of **Error** or **RuntimeException** don't need to be specified in a **throws** list. Java simply assumes that a method may throw one. All other types of exceptions *do* need to be declared. Failure to do so causes a compile-time error.

Actually, you saw an example of a **throws** clause earlier in this book. As you will recall, when performing keyboard input, you needed to add the clause

```
throws java.io.IOException
```

to **main( )**. Now you can understand why. An input statement might generate an **IOException**, and at that time, we weren't able to handle that exception. Thus, such an exception would be thrown out of **main( )** and needed to be specified as such. Now that you know about exceptions, you can easily handle **IOException**.

Let's look at an example that handles **IOException**. It creates a method called **prompt( )**, which displays a prompting message and then reads a character from the keyboard. Since input is being performed, an **IOException** might occur. However, the **prompt( )** method does not handle **IOException** itself. Instead, it uses a **throws** clause, which means that the calling method must handle it. In this example, the calling method is **main( )**, and it deals with the error.

```
// Use throws.
class ThrowsDemo {
  public static char prompt(String str)
    throws java.io.IOException {

    System.out.print(str + ": ");
    return (char) System.in.read();
  }

  public static void main(String[] args) {
    char ch;

    try {
      ch = prompt("Enter a letter");
    }
    catch(java.io.IOException exc) {
      System.out.println("I/O exception occurred.");
      ch = 'X';
    }

    System.out.println("You pressed " + ch);
  }
}
```

Notice the **throws** clause.

Since **prompt( )** might throw an exception, a call to it must be enclosed within a **try** block.

On a related point, notice that **IOException** is fully qualified by its package name **java.io**. As you will learn in Chapter 10, Java's I/O system is contained in the **java.io** package. Thus, the **IOException** is also contained there. It would also have been possible to import **java.io** and then refer to **IOException** directly.

Three Additional Exception Features

In addition to the exception handling features already discussed, modern versions of Java include three more. The first supports *automatic resource management*, which automates the process of releasing a resource, such as a file, when it is no longer needed. It is based on an expanded form of **try**, called the ***try**-with-resources* statement, and it is described in Chapter 10, when files are discussed. The second feature is called *multi-catch*, and the third is sometimes called *final rethrow* or *more precise rethrow.* These two features are described here.

Multi-catch allows two or more exceptions to be caught by the same **catch** clause. As you learned earlier, it is possible (indeed, common) for a **try** to be followed by two or more **catch** clauses. Although each **catch** clause often supplies its own unique code sequence, it is not uncommon to have situations in which two or more **catch** clauses execute *the same code sequence* even though they catch different exceptions. Instead of having to catch each exception type individually, you can use a single **catch** clause to handle the exceptions without code duplication.

To create a multi-catch, specify a list of exceptions within a single **catch** clause. You do this by separating each exception type in the list with the OR operator. Each multi-catch parameter is implicitly **final**. (You can explicitly specify **final**, if desired, but it is not necessary.) Because each multi-catch parameter is implicitly **final**, it can't be assigned a new value.

Here is how you can use the multi-catch feature to catch both **ArithmeticException** and **ArrayIndexOutOfBoundsException** with a single **catch** clause:

```
catch(ArithmeticException | ArrayIndexOutOfBoundsException e) {
```

Here is a simple program that demonstrates the use of this multi-catch:

```
// Use the multi-catch feature.  Note: This code requires JDK 7 or
// later to compile.
class MultiCatch {
  public static void main(String[] args) {
    int a=88, b=0;
    int result;
    char[] chrs = { 'A', 'B', 'C' };

    for(int i=0; i < 2; i++) {
      try {
        if(i == 0)
          result = a / b; // generate an ArithmeticException
        else
          chrs[5] = 'X'; // generate an ArrayIndexOutOfBoundsException

      // This catch clause catches both exceptions.
      }
      catch(ArithmeticException | ArrayIndexOutOfBoundsException e) {
        System.out.println("Exception caught: " + e);
      }
    }

    System.out.println("After multi-catch.");
  }
}
```

The program will generate an **ArithmeticException** when the division by zero is attempted. It will generate an **ArrayIndexOutOfBoundsException** when the attempt is made to access outside the bounds of **chrs**. Both exceptions are caught by the single **catch** statement.

The more precise rethrow feature restricts the type of exceptions that can be rethrown to only those checked exceptions that the associated **try** block throws, that are not handled by a preceding **catch** clause, and that are a subtype or supertype of the parameter. While this capability might not be needed often, it is now available for use. For the final rethrow feature to be in force, the **catch** parameter must be effectively **final**. This means that it must not be assigned a new value inside the **catch** block. It can also be explicitly specified as **final**, but this is not necessary.

Java’s Built-in Exceptions

Inside the standard package **java.lang**, Java defines several exception classes. A few have been used by the preceding examples. The most general of these exceptions are subclasses of the standard type **RuntimeException**. Since **java.lang** is implicitly imported into all Java programs, many exceptions derived from **RuntimeException** are automatically available. Furthermore, they need not be included in any method’s **throws** list. In the language of Java, these are called *unchecked exceptions* because the compiler does not check to see if a method handles or throws these exceptions. The unchecked exceptions defined in **java.lang** are listed in Table 9-2. Table 9-3 lists those exceptions defined by **java.lang** that must be included in a method’s **throws** list if that method can generate one of these exceptions and does not handle it itself. These are called *checked exceptions*. In addition to the exceptions in **java.lang**, Java defines several other types of exceptions that relate to other packages, such as **IOException** mentioned earlier.

Exception	Meaning
ArithmeticException	Arithmetic error, such as integer divide-by-zero.
ArrayIndexOutOfBoundsException	Array index is out-of-bounds.
ArrayStoreException	Assignment to an array element of an incompatible type.
ClassCastException	Invalid cast.
EnumConstantNotPresentException	An attempt is made to use an undefined enumeration value.
IllegalArgumentException	Illegal argument used to invoke a method.
IllegalCallerException	A method cannot be legally executed by the calling code.
IllegalMonitorStateException	Illegal monitor operation, such as waiting on an unlocked thread.
IllegalStateException	Environment or application is in incorrect state.
IllegalThreadStateException	Requested operation not compatible with current thread state.
IndexOutOfBoundsException	Some type of index is out-of-bounds.
LayerInstantiationException	A module layer cannot be created.
NegativeArraySizeException	Array created with a negative size.
NullPointerException	Invalid use of a null reference.
NumberFormatException	Invalid conversion of a string to a numeric format.
SecurityException	Attempt to violate security.
StringIndexOutOfBoundsException	Attempt to index outside the bounds of a string.
TypeNotPresentException	Type not found.
UnsupportedOperationException	An unsupported operation was encountered.

Table 9-2 The Unchecked Exceptions Defined in **java.lang**

Creating Exception Subclasses

Exception	Meaning
ClassNotFoundException	Class not found.
CloneNotSupportedException	Attempt to clone an object that does not implement the **Cloneable** interface.
IllegalAccessException	Access to a class is denied.
InstantiationException	Attempt to create an object of an abstract class or interface.
InterruptedException	One thread has been interrupted by another thread.
NoSuchFieldException	A requested field does not exist.
NoSuchMethodException	A requested method does not exist.
ReflectiveOperationException	Superclass of reflection-related exceptions.

Table 9-3 The Checked Exceptions Defined in **java.lang**

Ask the Expert

Q: I have heard that Java supports something called *chained exceptions.* What are they?

A: A number of years ago, chained exceptions were incorporated into Java. The chained exception feature allows you to specify one exception as the underlying cause of another. For example, imagine a situation in which a method throws an **ArithmeticException** because of an attempt to divide by zero. However, the actual cause of the problem was that an I/O error occurred, which caused the divisor to be set improperly. Although the method must certainly throw an **ArithmeticException**, since that is the error that occurred, you might also want to let the calling code know that the underlying cause was an I/O error. Chained exceptions let you handle this, and any other situation, in which layers of exceptions exist.

To allow chained exceptions, two constructors and two methods were added to **Throwable**. The constructors are shown here:

```
Throwable(Throwable causeExc)
Throwable(String msg, Throwable causeExc)
```

)In the first form, *causeExc* is the exception that causes the current exception. That is, *causeExc* is the underlying reason that an exception occurred. The second form allows you to specify a description at the same time that you specify a cause exception. These two constructors were also added to the **Error**, **Exception**, and **RuntimeException** classes.

The chained exception methods added to **Throwable** are **getCause( )** and **initCause( )**. These methods are shown here:

```
Throwable getCause( )
Throwable initCause(Throwable causeExc)
```

The **getCause( )** method returns the exception that underlies the current exception. If there is no underlying exception, **null** is returned. The **initCause( )** method associates *causeExc* with the invoking exception and returns a reference to the exception. Thus, you can associate a cause with an exception after the exception has been created. In general, **initCause( )** is used to set a cause for legacy exception classes that don't support the two additional constructors described earlier.

Chained exceptions are not something that every program will need. However, in cases in which knowledge of an underlying cause is useful, they offer an elegant solution.

Although Java's built-in exceptions handle most common errors, Java's exception handling mechanism is not limited to these errors. In fact, part of the power of Java's approach to exceptions is its ability to handle exception types that you create. Through the use of custom exceptions, you can manage errors that relate specifically to your application. Creating an exception class is easy. Just define a subclass of **Exception** (which is, of course, a subclass of **Throwable**). Your subclasses don't need to actually implement anything—it is their existence in the type system that allows you to use them as exceptions.

The **Exception** class does not define any methods of its own. It does, of course, inherit those methods provided by **Throwable**. Thus, all exceptions, including those that you create, have the methods defined by **Throwable** available to them. Of course, you can override one or more of these methods in exception subclasses that you create.

Here is an example that creates an exception called **NonIntResultException**, which is generated when the result of dividing two integer values produces a result with a fractional component. **NonIntResultException** has two fields which hold the integer values; a constructor; and an override of the **toString( )** method, allowing the description of the exception to be displayed using **println( )**.

```
// Use a custom exception.

// Create an exception.
class NonIntResultException extends Exception {
  int n;
  int d;

  NonIntResultException(int i, int j) {
    n = i;
    d = j;
  }
  public String toString() {
    return "Result of " + n + " / " + d +
           " is non-integer.";
  }
}

class CustomExceptDemo {
  public static void main(String[] args) {

    // Here, numer contains some odd values.
    int[] numer = { 4, 8, 15, 32, 64, 127, 256, 512 };
    int[] denom = { 2, 0, 4, 4, 0, 8 };

    for(int i=0; i<numer.length; i++) {
      try {
        if((numer[i]%2) != 0)
          throw new
            NonIntResultException(numer[i], denom[i]);

        System.out.println(numer[i] + " / " +
                           denom[i] + " is " +
                           numer[i]/denom[i]);
      }
      catch (ArithmeticException exc) {
        // catch the exception
        System.out.println("Can't divide by Zero!");
      }
      catch (ArrayIndexOutOfBoundsException exc) {
        // catch the exception
        System.out.println("No matching element found.");
      }
      catch (NonIntResultException exc) {
        System.out.println(exc);
      }
    }
  }
}
```

The output from the program is shown here:

```
4 / 2 is 2
Can't divide by Zero!
Result of 15 / 4 is non-integer.
32 / 4 is 8
Can't divide by Zero!
Result of 127 / 8 is non-integer.
No matching element found.
No matching element found.
```

Ask the Expert

Q: When should I use exception handling in a program? When should I create my own custom exception classes?

A: Since the Java API makes extensive use of exceptions to report errors, nearly all real-world programs will make use of exception handling. This is the part of exception handling that most new Java programmers find easy. It is harder to decide when and how to use your own custom-made exceptions. In general, errors can be reported in two ways: return values and exceptions. When is one approach better than the other? Simply put, in Java, exception handling should be the norm. Certainly, returning an error code is a valid alternative in some cases, but exceptions provide a more powerful, structured way to handle errors. They are the way professional Java programmers handle errors in their code.

Try This 9-1 Adding Exceptions to the Queue Class

```
QueueFullException.java
QueueEmptyException.java
FixedQueue.java
QExcDemo.java
```

In this project, you will create two exception classes that can be used by the queue classes developed by Project 8-1. They will indicate the queue-full and queue-empty error conditions. These exceptions can be thrown by the **put( )** and **get( )** methods, respectively. For the sake of simplicity, this project will add these exceptions to the **FixedQueue** class, but you can easily incorporate them into the other queue classes from Project 8-1.

1. You will create two files that will hold the queue exception classes. Call the first file **QueueFullException.java** and enter into it the following:

```
// An exception for queue-full errors.
public class QueueFullException extends Exception {
  int size;

  QueueFullException(int s) { size = s; }

  public String toString() {
   return "\nQueue is full. Maximum size is " +
          size;
  }
}
```

A **QueueFullException** will be generated when an attempt is made to store an item in an already full queue.

2. Create the second file **QueueEmptyException.java** and enter into it the following:

```
// An exception for queue-empty errors.
public class QueueEmptyException extends Exception {

  public String toString() {
   return "\nQueue is empty.";
  }
}
```

A **QueueEmptyException** will be generated when an attempt is made to remove an element from an empty queue.

3. Modify the **FixedQueue** class so that it throws exceptions when an error occurs, as shown here. Put it in a file called **FixedQueue.java**.

```
// A fixed-size queue class for characters that uses exceptions.
class FixedQueue implements ICharQ {
  private char[] q; // this array holds the queue
  private int putloc, getloc; // the put and get indices

  // Construct an empty queue given its size.
  public FixedQueue(int size) {
    q = new char[size]; // allocate memory for queue
    putloc = getloc = 0;
  }

  // Put a character into the queue.
  public void put(char ch)
    throws QueueFullException {

    if(putloc==q.length)
      throw new QueueFullException(q.length);

    q[putloc++] = ch;
  }

  // Get a character from the queue.
  public char get()
    throws QueueEmptyException {

    if(getloc == putloc)
      throw new QueueEmptyException();

    return q[getloc++];
  }
}
```

Notice that two steps are required to add exceptions to **FixedQueue**. First, **get( )** and **put( )** must have a **throws** clause added to their declarations. Second, when an error occurs, these methods throw an exception. Using exceptions allows the calling code to handle the error in a rational fashion. You might recall that the previous versions simply reported the error. Throwing an exception is a much better approach.

4. To try the updated **FixedQueue** class, use the **QExcDemo** class shown here. Put it into a file called **QExcDemo.java**:

```
// Demonstrate the queue exceptions.
class QExcDemo {
  public static void main(String[] args) {
    FixedQueue q = new FixedQueue(10);
    char ch;
    int i;

    try {
      // overrun the queue
      for(i=0; i < 11; i++) {
        System.out.print("Attempting to store : " +
                         (char) ('A' + i));
        q.put((char) ('A' + i));
        System.out.println(" - OK");
      }
      System.out.println();
    }
    catch (QueueFullException exc) {
      System.out.println(exc);
    }
    System.out.println();

    try {
      // over-empty the queue
      for(i=0; i < 11; i++) {
        System.out.print("Getting next char: ");
        ch = q.get();
        System.out.println(ch);
      }
    }
    catch (QueueEmptyException exc) {
      System.out.println(exc);
    }
  }
}
```

5. Since **FixedQueue** implements the **ICharQ** interface, which defines the two queue methods **get( )** and **put( )**, **ICharQ** will need to be changed to reflect the **throws** clause. Here is the updated **ICharQ** interface. Remember, this must be in a file by itself called **ICharQ.java**.

```
// A character queue interface that throws exceptions.
public interface ICharQ {
  // Put a character into the queue.
  void put(char ch) throws QueueFullException;

  // Get a character from the queue.
  char get() throws QueueEmptyException;
}
```

6. Now, compile the updated **ICharQ.java** file. Then, compile **FixedQueue.java**, **QueueFullException.java**, **QueueEmptyException.java**, and **QExcDemo.java**. Finally, run **QExcDemo**. You will see the following output:

```
Attempting to store : A - OK
Attempting to store : B - OK
Attempting to store : C - OK
Attempting to store : D - OK
Attempting to store : E - OK
Attempting to store : F - OK
Attempting to store : G - OK
Attempting to store : H - OK
Attempting to store : I - OK
Attempting to store : J - OK
Attempting to store : K
Queue is full. Maximum size is 10

Getting next char: A
Getting next char: B
Getting next char: C
Getting next char: D
Getting next char: E
Getting next char: F
Getting next char: G
Getting next char: H
Getting next char: I
Getting next char: J
Getting next char:
Queue is empty.
```

✓ *Chapter 9 Self Test*

1. What class is at the top of the exception hierarchy?
2. Briefly explain how to use **try** and **catch**.

3. What is wrong with this fragment?

```
// ...
vals[18] = 10;
catch (ArrayIndexOutOfBoundsException exc) {
  // handle error
}
```

4. What happens if an exception is not caught?
5. What is wrong with this fragment?

```
class A extends Exception { ...

class B extends A { ...

// ...

try {
  // ...
}
catch (A exc) { ... }
catch (B exc) { ... }
```

6. Can an inner **catch** rethrow an exception to an outer **catch**?
7. The **finally** block is the last bit of code executed before your program ends. True or False? Explain your answer.
8. What type of exceptions must be explicitly declared in a **throws** clause of a method?
9. What is wrong with this fragment?

```
class MyClass { // ... }
// ...
throw new MyClass();
```

10. In question 3 of the Chapter 6 Self Test, you created a **Stack** class. Add custom exceptions to your class that report stack full and stack empty conditions.
11. What are the three ways that an exception can be generated?
12. What are the two direct subclasses of **Throwable**?
13. What is the multi-catch feature?
14. Should your code typically catch exceptions of type **Error**?