Section 3.1

Blocks, Loops, and Branches

Subsections

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THE ABILITY OF A COMPUTER TO PERFORM complex tasks is built on just a few ways of combining simple commands into control structures. In Java, there are just six such structures that are used to determine the normal flow of control in a program -- and, in fact, just three of them would be enough to write programs to perform any task. The six control structures are: the block, the while loop, the do..while loop, the for loop, the if statement, and the switch statement. Each of these structures is considered to be a single "statement," but a **structured** statement that can contain one or more other statements inside itself.

3.1.1 Blocks

The block is the simplest type of structured statement. Its purpose is simply to group a sequence of statements into a single statement. The format of a block is:

```
{
    statements
}
```

That is, it consists of a sequence of statements enclosed between a pair of braces, "{" and "}". In fact, it is possible for a block to contain no statements at all; such a block is called an empty block, and can actually be useful at times. An empty block consists of nothing but an empty pair of braces. Block statements usually occur inside other statements, where their purpose is to group together several statements into a unit. However, a block can be legally used wherever a statement can occur. There is one place where a block is required: As you might have already noticed in the case of the `main` subroutine of a program, the definition of a subroutine is a block, since it is a sequence of statements enclosed inside a pair of braces.

I should probably note again at this point that Java is what is called a free-format language. There are no syntax rules about how the language has to be arranged on a page. So, for example, you could write an entire block on one line if you want. But as a matter of good programming style, you should lay out your program on the page in a way that will make its structure as clear as possible. In general, this means putting one statement per line and using indentation to indicate statements that are contained inside control structures. This is the format that I will generally use in my examples.

Here are two examples of blocks:

```
{
   System.out.print("The answer is ");
   System.out.println(ans);
}


{  // This block exchanges the values of x and y
   int temp;      // A temporary variable for use in this block.
   temp = x;      // Save a copy of the value of x in temp.
   x = y;         // Copy the value of y into x.
   y = temp;      // Copy the value of temp into y.
}
```

In the second example, a variable, `temp`, is declared inside the block. This is perfectly legal, and it is good style to declare a variable inside a block if that variable is used nowhere else but inside the block. A variable declared inside a block is completely inaccessible and invisible from outside that block. When the computer executes the variable declaration statement, it allocates memory to hold the value of the variable. When the block ends, that memory is discarded (that is, made available for reuse). The variable is said to be local to the block. There is a general concept called the "scope" of an identifier. The scope of an identifier is the part of the program in which that identifier is valid. The scope of a variable defined inside a block is limited to that block, and more specifically to the part of the block that comes after the declaration of the variable.

3.1.2 The Basic While Loop

The block statement by itself really doesn't affect the flow of control in a program. The five remaining control structures do. They can be divided into two classes: loop statements and branching statements. You really just need one control structure from each category in order to have a completely general-purpose programming language. More than that is just convenience. In this section, I'll introduce the `while` loop and the `if` statement. I'll give the full details of these statements and of the other three control structures in later sections.

A while loop is used to repeat a given statement over and over. Of course, it's not likely that you would want to keep repeating it forever. That would be an infinite loop, which is generally a bad thing. (There is an old story about computer pioneer Grace Murray Hopper, who read instructions on a bottle of shampoo telling her to "lather, rinse, repeat." As the story goes, she claims that she tried to follow the directions, but she ran out of shampoo. (In case you don't get it, this is a joke about the way that computers mindlessly follow instructions.))

To be more specific, a `while` loop will repeat a statement over and over, but only so long as a specified condition remains true. A `while` loop has the form:

```
while (boolean-expression)
     statement
```

Since the statement can be, and usually is, a block, most `while` loops have the form:

```
while (boolean-expression) {
    statements
}
```

Some programmers think that the braces should always be included as a matter of style, even when there is only one statement between them, but I don't always follow that advice myself.

The semantics of the `while` statement go like this: When the computer comes to a `while` statement, it evaluates the **boolean-expression**, which yields either `true` or `false` as its value. If the value is `false`, the computer skips over the rest of the `while` loop and proceeds to the next command in the program. If the value of the expression is `true`, the computer executes the **statement** or block of **statements** inside the loop. Then it returns to the beginning of the `while` loop and repeats the process. That is, it re-evaluates the **boolean-expression**, ends the loop if the value is `false`, and continues it if the value is `true`. This will continue over and over until the value of the expression is `false` when the computer evaluates it; if that never happens, then there will be an infinite loop.

Here is an example of a `while` loop that simply prints out the numbers 1, 2, 3, 4, 5:

```
int number;   // The number to be printed.
number = 1;   // Start with 1.
while ( number < 6 ) {  // Keep going as long as number is < 6.
```

```
      System.out.println(number);
      number = number + 1;  // Go on to the next number.
   }
   System.out.println("Done!");
```

The variable `number` is initialized with the value 1. So when the computer evaluates the expression "`number < 6`" for the first time, it is asking whether 1 is less than 6, which is `true`. The computer therefore proceeds to execute the two statements inside the loop. The first statement prints out "1". The second statement adds 1 to `number` and stores the result back into the variable `number`; the value of `number` has been changed to 2. The computer has reached the end of the loop, so it returns to the beginning and asks again whether `number` is less than 6. Once again this is true, so the computer executes the loop again, this time printing out 2 as the value of `number` and then changing the value of `number` to 3. It continues in this way until eventually `number` becomes equal to 6. At that point, the expression "`number < 6`" evaluates to `false`. So, the computer jumps past the end of the loop to the next statement and prints out the message "Done!". Note that when the loop ends, the value of `number` is 6, but the last value that was printed was 5.

By the way, you should remember that you'll never see a `while` loop standing by itself in a real program. It will always be inside a subroutine which is itself defined inside some class. As an example of a `while` loop used inside a complete program, here is a little program that computes the interest on an investment over several years. This is an improvement over examples from the previous chapter that just reported the results for one year:

```
/**
 *  This class implements a simple program that will compute the amount of
 *  interest that is earned on an investment over a period of 5 years.  The
 *  initial amount of the investment and the interest rate are input by the
 *  user.  The value of the investment at the end of each year is output.
 */

public class Interest3 {


   public static void main(String[] args) {

      double principal;  // The value of the investment.
      double rate;       // The annual interest rate.

      /* Get the initial investment and interest rate from the user. */

      System.out.print("Enter the initial investment: ");
      principal = TextIO.getlnDouble();

      System.out.println();
      System.out.println("Enter the annual interest rate.");
      System.out.print("Enter a decimal, not a percentage: ");
      rate = TextIO.getlnDouble();
      System.out.println();

      /* Simulate the investment for 5 years. */

      int years;  // Counts the number of years that have passed.

      years = 0;
      while (years < 5) {
         double interest;  // Interest for this year.
         interest = principal * rate;
         principal = principal + interest;     // Add it to principal.
         years = years + 1;    // Count the current year.
         System.out.print("The value of the investment after ");
         System.out.print(years);
```

```
              System.out.print(" years is $");
              System.out.printf("%1.2f", principal);
              System.out.println();
           } // end of while loop

        } // end of main()

     } // end of class Interest3
```

You should study this program, and make sure that you understand what the computer does step-by-step as it executes the `while` loop.

3.1.3 The Basic If Statement

An if statement tells the computer to take one of two alternative courses of action, depending on whether the value of a given boolean-valued expression is true or false. It is an example of a "branching" or "decision" statement. An `if` statement has the form:

```
if ( boolean-expression )
    statement1
else
    statement2
```

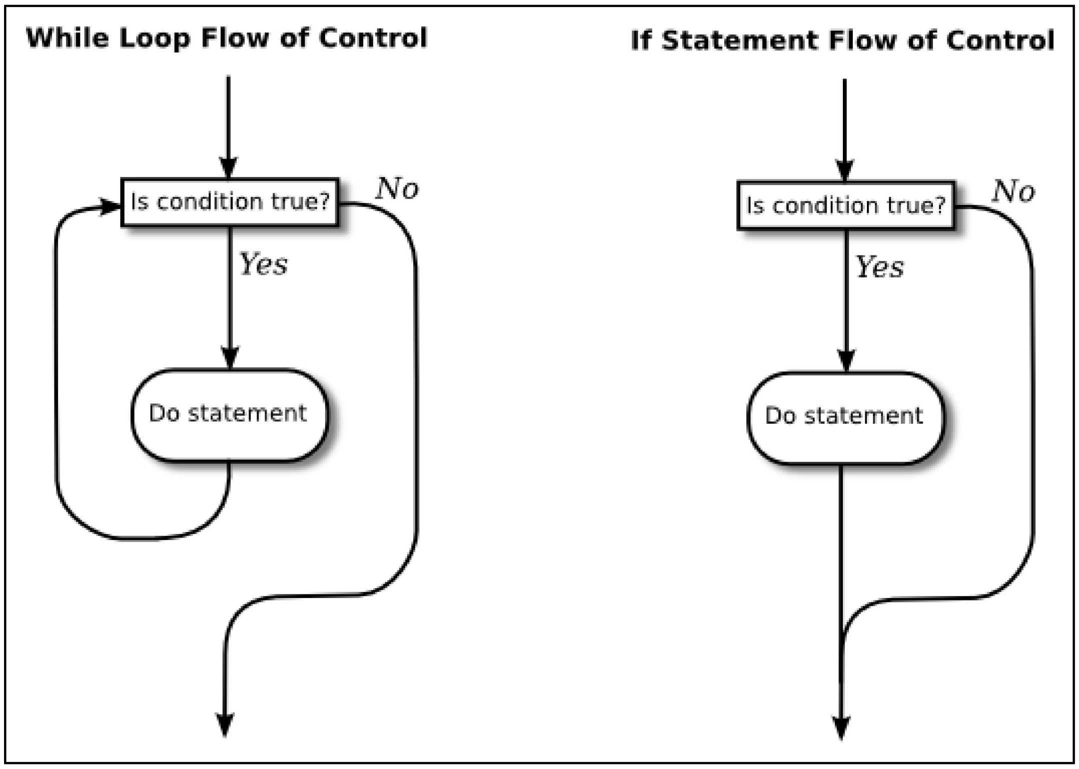
When the computer executes an `if` statement, it evaluates the boolean expression. If the value is `true`, the computer executes the first statement and skips the statement that follows the "`else`". If the value of the expression is `false`, then the computer skips the first statement and executes the second one. Note that in any case, one and only one of the two statements inside the `if` statement is executed. The two statements represent alternative courses of action; the computer decides between these courses of action based on the value of the boolean expression.

In many cases, you want the computer to choose between doing something and not doing it. You can do this with an `if` statement that omits the `else` part:

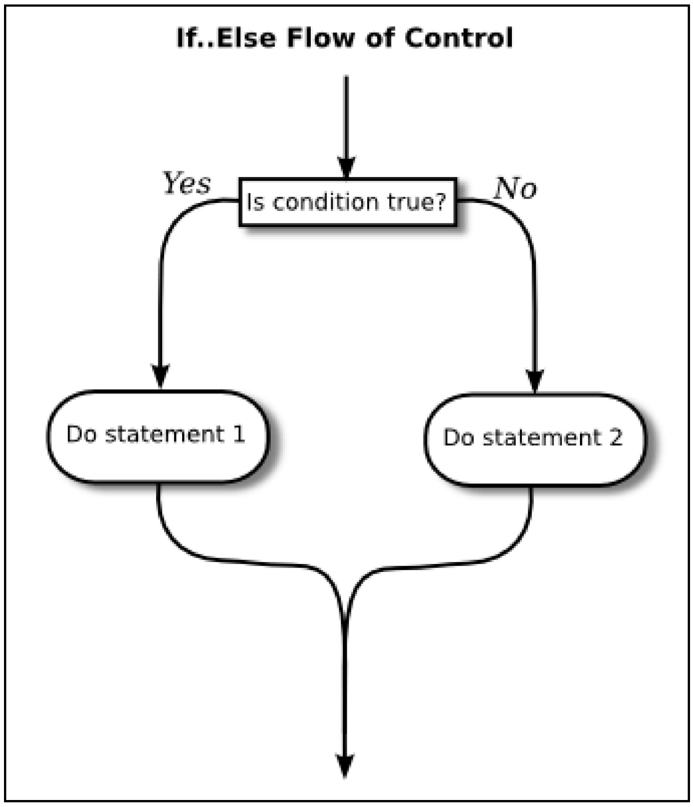
```
if ( boolean-expression )
    statement
```

To execute this statement, the computer evaluates the expression. If the value is `true`, the computer executes the **statement** that is contained inside the `if` statement; if the value is `false`, the computer skips over that **statement**. In either case, the computer then continues with whatever follows the `if` statement in the program.

Sometimes, novice programmers confuse `while` statements with simple `if` statements (with no `else` part), although their meanings are quite different. The **statement** in an `if` is executed at most once, while the **statement** in a `while` can be executed any number of times. It can be helpful to look at diagrams of the the flow of control for `while` and simple `if` statements:



In these diagrams, the arrows represent the flow of time as the statement is executed. Control enters the diagram at the top and leaves at the bottom. Similarly, a flow control diagram for an `if..else` statement makes it clear that exactly one of the two nested statements is executed:



Of course, either or both of the **statements** in an `if` statement can be a block, and again many programmers prefer to add the braces even when they contain just a single statement. So an `if` statement often looks like:

```
if ( boolean-expression ) {
    statements
}
else {
    statements
}
```

or:

```
if ( boolean-expression ) {
    statements
}
```

As an example, here is an `if` statement that exchanges the value of two variables, `x` and `y`, but only if `x` is greater than `y` to begin with. After this `if` statement has been executed, we can be sure that the value of `x` is definitely less than or equal to the value of `y`:

```
if ( x > y ) {
    int temp;      // A temporary variable for use in this block.
    temp = x;      // Save a copy of the value of x in temp.
    x = y;         // Copy the value of y into x.
    y = temp;      // Copy the value of temp into y.
}
```

Finally, here is an example of an `if` statement that includes an `else` part. See if you can figure out what it does, and why it would be used:

```
if ( years > 1 ) {  // handle case for 2 or more years
    System.out.print("The value of the investment after ");
    System.out.print(years);
    System.out.print(" years is $");
}
else {  // handle case for 1 year
    System.out.print("The value of the investment after 1 year is $");
}  // end of if statement
System.out.printf("%1.2f", principal);  // this is done in any case
```

I'll have more to say about control structures later in this chapter. But you already know the essentials. If you never learned anything more about control structures, you would already know enough to perform any possible computing task. Simple looping and branching are all you really need!

3.1.4 Definite Assignment

I will finish this introduction to control structures with a somewhat technical issue that you might not fully understand the first time you encounter it. Consider the following two code segments, which seem to be entirely equivalent:

```
int y;                          int y;
if (x < 0) {                    if (x < 0) {
    y = 1;                           y = 1;
}                               }
else {                          if (x >= 0) {
    y = 2;                           y = 2;
}                               }
System.out.println(y);          System.out.println(y);
```

In the version on the left, `y` is assigned the value 1 if `x < 0` and is assigned the value 2 otherwise, that is, if `x >= 0`. Exactly the same is true of the version on the right. However, there is a subtle difference.

In fact, the Java compiler will report an error for the `System.out.println` statement in the code on the right, while the code on the left is perfectly fine!

The problem is that in the code on the right, the computer can't tell that the variable `y` has definitely been assigned a value. When an `if` statement has no `else` part, the statement inside the `if` might or might not be executed, depending on the value of the condition. The compiler can't tell whether it will be executed or not, since the condition will only be evaluated when the program is running. For the code on the right above, as far as the compiler is concerned, it is possible that **neither** statement, `y = 1` or `y = 2`, will be evaluated, so it is possible that the output statement is trying to print an undefined value. The compiler considers this to be an error. The value of a variable can only be used if the compiler can **verify** that the variable will have been assigned a value at that point when the program is running. This is called definite assignment. (It doesn't matter that **you** can tell that `y` will always be assigned a value in this example. The question is whether the compiler can tell.)

Note that in the code on the left above, `y` is definitely assigned a value, since in an `if..else` statement, one of the two alternatives will be executed no matter what the value of the condition in the `if`. It is important that you understand that there is a difference between an `if..else` statement and a pair of plain `if` statements. Here is another pair of code segments that might seem to do the same thing, but don't. What's the value of `x` after each code segment is executed?

```
int x;                                 int x;
x = -1;                                x = -1;
if (x < 0)                             if (x < 0)
    x = 1;                                 x = 1;
else                                   if (x >= 0)
    x = 2;                                 x = 2;
```

After the code on the left is executed, `x` is 1; after the code on the right, `x` is 2.

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