Section 2.2

Variables and the Primitive Types

NAMES ARE FUNDAMENTAL TO PROGRAMMING. In programs, names are used to refer to many different sorts of things. In order to use those things, a programmer must understand the rules for giving names to things and the rules for using the names to work with those things. That is, the programmer must understand the syntax and the semantics of names.

According to the syntax rules of Java, a name is a sequence of one or more characters. It must begin with a letter or underscore and must consist entirely of letters, digits, and underscores. ("Underscore" refers to the character '_'.) For example, here are some legal names:

```
        N   n   rate  x15   quite_a_long_name   HelloWorld
```

No spaces are allowed in identifiers; `HelloWorld` is a legal identifier, but "Hello World" is not. Upper case and lower case letters are considered to be different, so that `HelloWorld`, `helloworld`, `HELLOWORLD`, and `hElloWorLD` are all distinct names. Certain names are reserved for special uses in Java, and cannot be used by the programmer for other purposes. These reserved words include: `class`, `public`, `static`, `if`, `else`, `while`, and several dozen other words.

Java is actually pretty liberal about what counts as a letter or a digit. Java uses the Unicode character set, which includes thousands of characters from many different languages and different alphabets, and many of these characters count as letters or digits. However, I will be sticking to what can be typed on a regular English keyboard.

The pragmatics of naming includes style guidelines about how to choose names for things. For example, it is customary for names of classes to begin with upper case letters, while names of variables and of subroutines begin with lower case letters; you can avoid a lot of confusion by following the same convention in your own programs. Most Java programmers do not use underscores in names, although some do use them at the beginning of the names of certain kinds of variables. When a name is made up of several words, such as `HelloWorld` or `interestRate`, it is customary to capitalize each word, except possibly the first; this is sometimes referred to as camel case, since the upper case letters in the middle of a name are supposed to look something like the humps on a camel's back.

Finally, I'll note that things are often referred to by compound names which consist of several ordinary names separated by periods. (Compound names are also called qualified names.) You've already seen an example: `System.out.println`. The idea here is that things in Java can contain other things. A compound name is a kind of path to an item through one or more levels of containment. The name `System.out.println` indicates that something called "System" contains something called "out" which in turn contains something called "println". Non-compound names are called simple identifiers. I'll use the term identifier to refer to any name -- simple or compound

-- that can be used to refer to something in Java. (Note that the reserved words are **not** identifiers, since they can't be used as names for things.)

2.2.1 Variables

Programs manipulate data that are stored in memory. In machine language, data can only be referred to by giving the numerical address of the location in memory where it is stored. In a high-level language such as Java, names are used instead of numbers to refer to data. It is the job of the computer to keep track of where in memory the data is actually stored; the programmer only has to remember the name. A name used in this way -- to refer to data stored in memory -- is called a variable.

Variables are actually rather subtle. Properly speaking, a variable is not a name for the data itself but for a location in memory that can hold data. You should think of a variable as a container or box where you can store data that you will need to use later. The variable refers directly to the box and only indirectly to the data in the box. Since the data in the box can change, a variable can refer to different data values at different times during the execution of the program, but it always refers to the same box. Confusion can arise, especially for beginning programmers, because when a variable is used in a program in certain ways, it refers to the container, but when it is used in other ways, it refers to the data in the container. You'll see examples of both cases below.

(In this way, a variable is something like the title, "The President of the United States." This title can refer to different people at different times, but it always refers to the same office. If I say "the President is playing basketball," I mean that Barack Obama is playing basketball. But if I say "Sarah Palin wants to be President" I mean that she wants to fill the office, not that she wants to be Barack Obama.)

In Java, the **only** way to get data into a variable -- that is, into the box that the variable names -- is with an assignment statement. An assignment statement takes the form:

```
variable = expression;
```

where **expression** represents anything that refers to or computes a data value. When the computer comes to an assignment statement in the course of executing a program, it evaluates the expression and puts the resulting data value into the variable. For example, consider the simple assignment statement

```
rate = 0.07;
```

The **variable** in this assignment statement is `rate`, and the **expression** is the number 0.07. The computer executes this assignment statement by putting the number 0.07 in the variable `rate`, replacing whatever was there before. Now, consider the following more complicated assignment statement, which might come later in the same program:

```
interest = rate * principal;
```

Here, the value of the expression "`rate * principal`" is being assigned to the variable `interest`.

In the expression, the `*` is a "multiplication operator" that tells the computer to multiply `rate` times `principal`. The names `rate` and `principal` are themselves variables, and it is really the **values** stored in those variables that are to be multiplied. We see that when a variable is used in an expression, it is the value stored in the variable that matters; in this case, the variable seems to refer to the data in the box, rather than to the box itself. When the computer executes this assignment statement, it takes the **value** of `rate`, multiplies it by the **value** of `principal`, and stores the answer in the **box** referred to by `interest`. When a variable is used on the left-hand side of an assignment statement, it refers to the box that is named by the variable.

(Note, by the way, that an assignment statement is a command that is executed by the computer at a certain time. It is not a statement of fact. For example, suppose a program includes the statement "`rate = 0.07;`". If the statement "`interest = rate * principal;`" is executed later in the program, can we say that the `principal` is multiplied by 0.07? No! The value of `rate` might have been changed in the meantime by another statement. The meaning of an assignment statement is completely different from the meaning of an equation in mathematics, even though both use the symbol "=".)

2.2.2 Types and Literals

A variable in Java is designed to hold only one particular type of data; it can legally hold that type of data and no other. The compiler will consider it to be a syntax error if you try to violate this rule. We say that Java is a strongly typed language because it enforces this rule.

There are eight so-called primitive types built into Java. The primitive types are named byte, short, int, long, float, double, char, and boolean. The first four types hold integers (whole numbers such as 17, -38477, and 0). The four integer types are distinguished by the ranges of integers they can hold. The float and double types hold real numbers (such as 3.6 and -145.99). Again, the two real types are distinguished by their range and accuracy. A variable of type char holds a single character from the Unicode character set. And a variable of type boolean holds one of the two logical values `true` or `false`.

Any data value stored in the computer's memory must be represented as a binary number, that is as a string of zeros and ones. A single zero or one is called a bit. A string of eight bits is called a byte. Memory is usually measured in terms of bytes. Not surprisingly, the byte data type refers to a single byte of memory. A variable of type byte holds a string of eight bits, which can represent any of the integers between -128 and 127, inclusive. (There are 256 integers in that range; eight bits can represent 256 -- two raised to the power eight -- different values.) As for the other integer types,

- short corresponds to two bytes (16 bits). Variables of type short have values in the range -32768 to 32767.
- int corresponds to four bytes (32 bits). Variables of type int have values in the range -2147483648 to 2147483647.
- long corresponds to eight bytes (64 bits). Variables of type long have values in the range -9223372036854775808 to 9223372036854775807.

You don't have to remember these numbers, but they do give you some idea of the size of integers that you can work with. Usually, for representing integer data you should just stick to the int data type, which is good enough for most purposes.

The float data type is represented in four bytes of memory, using a standard method for encoding real numbers. The maximum value for a float is about 10 raised to the power 38. A float can have about 7 significant digits. (So that 32.3989231134 and 32.3989234399 would both have to be rounded off to about 32.398923 in order to be stored in a variable of type float.) A double takes up 8 bytes, can range up to about 10 to the power 308, and has about 15 significant digits. Ordinarily, you should stick to the double type for real values.

A variable of type char occupies two bytes in memory. The value of a char variable is a single character such as A, *, `x`, or a space character. The value can also be a special character such a tab or a carriage return or one of the many Unicode characters that come from different languages. When a character is typed into a program, it must be surrounded by single quotes; for example: `'A'`, `'*'`, or `'x'`. Without the quotes, `A` would be an identifier and `*` would be a multiplication operator. The quotes are not part of the value and are not stored in the variable; they are just a convention for naming a particular character constant in a program.

A name for a constant value is called a literal. A literal is what you have to type in a program to represent a value. `'A'` and `'*'` are literals of type char, representing the character values A and *. Certain special characters have special literals that use a backslash, `\`, as an "escape character". In particular, a tab is represented as `'\t'`, a carriage return as `'\r'`, a linefeed as `'\n'`, the single quote character as `'\''`, and the backslash itself as `'\\'`. Note that even though you type two characters between the quotes in `'\t'`, the value represented by this literal is a single tab character.

Numeric literals are a little more complicated than you might expect. Of course, there are the obvious literals such as 317 and 17.42. But there are other possibilities for expressing numbers in a Java program. First of all, real numbers can be represented in an exponential form such as 1.3e12 or 12.3737e-108. The "e12" and "e-108" represent powers of 10, so that 1.3e12 means 1.3 times 10^{12} and 12.3737e-108 means 12.3737 times 10^{-108}. This format can be used to express very large and very small numbers. Any numerical literal that contains a decimal point or exponential is a literal of type double. To make a literal of type float, you have to append an "F" or "f" to the end of the number. For example, "1.2F" stands for 1.2 considered as a value of type float. (Occasionally, you need to know this because the rules of Java say that you can't assign a value of type double to a variable of type float, so you might be confronted with a ridiculous-seeming error message if you try to do something like "`x = 1.2;`" when `x` is a variable of type float. You have to say "`x = 1.2F;`". This is one reason why I advise sticking to type double for real numbers.)

Even for integer literals, there are some complications. Ordinary integers such as 177777 and -32 are literals of type byte, short, or int, depending on their size. You can make a literal of type long by adding "L" as a suffix. For example: 17L or 728476874368L. As another complication, Java allows octal (base-8) and hexadecimal (base-16) literals. I don't want to cover base-8 and base-16 in detail, but in case you run into them in other people's programs, it's worth knowing a few things: Octal numbers use only the digits 0 through 7. In Java, a numeric literal that begins with a 0 is interpreted as an octal number; for example, the literal 045 represents the number 37, not the number 45. Hexadecimal numbers use 16 digits, the usual digits 0 through 9 and the letters A, B, C, D, E, and F. Upper case and lower case letters can be used interchangeably in this context. The letters represent the numbers 10 through 15. In Java, a hexadecimal literal begins with `0x` or `0X`, as in `0x45` or `0xFF7A`.

Hexadecimal numbers are also used in character literals to represent arbitrary Unicode characters. A Unicode literal consists of `\u` followed by four hexadecimal digits. For example, the character literal `'\u00E9'` represents the Unicode character that is an "e" with an acute accent.

Java 7 introduces a couple of minor improvements in numeric literals. First of all, numeric literals in Java 7 can include the underscore character ("_"), which can be used to separate groups of digits. For example, the integer constant for one billion could be written 1_000_000_000, which is a good deal easier to decipher than 1000000000. There is no rule about how many digits have to be in each group. Java 7 also supports binary numbers, using the digits 0 and 1 and the prefix `0b` (or `0B`). For example: `0b10110` or `0b1010_1100_1011`.

For the type boolean, there are precisely two literals: `true` and `false`. These literals are typed just as I've written them here, without quotes, but they represent values, not variables. Boolean values occur most often as the values of conditional expressions. For example,

```
rate > 0.05
```

is a boolean-valued expression that evaluates to `true` if the value of the variable `rate` is greater than 0.05, and to `false` if the value of `rate` is not greater than 0.05. As you'll see in Chapter 3, boolean-valued expressions are used extensively in control structures. Of course, boolean values can also be assigned to variables of type boolean.

Java has other types in addition to the primitive types, but all the other types represent objects rather than "primitive" data values. For the most part, we are not concerned with objects for the time being. However, there is one predefined object type that is very important: the type *String*. A *String* is a sequence of characters. You've already seen a string literal: `"Hello World!"`. The double quotes are part of the literal; they have to be typed in the program. However, they are not part of the actual string value, which consists of just the characters between the quotes. Within a string, special characters can be represented using the backslash notation. Within this context, the double quote is itself a special character. For example, to represent the string **value**

```
I said, "Are you listening!"
```

with a linefeed at the end, you would have to type the string **literal**:

```
"I said, \"Are you listening!\"\n"
```

You can also use `\t`, `\r`, `\\`, and Unicode sequences such as `\u00E9` to represent other special characters in string literals. Because strings are objects, their behavior in programs is peculiar in some respects (to someone who is not used to objects). I'll have more to say about them in the next section.

2.2.3 Variables in Programs

A variable can be used in a program only if it has first been declared. A variable declaration statement is used to declare one or more variables and to give them names. When the computer executes a variable declaration, it sets aside memory for the variable and associates the variable's name with that memory. A simple variable declaration takes the form:

```
type-name  variable-name-or-names;
```

The **variable-name-or-names** can be a single variable name or a list of variable names separated by commas. (We'll see later that variable declaration statements can actually be somewhat more complicated than this.) Good programming style is to declare only one variable in a declaration statement, unless the variables are closely related in some way. For example:

```
int numberOfStudents;
String name;
double x, y;
boolean isFinished;
char firstInitial, middleInitial, lastInitial;
```

It is also good style to include a comment with each variable declaration to explain its purpose in the program, or to give other information that might be useful to a human reader. For example:

```
double principal;    // Amount of money invested.
double interestRate; // Rate as a decimal, not percentage.
```

In this chapter, we will only use variables declared inside the `main()` subroutine of a program. Variables declared inside a subroutine are called local variables for that subroutine. They exist only inside the subroutine, while it is running, and are completely inaccessible from outside. Variable declarations can occur anywhere inside the subroutine, as long as each variable is declared before it is used in any expression. Some people like to declare all the variables at the beginning of the subroutine. Others like to wait to declare a variable until it is needed. My preference: Declare important variables at the beginning of the subroutine, and use a comment to explain the purpose of each variable. Declare "utility variables" which are not important to the overall logic of the subroutine at the point in the subroutine where they are first used. Here is a simple program using some variables and assignment statements:

```
/**
 * This class implements a simple program that
 * will compute the amount of interest that is
 * earned on $17,000 invested at an interest
 * rate of 0.07 for one year.  The interest and
 * the value of the investment after one year are
 * printed to standard output.
 */

public class Interest {

   public static void main(String[] args) {

       /* Declare the variables. */

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

```
            double interest;      // Interest earned in one year.

            /* Do the computations. */

            principal = 17000;
            rate = 0.07;
            interest = principal * rate;   // Compute the interest.

            principal = principal + interest;
                  // Compute value of investment after one year, with interest.
                  // (Note: The new value replaces the old value of principal.)

            /* Output the results. */

            System.out.print("The interest earned is $");
            System.out.println(interest);
            System.out.print("The value of the investment after one year is $");
            System.out.println(principal);

        } // end of main()

     } // end of class Interest
```

This program uses several subroutine call statements to display information to the user of the program. Two different subroutines are used: `System.out.print` and `System.out.println`. The difference between these is that `System.out.println` adds a linefeed after the end of the information that it displays, while `System.out.print` does not. Thus, the value of `interest`, which is displayed by the subroutine call "`System.out.println(interest);`", follows on the same line after the string displayed by the previous `System.out.print` statement. Note that the value to be displayed by `System.out.print` or `System.out.println` is provided in parentheses after the subroutine name. This value is called a parameter to the subroutine. A parameter provides a subroutine with information it needs to perform its task. In a subroutine call statement, any parameters are listed in parentheses after the subroutine name. Not all subroutines have parameters. If there are no parameters in a subroutine call statement, the subroutine name must be followed by an empty pair of parentheses.

All the sample programs for this textbook are available in separate source code files in the on-line version of this text at http://math.hws.edu/javanotes/source. They are also included in the downloadable archives of the web site. The source code for the `Interest` program, for example, can be found in the file *Interest.java*.

By the way, recall that one of the neat features of Java is that it can be used to write applets that can run on pages in a Web browser. Applets are very different things from stand-alone programs such as the *Interest* program, and they are not written in the same way. For one thing, an applet doesn't have a `main()` routine. Applets will be covered in Chapter 6. In the meantime, you will see applets in this text that **simulate** stand-alone programs. The applets you see are not really the same as the stand-alone programs that they simulate, since they run right on a Web page, but they will have the same behavior as the programs I describe. Here, just for fun, is an applet simulating the *Interest* program. To run the program, click on the button labeled "Run the Program". You will see the output from the program in the large white area of the applet:

Click to use Java

This applet requires Java 5.0 (or higher). It will not work in a web browser that does not support Java or that uses an earlier version of Java.

I will include many applets like this one in the text to simulate my example programs. This example isn't very interesting, since it does exactly the same thing every time you run it. That's not true of most programs, and it won't be true of future examples. You don't need to know how these applets are written, but if you are curious about how I convert my programs into applets, you can look at the source code file *TextIOApplet.java*.

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