[Next Section | Chapter Index | Main Index]

Section 5.1

Objects, Instance Methods, and Instance Variables

Subsections

OBJECT-ORIENTED PROGRAMMING (OOP) represents an attempt to make programs more closely model the way people think about and deal with the world. In the older styles of programming, a programmer who is faced with some problem must identify a computing task that needs to be performed in order to solve the problem. Programming then consists of finding a sequence of instructions that will accomplish that task. But at the heart of object-oriented programming, instead of tasks we find objects -- entities that have behaviors, that hold information, and that can interact with one another. Programming consists of designing a set of objects that somehow model the problem at hand. Software objects in the program can represent real or abstract entities in the problem domain. This is supposed to make the design of the program more natural and hence easier to get right and easier to understand.

To some extent, OOP is just a change in point of view. We can think of an object in standard programming terms as nothing more than a set of variables together with some subroutines for manipulating those variables. In fact, it is possible to use object-oriented techniques in any programming language. However, there is a big difference between a language that makes OOP possible and one that actively supports it. An object-oriented programming language such as Java includes a number of features that make it very different from a standard language. In order to make effective use of those features, you have to "orient" your thinking correctly.

As I have mentioned before, in the context of object-oriented programming, subroutines are often referred to as methods. Now that we are starting to use objects, I will be using the term "method" more often than "subroutine."

5.1.1 Objects, Classes, and Instances

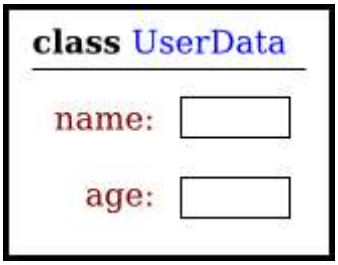
Objects are closely related to classes. We have already been working with classes for several chapters, and we have seen that a class can contain variables and methods (that is, subroutines). If an object is also a collection of variables and methods, how do they differ from classes? And why does it require a different type of thinking to understand and use them effectively? In the one section where we worked with objects rather than classes, Section 3.9, it didn't seem to make much difference: We just left the word "`static`" out of the subroutine definitions!

I have said that classes "describe" objects, or more exactly that the non-static portions of classes describe objects. But it's probably not very clear what this means. The more usual terminology is to say that objects belong to classes, but this might not be much clearer. (There is a real shortage of English words to properly distinguish all the concepts involved. An object certainly doesn't "belong" to a class in the same way that a member variable "belongs" to a class.) From the point of view of programming, it is more exact to say that classes are used to create objects. A class is a kind of factory -- or blueprint -- for constructing objects. The non-static parts of the class specify, or describe, what variables and methods the objects will contain. This is part of the explanation of how objects differ from classes: Objects are created and destroyed as the program runs, and there can be many objects with the same structure, if they are created using the same class.

Consider a simple class whose job is to group together a few static member variables. For example, the following class could be used to store information about the person who is using the program:

```
class UserData {
    static String name;
    static int age;
}
```

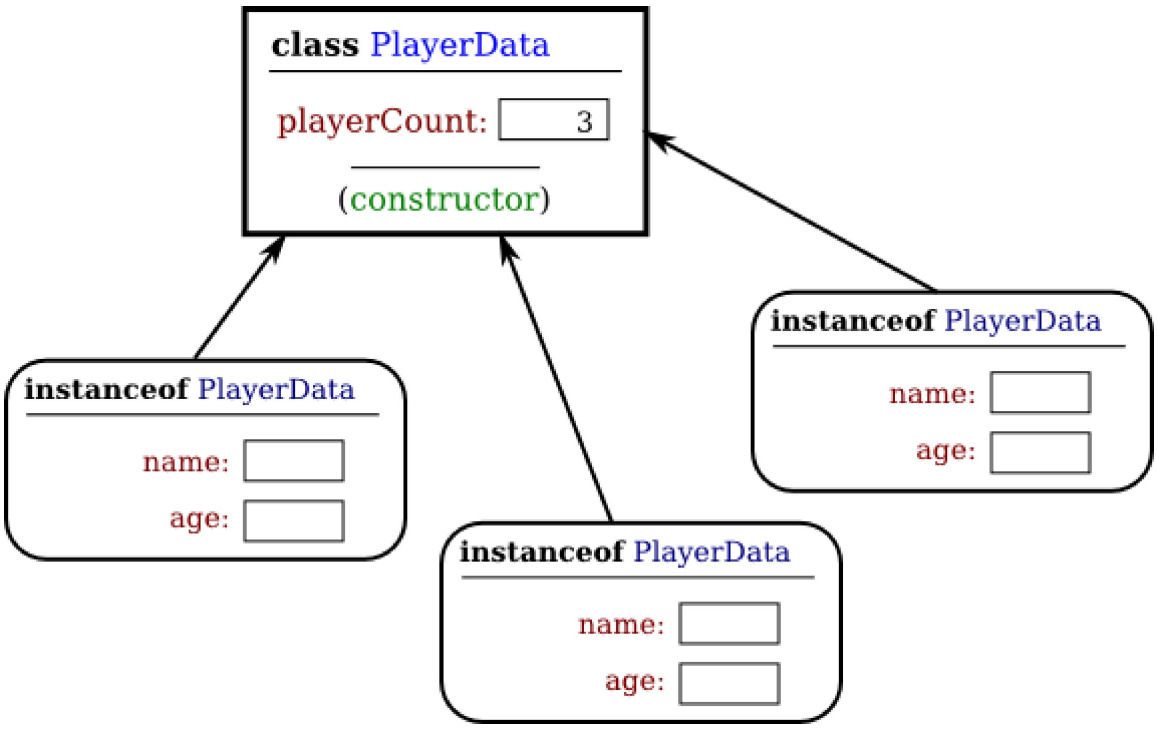
In a program that uses this class, there is only one copy of each of the variables `UserData.name` and `UserData.age`. When the class is loaded into the computer, there is a section of memory devoted to the class, and that section of memory includes space for the values of the variables `name` and `age`. We can picture the class in memory as looking like this:



An important point is that the static member variables are part of the representation of the class in memory. Their full names, `UserData.name` and `UserData.age`, use the name of the class, since they are part of the class. When we use class UserData to represent the user of the program, there can only be **one** user, since we only have memory space to store data about one user. Note that the class, `UserData`, and the variables it contains exist as long as the program runs. (That is essentially what it means to be "static.") Now, consider a similar class that includes some non-static variables:

```
class PlayerData {
   static int playerCount;
   String name;
   int age;
}
```

I've also included a static variable in the PlayerData class. Here, the static variable `playerCount` is stored as part of the representation of the class in memory. It's full name is `PlayerData.playerCount`, and there is only one of it, which exists as long as the program runs. However, the other two variables in the class definition are non-static. There is no such variable as `PlayerData.name` or `PlayerData.age`, since non-static variables do not become part of the class itself. But the PlayerData class can be used to create objects. There can be many objects created using the class, and each one will have its **own** variables called `name` and `age`. This is what it means for the non-static parts of the class to be a template for objects: Every object gets its own copy of the non-static part of the class. We can visualize the situation in the computer's memory after several object have been created like this:



Note that the static variable `playerCount` is part of the class, and there is only one copy. On the other hand, every object contains a `name` and an `age`. An object that is created from a class is called an instance of that class, and as the picture shows every object "knows" which class was used to create it. I've shown class PlayerData as containing something called a "constructor;" the constructor is a subroutine that creates objects.

Now there can be many "players" because we can make new objects to represent new players on demand. A program might use the PlayerData class to store information about multiple players in a game. Each player has a name and an age. When a player joins the game, a new `PlayerData` object can be created to represent that player. If a player leaves the game, the `PlayerData` object that represents that player can be destroyed. A system of objects in the program is being used to dynamically model what is happening in the game. You can't do this with static variables! "Dynamic" is the opposite of "static."

An object that is created using a class is said to be an instance of that class. We will sometimes say that the object belongs to the class. The variables that the object contains are called instance variables. The methods (that is, subroutines) that the object contains are called instance methods. For example, if the `PlayerData` class, as defined above, is used to create an object, then that object is an instance of the `PlayerData` class, and `name` and `age` are instance variables in the object.

My examples here don't include any methods, but methods work similarly to variables. Static methods are part of the class; non-static, or instance, methods become part of objects created from the class. It's not literally true that each object contains its own copy of the actual compiled code for an instance method. But logically an instance method is part of the object, and I will continue to say that the object "contains" the instance method.

Note that you should distinguish between the **source code** for the class, and the **class itself** (in memory). The source code determines both the class and the objects that are created from that class. The "static" definitions in the source code specify the things that are part of the class itself (in the computer's memory), whereas the non-static definitions in the source code specify things that will become part of every instance object that is created from the class. By the way, static member variables and static member subroutines in a class are sometimes called class variables and class methods, since they belong to the class itself, rather than to instances of that class.

As you can see, the static and the non-static portions of a class are very different things and serve very different purposes. Many classes contain only static members, or only non-static, and we will see only a few examples of classes that contain a mixture of the two.

5.1.2 Fundamentals of Objects

So far, I've been talking mostly in generalities, and I haven't given you much of an idea about what you have to put in a program if you want to work with objects. Let's look at a specific example to see how it works. Consider this extremely simplified version of a `Student` class, which could be used to store information about students taking a course:

```
public class Student {

   public String name;  // Student's name.
   public double test1, test2, test3;   // Grades on three tests.

   public double getAverage() {  // compute average test grade
      return (test1 + test2 + test3) / 3;
   }

}  // end of class Student
```

None of the members of this class are declared to be `static`, so the class exists only for creating objects. This class definition says that any object that is an instance of the `Student` class will include instance variables named `name`, `test1`, `test2`, and `test3`, and it will include an instance method named `getAverage()`. The names and tests in different objects will generally have different values. When called for a particular student, the method `getAverage()` will compute an average using **that student's** test grades. Different students can have different averages. (Again, this is what it means to say that an instance method belongs to an individual object, not to the class.)

In Java, a class is a **type**, similar to the built-in types such as int and boolean. So, a class name can be used to specify the type of a variable in a declaration statement, or the type of a formal parameter, or the return type of a function. For example, a program could define a variable named `std` of type `Student` with the statement

```
Student std;
```

However, declaring a variable does **not** create an object! This is an important point, which is related to this Very Important Fact:

In Java, no variable can ever hold an object.
A variable can only hold a reference to an object.

You should think of objects as floating around independently in the computer's memory. In fact, there is a special portion of memory called the heap where objects live. Instead of holding an object itself, a variable holds the information necessary to find the object in memory. This information is called a reference or pointer to the object. In effect, a reference to an object is the address of the memory location where the object is stored. When you use a variable of object type, the computer uses the reference in the variable to find the actual object.

In a program, objects are created using an operator called `new`, which creates an object and returns a reference to that object. (In fact, the `new` operator calls a special subroutine called a "constructor" in the class.) For example, assuming that `std` is a variable of type `Student`, declared as above, the assignment statement

```
std = new Student();
```

would create a new object which is an instance of the class `Student`, and it would store a reference to that object in the variable `std`. The value of the variable is a reference, or pointer, to the object. The object itself is somewhere in the heap. It is not quite true, then, to say that the object is the "value of the variable `std`" (though sometimes it is hard to avoid using this terminology). It is certainly **not at all true** to say that the object is "stored in the variable `std`." The proper terminology is that "the variable `std` refers to or points to the object," and I will try to stick to that terminology as much as possible. If I ever say something like "std **is** an object," you should read it as meaning "std is a variable that refers to an object."

So, suppose that the variable `std` refers to an object that is an instance of class `Student`. That object contains instance variables `name`, `test1`, `test2`, and `test3`. These instance variables can be referred to as `std.name`, `std.test1`, `std.test2`, and `std.test3`. This follows the usual naming convention that when `B` is part of `A`, then the full name of `B` is `A.B`. For example, a program might include the lines

```
System.out.println("Hello, "  +  std.name  +  ".  Your test grades are:");
System.out.println(std.test1);
System.out.println(std.test2);
System.out.println(std.test3);
```

This would output the name and test grades from the object to which `std` refers. Similarly, `std` can be used to call the `getAverage()` instance method in the object by saying `std.getAverage()`. To print out the student's average, you could say:

```
System.out.println( "Your average is "  +  std.getAverage() );
```

More generally, you could use `std.name` any place where a variable of type String is legal. You can use it in expressions. You can assign a value to it. You can even use it to call subroutines from the String class. For example, `std.name.length()` is the number of characters in the student's name.

It is possible for a variable like `std`, whose type is given by a class, to refer to no object at all. We say in this case that `std` holds a null pointer or null reference. The null pointer is written in Java as "`null`". You can store a null reference in the variable `std` by saying

```
std = null;
```

`null` is an actual value that is stored in the variable, not a pointer to something else. It is **not** correct to say that the variable "points to null"; in fact, the variable **is** null. For example, you can test whether the value of `std` is null by testing

```
if (std == null) . . .
```

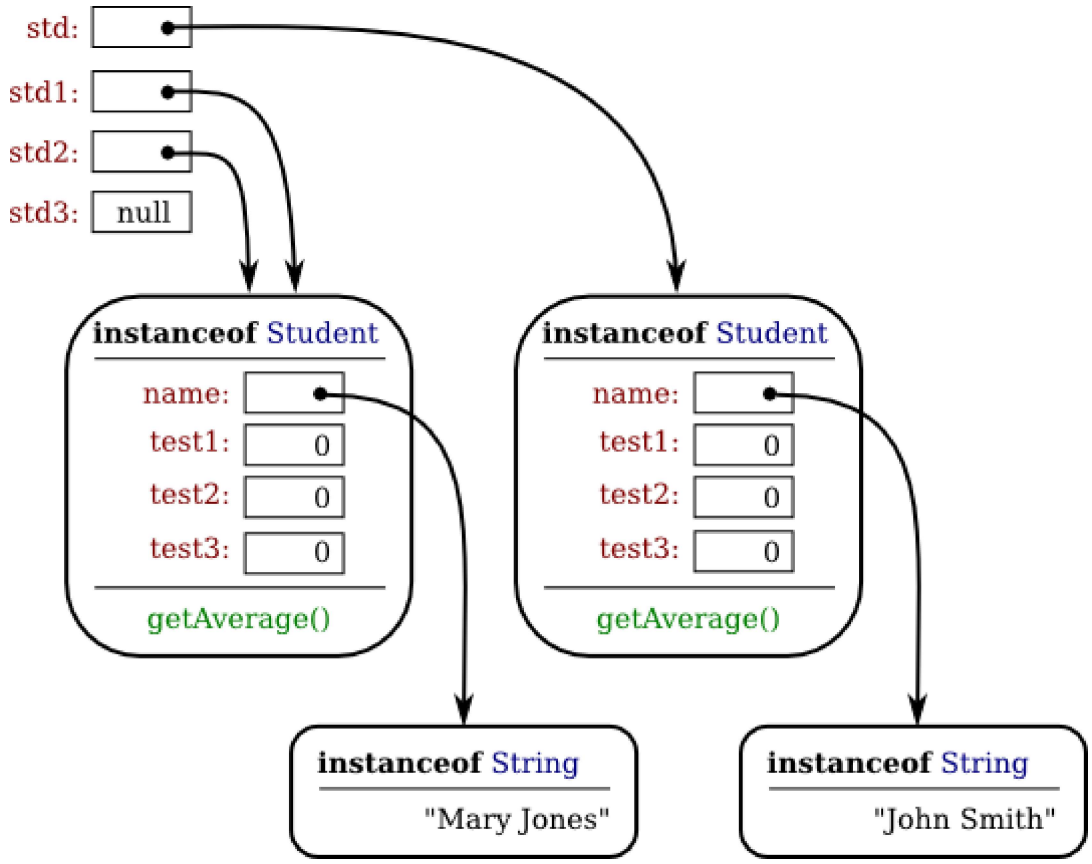
If the value of a variable is `null`, then it is, of course, illegal to refer to instance variables or instance methods through that variable -- since there **is** no object, and hence no instance variables to refer to! For example, if the value of the variable `std` is `null`, then it would be illegal to refer to `std.test1`. If your program attempts to use a null pointer illegally in this way, the result is an error called a null pointer exception. When this happens while the program is running, an exception of type NullPointerException is thrown.

Let's look at a sequence of statements that work with objects:

```
Student std, std1,       // Declare four variables of
          std2, std3;    //   type Student.

std = new Student();     // Create a new object belonging
                         //   to the class Student, and
                         //   store a reference to that
```

```
                                //   object in the variable std.

std1 = new Student();           // Create a second Student object
                                //   and store a reference to
                                //   it in the variable std1.

std2 = std1;                    // Copy the reference value in std1
                                //   into the variable std2.

std3 = null;                    // Store a null reference in the
                                //   variable std3.

std.name = "John Smith";  // Set values of some instance variables.
std1.name = "Mary Jones";

     // (Other instance variables have default
     //    initial values of zero.)
```

After the computer executes these statements, the situation in the computer's memory looks like this:



In this picture, when a variable contains a reference to an object, the value of that variable is shown as an arrow pointing to the object. Note, by the way, that the Strings are objects! The variable `std3`, with a value of `null`, doesn't point anywhere. The arrows from `std1` and `std2` both point to the same object. This illustrates a Very Important Point:

When one object variable is assigned to another, only a reference is copied. The object referred to is not copied.

When the assignment "`std2 = std1;`" was executed, no new object was created. Instead, `std2` was set to refer to the very same object that `std1` refers to. This is to be expected, since the assignment statement just copies the value that is stored in `std1` into `std2`, and that value is a pointer, not an object. But this has some consequences that might be surprising. For example, `std1.name` and

`std2.name` are two different names for the same variable, namely the instance variable in the object that both `std1` and `std2` refer to. After the string `"Mary Jones"` is assigned to the variable **`std1.`**`name`, it is also true that the value of **`std2.`**`name` is `"Mary Jones"`. There is a potential for a lot of confusion here, but you can help protect yourself from it if you keep telling yourself, "The object is not in the variable. The variable just holds a pointer to the object."

You can test objects for equality and inequality using the operators `==` and `!=`, but here again, the semantics are different from what you are used to. When you make a test "`if (std1 == std2)`", you are testing whether the values stored in `std1` and `std2` are the same. But the values that you are comparing are references to objects; they are not objects. So, you are testing whether `std1` and `std2` refer to the same object, that is, whether they point to the same location in memory. This is fine, if it's what you want to do. But sometimes, what you want to check is whether the instance variables in the objects have the same values. To do that, you would need to ask whether "`std1.test1 == std2.test1 && std1.test2 == std2.test2 && std1.test3 == std2.test3 && std1.name.equals(std2.name)`".

I've remarked previously that Strings are objects, and I've shown the strings `"Mary Jones"` and `"John Smith"` as objects in the above illustration. (Strings are special objects, treated by Java in a special way, and I haven't attempted to show the actual internal structure of the String objects.) Since strings are objects, a variable of type String can only hold a reference to a string, not the string itself. This explains why using the `==` operator to test strings for equality is not a good idea. Suppose that `greeting` is a variable of type String, and that it refers to the string `"Hello"`. Then would the test `greeting == "Hello"` be true? Well, maybe, maybe not. The variable `greeting` and the String literal `"Hello"` each refer to a string that contains the characters H-e-l-l-o. But the strings could still be different objects, that just happen to contain the same characters; in that case, `greeting == "Hello"` would be false. The function `greeting.equals("Hello")` tests whether `greeting` and `"Hello"` contain the same characters, which is almost certainly the question you want to ask. The expression `greeting == "Hello"` tests whether `greeting` and `"Hello"` contain the same characters **stored in the same memory location**. (Of course, a String variable such as `greeting` can also contain the special value `null`, and it **would** make sense to use the `==` operator to test whether "`greeting == null`".)

The fact that variables hold references to objects, not objects themselves, has a couple of other consequences that you should be aware of. They follow logically, if you just keep in mind the basic fact that the object is not stored in the variable. The object is somewhere else; the variable points to it.

Suppose that a variable that refers to an object is declared to be `final`. This means that the value stored in the variable can never be changed, once the variable has been initialized. The value stored in the variable is a reference to the object. So the variable will continue to refer to the same object as long as the variable exists. However, this does not prevent the data **in the object** from changing. The variable is `final`, not the object. It's perfectly legal to say

```
final Student stu = new Student();

stu.name = "John Doe";  // Change data in the object;
                        // The value stored in stu is not changed!
                        // It still refers to the same object.
```

Next, suppose that `obj` is a variable that refers to an object. Let's consider what happens when `obj` is passed as an actual parameter to a subroutine. The value of `obj` is assigned to a formal parameter in the subroutine, and the subroutine is executed. The subroutine has no power to change the value stored in the variable, `obj`. It only has a copy of that value. However, the value is a reference to an object. Since the subroutine has a reference to the object, it can change the data stored **in** the object. After the subroutine ends, `obj` still points to the same object, but the data stored **in the object** might have changed. Suppose `x` is a variable of type int and `stu` is a variable of type `Student`. Compare:

```
void dontChange(int z) {
    z = 42;
}

The lines:

   x = 17;
   dontChange(x);
   System.out.println(x);

output the value 17.

The value of x is not
changed by the subroutine,
which is equivalent to

   z = x;
   z = 42;
```

```
void change(Student s) {
     s.name = "Fred";
}

The lines:

   stu.name = "Jane";
   change(stu);
   System.out.println(stu.name);

output the value "Fred".

The value of stu is not
changed, but stu.name is changed.
This is equivalent to

   s = stu;
   s.name = "Fred";
```

5.1.3 Getters and Setters

When writing new classes, it's a good idea to pay attention to the issue of access control. Recall that making a member of a class `public` makes it accessible from anywhere, including from other classes. On the other hand, a `private` member can only be used in the class where it is defined.

In the opinion of many programmers, almost all member variables should be declared `private`. This gives you complete control over what can be done with the variable. Even if the variable itself is private, you can allow other classes to find out what its value is by providing a `public` accessor method that returns the value of the variable. For example, if your class contains a `private` member variable, `title`, of type String, you can provide a method

```
public String getTitle() {
    return title;
}
```

that returns the value of `title`. By convention, the name of an accessor method for a variable is obtained by capitalizing the name of variable and adding "get" in front of the name. So, for the variable `title`, we get an accessor method named "get" + "Title", or `getTitle()`. Because of this naming convention, accessor methods are more often referred to as getter methods. A getter method provides "read access" to a variable. (Sometimes for boolean variables, "is" is used in place of "get". For example, a getter for a boolean member variable named `done` might be called `isDone()`.)

You might also want to allow "write access" to a `private` variable. That is, you might want to make it possible for other classes to specify a new value for the variable. This is done with a setter method. (If you don't like simple, Anglo-Saxon words, you can use the fancier term mutator method.) The name of a setter method should consist of "set" followed by a capitalized copy of the variable's name, and it should have a parameter with the same type as the variable. A setter method for the variable `title` could be written

```
public void setTitle( String newTitle ) {
   title = newTitle;
}
```

It is actually very common to provide both a getter and a setter method for a private member variable. Since this allows other classes both to see and to change the value of the variable, you might wonder why not just make the variable `public`? The reason is that getters and setters are not restricted to

simply reading and writing the variable's value. In fact, they can take any action at all. For example, a getter method might keep track of the number of times that the variable has been accessed:

```
public String getTitle() {
    titleAccessCount++;  // Increment member variable titleAccessCount.
    return title;
}
```

and a setter method might check that the value that is being assigned to the variable is legal:

```
public void setTitle( String newTitle ) {
   if ( newTitle == null )   // Don't allow null strings as titles!
      title = "(Untitled)";  // Use an appropriate default value instead.
   else
      title = newTitle;
}
```

Even if you can't think of any extra chores to do in a getter or setter method, you might change your mind in the future when you redesign and improve your class. If you've used a getter and setter from the beginning, you can make the modification to your class without affecting any of the classes that use your class. The `private` member variable is not part of the public interface of your class; only the `public` getter and setter methods are, and you are free to change their implementations without changing the public interface of your class. If you **haven't** used get and set from the beginning, you'll have to contact everyone who uses your class and tell them, "Sorry people, you'll have to track down every use that you've made of this variable and change your code to use my new get and set methods instead."

A couple of final notes: Some advanced aspects of Java rely on the naming convention for getter and setter methods, so it's a good idea to follow the convention rigorously. And though I've been talking about using getter and setter methods for a variable, you can define get and set methods even if there is no variable. A getter and/or setter method defines a property of the class, that might or might not correspond to a variable. For example, if a class includes a `public void` instance method with signature `setValue(double)`, then the class has a "property" named `value` of type double, and it has this property whether or not the class has a member variable named `value`.

5.1.4 Arrays and Objects

As I noted in Subsection 3.8.1, arrays are objects. Like Strings they are special objects, with their own unique syntax. An array type such as `int[]` or `String[]` is actually a class, and arrays are created using a special version of the `new` operator. As in the case for other object variables, an array variable can never hold an actual array -- only a reference to an array object. The array object itself exists in the heap. It is possible for an array variable to hold the value `null`, which means there is no actual array.

For example, suppose that `list` is a variable of type `int[]`. If the value of `list` is `null`, then any attempt to access `list.length` or an array element `list[i]` would be an error and would cause an exception of type NullPointerException. If `newlist` is another variable of type `int[]`, then the assignment statement

```
newlist = list;
```

only copies the reference value in `list` into `newlist`. If `list` is `null`, the result is that `newlist` will also be `null`. If `list` points to an array, the assignment statement does **not** make a copy of the array. It just sets `newlist` to refer to the same array as `list`. For example, the output of the following code segment

```
list = new int[3];
list[1] = 17;
```

```
newlist = list; // newlist points to the same array as list!
newlist[1] = 42;
System.out.println( list[1] );
```

would be 42, not 17, since `list[1]` and `newlist[1]` are just different names for the same element in the array. All this is very natural, once you understand that arrays are objects and array variables hold pointers to arrays.

This fact also comes into play when an array is passed as a parameter to a subroutine. The value that is copied into the subroutine is a pointer to the array. The array is not copied. Since the subroutine has a reference to the original array, any changes that it makes to elements of the array are being made to the original and will persist after the subroutine returns.

Arrays are objects. They can also hold objects. The base type of an array can be a class. We have already seen this when we used arrays of type `String[]`, but any class can be used as the base type. For example, suppose Student is the class defined earlier in this section. Then we can have arrays of type `Student[]`. For an array of type `Student[]`, each element of the array is a variable of type Student. To store information about 30 students, we could use an array

```
Student[] classlist;  // Declare a variable of type Student[].
classlist = new Student[30];  // The variable now points to an array.
```

The array has 30 elements, `classlist[0]`, `classlist[1]`, ... `classlist[29]`. When the array is created, it is filled with the default initial value, which for an object type is `null`. So, although we have 30 array elements of type Student, we don't yet have any actual Student objects! All we have is 30 nulls. If we want student objects, we have to create them:

```
Student[] classlist;
classlist = new Student[30];
for ( int i = 0; i < 30; i++ ) {
    classlist[i] = new Student();
}
```

Once we have done this, each `classlist[i]` points to an object of type Student. If we want to talk about the name of student number 3, we can use `classlist[3].name`. The average for student number `i` can be computed by calling `classlist[i].getAverage()`. You can do anything with `classlist[i]` that you could do with any other variable of type Student.

[Next Section | Chapter Index | Main Index]