Objects, Instance Methods, and Instance Variables

OBJECT-ORIENTED PROGRAMMING (OOP) represents an attempt to make programs more closely model the way people think about and deal with the world. 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.

Objects, Classes, and Instances

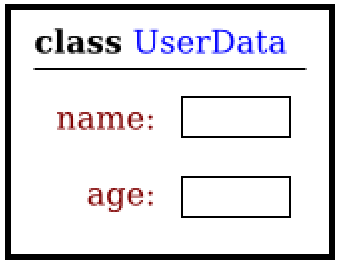
Objects are closely related to classes. We have seen that a class can contain variables and methods (that is, subroutines). If an object is also a collection of variables and methods, how do they differ from classes? And why does it require a different type of thinking to understand and use them effectively?

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;
}
```

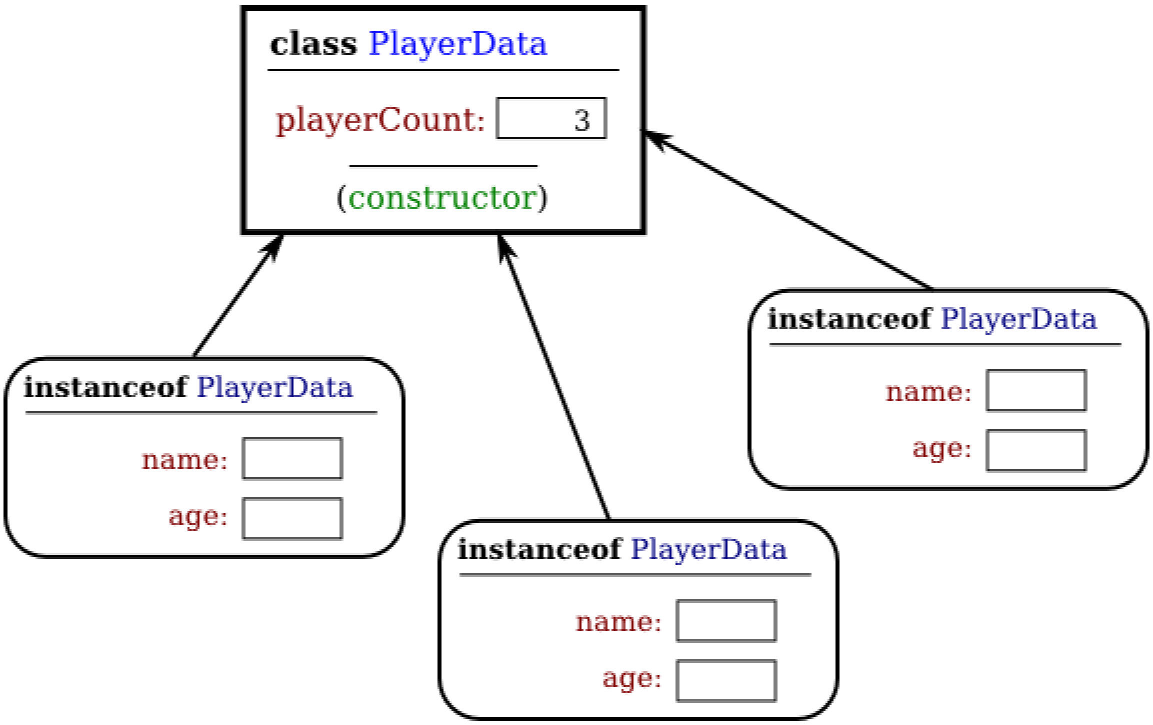
In a program that uses this class, there is only one copy of each of the variables UserData.name and UserData.age. When the class is loaded into the computer, there is a section of memory devoted to the class, and that section of memory includes space for the values of the variables name and age. We 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. Its 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 objects 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.

Fundamentals of Objects

Consider another example, 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 test grades 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.

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,".

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. 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

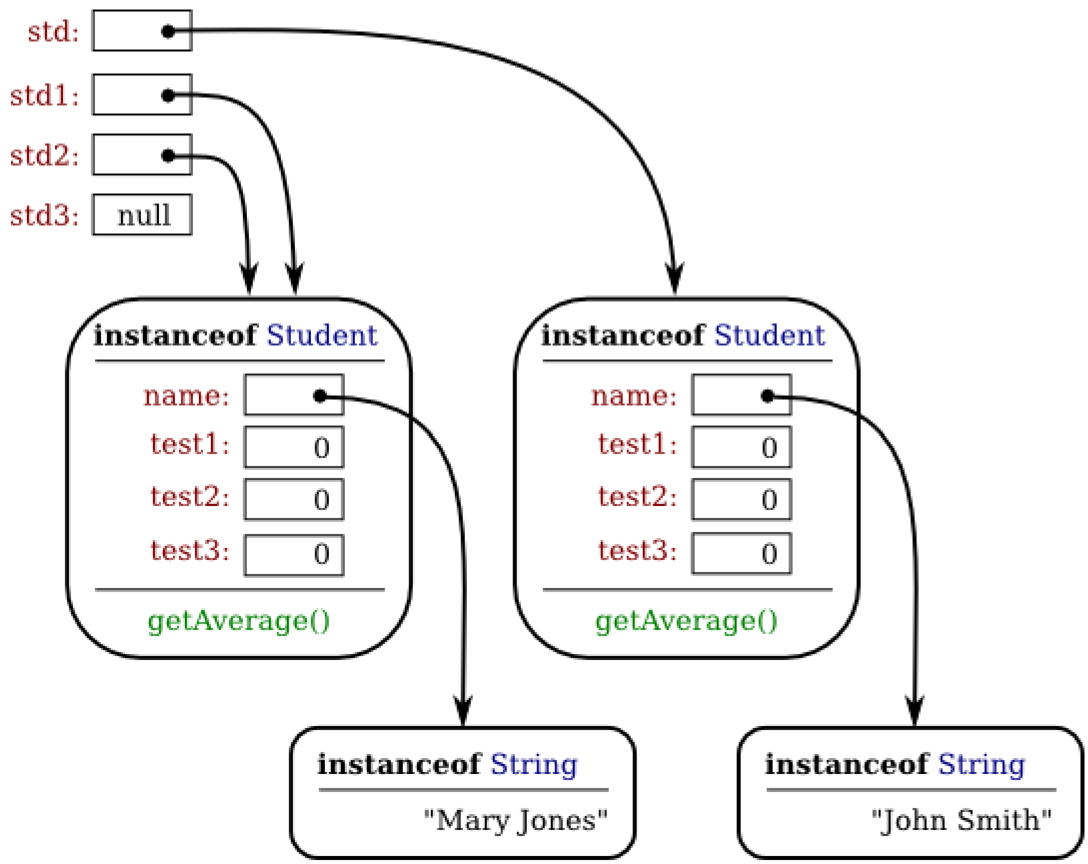
```
if (std == null) . . .
```

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".

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)".

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".)

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);
System.out.println(stu.name);

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);

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";
```

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.

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. 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;
}
```

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.

Arrays and Objects

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.

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*.