Lab: Parameter Passing

The Problem

This lab tackles a fundamental issue in Java programs: the difference between primitive and reference types and how assignment and parameter passing behave with each of these types. The short (and possibly still confusing) story is as follows:

1. A *variable* is the name of a "location" that "stores" a value of a particular type.
2. For variables of *primitive* types, the value stored is the actual value of the type, e.g., an `int` variable stores what you should think of as a mathematical integer within some bounds.
3. For variables of *reference* types, the value stored is a reference (or a memory address referring) to an object whose value is the specified mathematical model of the type, e.g., a `String` variable stores the value of a reference to an object whose value is a string of characters.
4. Both assignment and parameter passing in Java are consistent in that they *copy* the value stored in the variable being assigned from or the argument being passed to the method call -- which for primitive types is the actual value, but for reference types is the reference value rather than the object value.
5. For example,

```
1  int i, j;
2  i = 3;
3  j = i;
4  i = i + 1;
```

   results in the value of (primitive variable) `i` being copied into `j` (line 3) and when we increment the value of `i` (line 4), `i` ends up with the value 4 but `j` still has value 3.
6. On the other hand,

```
1  NaturalNumber n, m;
2  n = new NaturalNumber2(3);
3  m = n;
4  n.increment();
```

   results in the value of (reference variable) `n` being copied into `m` (line 3) and that means that `n` and `m` are now referring to the same `NaturalNumber` object (i.e., they are *aliases*), and when we increment the value of the number `n` refers to (line 4), `n` ends up referring to an object with the value 4 and `m` also refers to the same object with value 4.
7. Parameter passing exhibits a similar behavior because it involves the copying of the actual arguments into the formal parameters.

Consider the following tracing tables: each of them has a short method declaration followed by short client code that invokes the method. Carefully complete each tracing table starting from the client code and tracing over the method call and through the method body. Discuss them with the classmate sitting next to you and write down all the answers so that an instructor can check them out. If you encounter any problems or you have any doubts about any of the traces, please make sure you ask an instructor for help.

1. Parameter passing for primitive types:

Statement	Variable Values
`private static void test1(int i) {`	
	i = 7
`    i = i + 1;`	
	i = 8
`}`	
Start tracing here	
`int x = 7;`	
	x = 7
`test1(x);`	
	x = 7

2. Parameter passing for (immutable) reference types:

Statement	Variable Values
`private static void test2(String s) {`	
	s → `"hello"`
`    s.toUpperCase();`	
	s → `"HELLO"`
`}`	
Start tracing here	
`String str1 = "hello";`	
	str1 → `"hello"`
`test2(str1);`	
	str1 → `"hello"`

3. Parameter passing for (mutable) reference types:

Statement	Variable Values
`private static void test3(NaturalNumber n) {`	
	n → `17`
`    n.increment();`	
	n → `18`
`}`	
Start tracing here	
`NaturalNumber num1 = new NaturalNumber2(17);`	
	num1 → `17`
`test3(num1);`	
	num1 → `18`

Setup

Follow these steps to set up a project for this lab.

1. Create a new Eclipse project by copying `ProjectTemplate`. Name the new project `ParameterPassing`.
2. Open the `src` folder of this project and then open `(default package)`. As a starting point you can use any of the Java files. Rename it `ParameterPassing` and delete the other files from the project.
3. Follow the link to `ParameterPassing.java`, select all the code on that page (click and hold the left mouse button at the start of the program and drag the mouse to the end of the program) and copy it to the clipboard (right-click the mouse on the selection and choose **Copy** from the contextual pop-up menu), then come back to this page and continue with these instructions.
4. Finally in Eclipse, open the `ParameterPassing.java` file; select all the code in the editor, right-click on it and select **Paste** from the contextual pop-up menu to replace the existing code with the code you copied in the previous step. Save your file.

Method

Run the program and compare the output for the first three test method calls (corresponding to the three tracing tables above). Does the observed behavior match the expected behavior from your tracing tables?

Let's use the Eclipse debugger to follow step-by-step the execution of the first three test methods. Set a breakpoint on the first line of the main method and start the program in the Eclipse debugger (see the debugging lab if you don't remember how to do that).

Single-step through the program until you reach the statement invoking `test1` , but do not execute the method call yet. Here is what to look for in the debugger perspective at this point in the execution.

- The editor shows we are about to execute the statement `test1(x)`.

- The **Variables** view shows the variables in scope and, in particular, that `int` variable `x` has value 7.

- The **Console** view displays the current output, including the value of `x` before the call to `test1(x)`.

- In the top left corner of the perspective, note the **Debug** view. This view contains some information that is beyond the scope of this lab, but note that the highlighted line tells us that we are on line 160 (in the screen shot; your line number may be different if you edited the program) of the `main` method in class `ParameterPassing`. Soon we'll see how useful this view can be.

Stepping Into a Method Call

Now we want to track what happens to the parameter inside the `test1` method body. Click on the **Step Into** button in the toolbar at the top of the perspective.

Note the following:

- The editor shows we are now in the body of `test1` ready to execute its first (and only) statement.

- The **Variables** view shows the variables in scope inside `test1`: there is only one and that is the parameter `i` whose value, as expected, is 7.

- The highlighted line in the **Debug** view tells us that we are on line 29 (in the screen shot) of the `test1` method in class `ParameterPassing`.

The beauty of the Eclipse debugging perspective (and all perspectives) is that all the views displayed are kept in sync. In the **Debug** view, click on the line `ParameterPassing.main(String[])...` and observe what happens in the **Console** and **Variables** views.

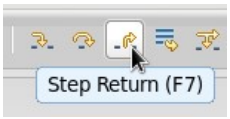
As you can see, they are updated to display the information about the state of the program back in the `main` method. If in the **Debug** view you click on the line `ParameterPassing.test1(int)...` , the various views revert back to showing the state of the program while inside the call to `test1` . This is an extremely useful feature and one that we can leverage in this lab to keep track of whether values of variables change and when.

Parameter Passing of Primitive Types

At this stage in the excution, we can see that the value of the argument `x` passed to method `test1` was copied into the formal parameter `i` and that's why the current value of `i` is 7.

Step over the assignment statement `i = i + 1;` in the body of `test1` by clicking on the **Step Over** button in the toolbar. You can see in the **Variables** view that the value of `i` is updated to the value 8. However, now click on the line `ParameterPassing.main(String[])...` in the **Debug** view and observe that the value of `x` is still 7.

Let's get out of `test1` . Click again on the line `ParameterPassing.test1(int)...` in the **Debug** view and then click on the **Step Return** button in the toolbar.

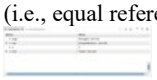


This takes us back to the `main` method just after the call to `test1` . Note that the value of `x` is still 7, so it is clear that the value of the parameter (`i` with value 8) has not been copied back into the actual argument. Click **Step Over** twice to complete the first test.

Parameter Passing of (Immutable) Reference Types

Let's step through the second test involving `String` s. Click **Step Over** three times to get to the call to the `test2` method. Look at the **Variables** view and note that the `String str1` has the value `"hello"` . However, because `String` is a *reference* type, Eclipse debugger displays also a numeric *id* that uniquely identifies a reference (in the screen shot, the id for `str1` is `id=25` ; the id you see may be different). This id allows us to recognize aliases

(i.e., equal references) because aliased references will have the same id value.



Now let's step into the `test2` method by clicking on the **Step Into** toolbar button. You can see that the **Variables** view is updated to display the only variable in the new scope which is the formal parameter `s` . Two things must be noted: first, the value of the `String` `s` is `"hello"` and second, the id for `s` is 25 (in the screen shots), the same as the id for the actual argument `str` . This shows that `str` and `s` are aliases, they refer to the same object whose value is `"hello"` .

Execute the statement in `test2` 's body by clicking the **Step Over** button. You might be surprised by what happens: *nothing*! The value of `s` does not change (the id is still the same and the object value is still the same). How is that possible? It turns out that `String` is an *immutable* type and that means that there are no methods in the `String` class that modify the value of the `String` they are called on. In particular, `s.toUpperCase` does not modify `s` ; it creates a new `String` object with the value of `s` converted to upper case and returns a reference to that object. The body of `test2` simply ignores the value returned by `s.toUpperCase` (which is probably not something the programmer should do and that's why *SpotBugs* marks this statement with an appropriate warning).

You can complete this test by clicking **Step Return** to return to the `main` method and then clicking **Step Over** twice. It should not be a surprise that `str` was not changed by the method call.

Parameter Passing of (Mutable) Reference Types

Single-step through the next test (`test3`) and use what you have learned about parameter passing, references, and the Eclipse debugger to see what happens and make sure you understand why. If needed, you should correct your trace and pay particular attention to those steps where the observed behavior differs from what you expected. If you have any question, make sure to ask your instructor.

More Traces

The program contains several more tests involving more examples of parameter passing. They are meant to help you understand this potentially confusing concept and they give you a chance to test your understanding.

For each of the following tracing tables, first complete the tracing table, and then single-step through the corresponding test to see whether the code behaves as you expected. Any time the observed behavior does not match your expectations, you should stop and try to understand where your trace went wrong. Make sure to ask your instructor for help if you cannot figure it out on your own.

Statement	Variable Values
`private static void test4(String s) {`	
	s → `"hello"`
`s = s.toUpperCase();`	
	s → `"HELLO"`
`}`	
Start tracing here	
`String str2 = "hello";`	
	str2 → `"hello"`
`test4(str2);`	
	str2 → `"hello"`

Statement	Variable Values
`private static void test5(String s) {`	
	s → `"Hello"`
`s = s + ", world!";`	
	s → `"Hello world!"`
`}`	
Start tracing here	

`String str3 = "Hello";`	
	str3 → "Hello"
`test5(str3);`	
	str3 → "Hello"

Statement	Variable Values
`private static void test6(NaturalNumber n) {`	
	n → 17
`    n = new NaturalNumber2(n.toString() + "1");`	
	n → 171
`}`	
Start tracing here	
`NaturalNumber num2 = new NaturalNumber2("17");`	
	num2 → 17
`test6(num2);`	
	num2 → 17

Statement	Variable Values
`private static void swap1(int i1, int i2) {`	
	i1 = 5 i2 = 8
`    int tmp = i1;`	
	i1 = 5 i2 = 8 tmp = 5
`    i1 = i2;`	
	i1 = 8 i2 = 8 tmp = 5
`    i2 = tmp;`	
	i1 = 8 i2 = 5 tmp = 5
`}`	
Start tracing here	
`int x1 = 5, x2 = 8;`	
	x1 = 5 x2 = 8
`swap1(x1, x2);`	
	x1 = 5 x2 = 8

Statement	Variable Values
`private static void swap2(String s1, String s2) {`	
	s1 → "legends" s2 → "leaders"
`    String tmp = s1;`	
	s1, tmp → "legends" s2 → "leaders"
`    s1 = s2;`	
	s1, s2 → "leaders" tmp → "legends"
`    s2 = tmp;`	
	s1 → "leaders" s2, tmp → "legends"
`}`	
Start tracing here	
`String str1 = "legends", str2 = "leaders";`	
	str1 → "legends" str2 → "leaders"
`swap2(str1, str2);`	
	str1 → "legends" str2 → "leaders"

Statement	Variable Values
`private static void swap3(NaturalNumber n1, NaturalNumber n2) {`	
	n1 → 43210 n2 → 24601
`    NaturalNumber tmp = n1;`	
	n1, tmp → 43210 n2 → 24601
`    n1 = n2;`	
	n1, n2 → 24601 tmp → 43210
`    n2 = tmp;`	
	n1 → 24601 n2, tmp → 43210
`}`	

Start tracing here	
`NaturalNumber num1 = new NaturalNumber2(43210), num2 = new NaturalNumber2(24601);`	
	num1 → `43210` num2 → `24601`
`swap3(num1, num2);`	
	num1 → `43210` num2 → `24601`

Additional Activities

For each of the following tracing tables involving arrays, first complete the tracing table, and then single-step through the corresponding test to see whether the code behaves as you expected. Any time the observed behavior does not match your expectations, you should stop and try to understand where your trace went wrong.

1. Parameter passing for array types:

Statement	Variable Values
`private static void test4(int[] a) {`	
	a → `{1, 2, 3}`
`    a[0] = a[0] + 1;`	
	a → `{2, 2, 3}`
`}`	
Start tracing here	
`int[] array = { 1, 2, 3 };`	
	array → `{1, 2, 3}`
`test4(array);`	
	array → `{2, 2, 3}`

2. Swapping for array types:

Statement	Variable Values
`private static void swap4(int[] a1, int[] a2) {`	
	a1 → `{ 2, 2, 2, 1 }` a2 → `{ 10, 2, 2012 }`
`    int[] tmp = a1;`	
	a1, tmp → `{ 2, 2, 2, 1 }` a2 → `{ 10, 2, 2012 }`
`    a1 = a2;`	
	a1, a2 → `{ 10, 2, 2012 }` tmp → `{ 2, 2, 2, 1 }`
`    a2 = tmp;`	

	a1 → `{ 10, 2, 2012 }` a2, tmp → `{ 2, 2, 2, 1 }`
}	
Start tracing here	
`int[] array1 = { 2, 2, 2, 1 };` `int[] array2 = { 10, 2, 2012 };`	
	array1 → `{ 2, 2, 2, 1 }` array2 → `{ 10, 2, 2012 }`
`swap4(array1, array2);`	
	array1 → `{ 2, 2, 2, 1 }` array2 → `{ 10, 2, 2012 }`