CS 228: Introduction to Data Structures
Lecture 5
Friday, January 23, 2015

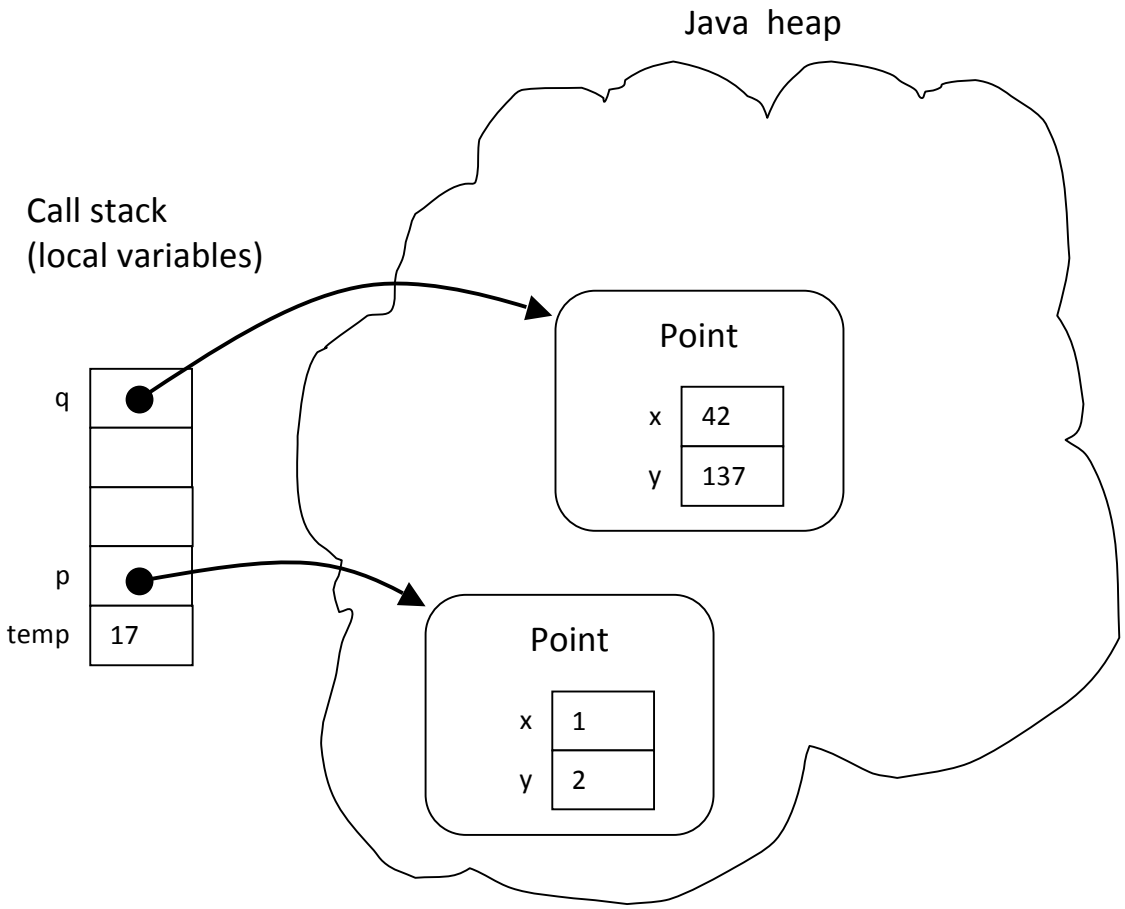
Primitive Types and Object Types

A Java ***primitive type*** variable is literally a memory location that stores the value of that variable. Java has 8 primitive types:

1. `byte`: 8-bit signed two's-complement integers
2. `short`: 16-bit signed two's-complement integers
3. `int`: 32-bit signed two's-complement integers
4. `long`: 64-bit signed two's-complement integers
5. `char`: 16-bit unsigned integers representing Unicode characters.
6. `float`: 32-bit IEEE 754 floating-point numbers
7. `double`: 64-bit IEEE 754 floating-point numbers.
8. `boolean`: has exactly two values: true and false.

Every non-primitive variable is an ***object reference***: Java does not store the actual value or values that make up the object, it only stores a ***reference*** to that object in the ***Java heap***.

```
int temp = 17;
Point p = new Point(1, 2);
Point q = new Point(42, 137);
```



Now suppose we write:

```
Point r = q;
```

By definition of non-primitive variables:

*The object is **not** copied, only the reference!*

Suppose we now write:

```
p = q;
```

The object that `p` referenced before the statement (the `Point` with coordinates (1,2)) is now unreferenced — it becomes "garbage". Unreferenced objects are eventually ***garbage collected***.

The next table compares object types and primitive types.

	Object types	**Primitive types**
Contains a	reference	built-in
How defined?	class definition	9, 42.5, 'h', `false`
How created?	"`new`"	default (usually zero)
How used?	method	operators: +, -, *, etc
Testing equality	`equals()` (override)	==

The last row deserves further explanation . . .

Equality and the `equals()` Method

The operation "`p == q`" determines whether variables p and q have the same values. When p and q are of the same primitive type, this corresponds to the usual notion of equality testing. For instance, suppose p and q are `int` variables and we set `p = 2`. Then, if we set `q = 3`, `p == q` is false and if we set `q = 2`, `p == q` is true.

When p and q are of object types, however, "`p == q`" determines whether variables p and q ***reference*** the same object. It does not determine whether the objects are "the same". For instance, suppose we execute the following statements.

```
Point p = new Point(1, 2);
Point q = new Point(1, 2);
```

Intuitively, p and q are "the same"; however, `p == q` is false, because p and q reference different objects.

In Java, the notion of equality testing is captured by the `equals()` method. The default implementation of `equals()` in `java.lang.Object` just compares object references. Thus, if we use this default implementation,

`p.equals(q)` would be false. We need to ***override*** the default `equals()` method to make it correspond to our notion of "sameness" of `Point` objects.[1] That is, we want `p.equals(q)` to return `true` if and only if the x and y coordinates of p and q match.

The code below (which should be inserted within the body of the `Point` class) illustrates the standard way to override `equals()`.

```
@Override
public boolean equals(Object obj)
{
  if (obj == null ||
      obj.getClass() != this.getClass())
  {
    return false;
  }

  Point other = (Point) obj;
  return x == other.x && y == other.y;
}
```

[1]The Java `Point` class (`java.awt.Point`) implements `equals()` exactly as we want it: Points are equal only if they have the same coordinates.

Note that `obj`, the method argument, must be an `Object`, not a `Point`, because the signature of `equals()` in `java.lang.Object` is

```
boolean equals(Object obj)
```

and, to override a method, we must match its signature.

Our implementation of `equals()` first verifies that `obj` is not `null` and that it is also a `Point` object (if the other object is not a `Point`, we should not attempt to examine its coordinates). After verifying that `obj` is indeed a `Point`, we need to downcast `obj` to the `Point` type, to let the compiler know that we can access the instance variables x and y.[2]

Note. Some textbook authors and developers use the `instanceof` operator in the `equals()` method to test if objects are of the same class:

```
if (!(obj instanceof Point))
   return false;
```

[2] Note that we can access the instance variables x and y, because `equals()` is defined within the body of the `Point` class.

We will not do that here; instead, we will always test for class equality using `getClass()`. The reason is that `instanceof` does not work correctly when inheritance is involved; in fact it will be incorrect for subtypes of `Point`. We will not go into further details; to fully understand the issues, you first need to understand the formal definition of `equals()` (which is given in the Appendix).

`equals()` and the `String` class

Suppose we do the following.

```
String s = "hurley";
String t = "HURLEY".toLowerCase();
```

Now strings `s` and `t` contain the same characters, but they ***are not*** the same object.

```
System.out.println(s == t);          // false
```

As you probably saw in ComS 227, the proper way to test if two strings are the same (i.e., contain the same characters), is to use the `equals()` method.

```
System.out.println(s.equals(t));   // true
```

This behaves as you would expect, because the implementors of Java have done some work for you: the `String` class overrides `equals()` to check whether the characters are the same.

Another Example

The same pattern we used for the `Point` class to override `equals()` for other classes. Here is an `equals()` method for the `Dog` class:

```
@Override
public boolean equals(Object obj)
{
   if (obj == null ||
          obj.getClass() != getClass())
      return false;

   Dog other = (Dog) obj;
   return name.equals(other.name) &&
           license.equals(other.license);
}
```

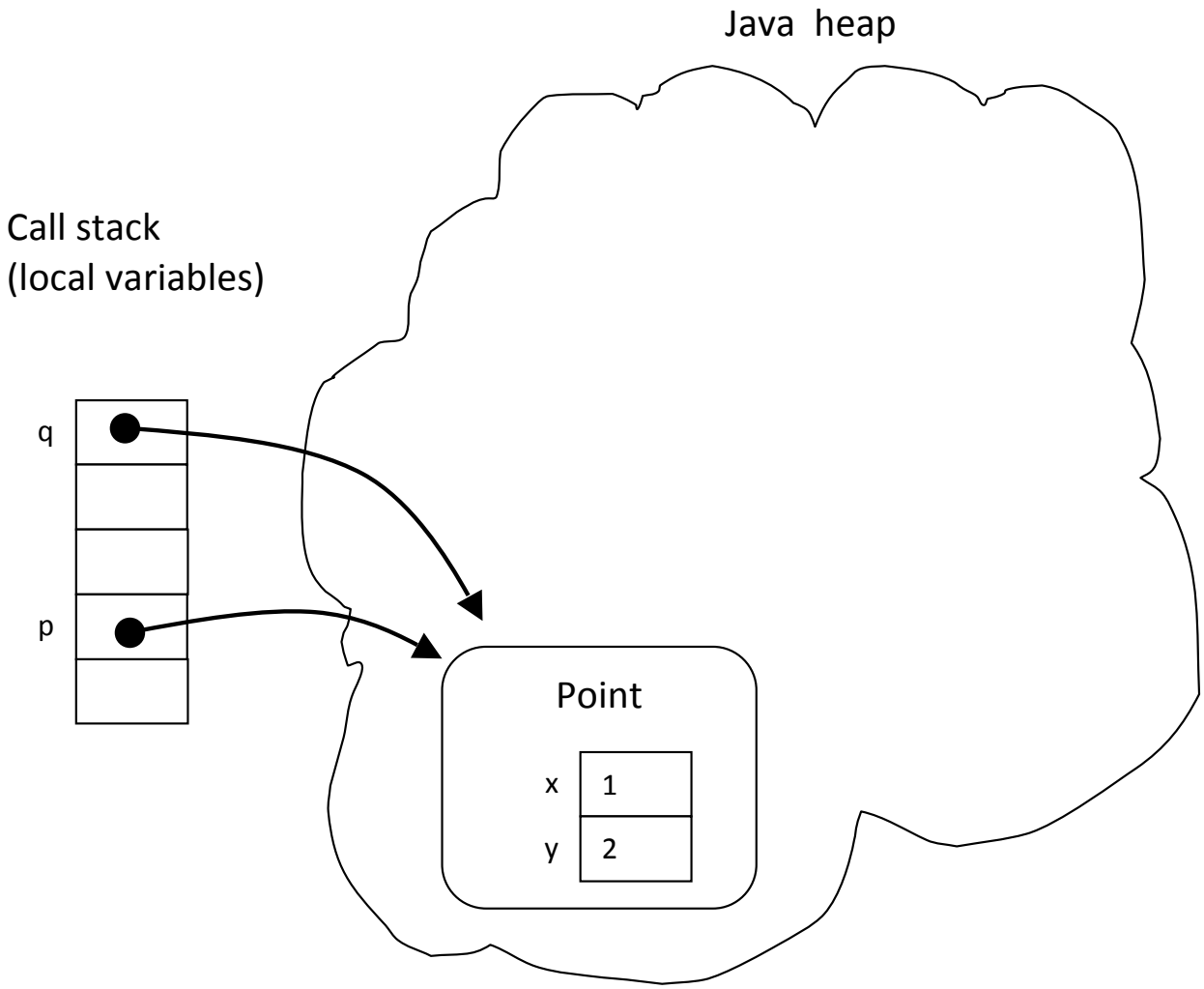
Note how `equals()` calls itself. Of course, this (recursive) call is to the `equals()` method for the `License` class (which we assume is implemented). Note that the same implementation can be used by subclasses such as `Retriever`.

Copying and Cloning

Suppose we execute these two statements:

```
Point p = new Point(1, 2);
Point q = p;
```

Here is the result:



The second assignment does not make a copy of the `Point` object, it just assigns the reference. That is, q is now an ***alias*** for p. This is potentially dangerous, since any changes we make through q affect p as well, which might not be what we want.

In order to make an actual copy of an object, we have to implement a special method to do so. Two common options are to

- write a ***copy constructor*** or

- write a cloning method.

We will illustrate these approaches using the `Point` class.

Copy Constructors

A copy constructor initializes the object under construction ("`this`" object) using the values from an existing one:

```
  public Point(Point existing)
  {
    this.x = existing.x;
    this.y = existing.y;
  }
```

Usage:

```
Point p = new Point(1, 2);
q = new Point(p);
```

Cloning

A cloning method returns a ***new*** object from the values in `this` object. Here is an an ad-hoc cloning method for the `Point` class.

```
public Point makeClone()
{
  Point copy = new Point();
  copy.x = this.x;
  copy.y = this.y;
  return copy;
}
```

Usage:

```
Point p = new Point(1, 2);
q = p.makeClone();
```

Another option is to override Java's `Object.clone()` method. For this, you either have to explicitly declare that your class implements the `Cloneable` interface or some superclass of your class must implement `Cloneable`. Thus, the declaration for Point would be

```
public class Point implements Cloneable{…}
```

We will see how to override `clone()` next time.

Appendix: Formal Definition of `equals()`

The Java documentation[3] specifies that `equals()` implements an *equivalence relation* on non-null object references. That is, it satisfies the following properties.

- **Reflexivity:** for any non-null reference value `x`, `x.equals(x)` should return `true`.
- **Symmetry:** for any non-null reference values `x` and `y`, `x.equals(y)` should return `true` if and only if `y.equals(x)` returns `true`.
- **Transitivity:** for any non-null reference values `x`, `y`, and `z`, if `x.equals(y)` returns `true` and `y.equals(z)` returns true, then `x.equals(z)` should return `true`.
- **Consistency:** for any non-null reference values `x` and `y`, multiple invocations of `x.equals(y)` consistently return `true` or consistently return `false`, provided no information used in `equals` comparisons on the objects is modified.
- **Nothing equals null except null:** For any non-null reference value `x`, `x.equals(null)` should return `false`.

[3] http://docs.oracle.com/javase/8/docs/api/java/lang/Object.html#equals(java.lang.Object)

Exercise: Which of these properties imply that we should use `getClass()` instead of `instanceof()` in `equals()`?