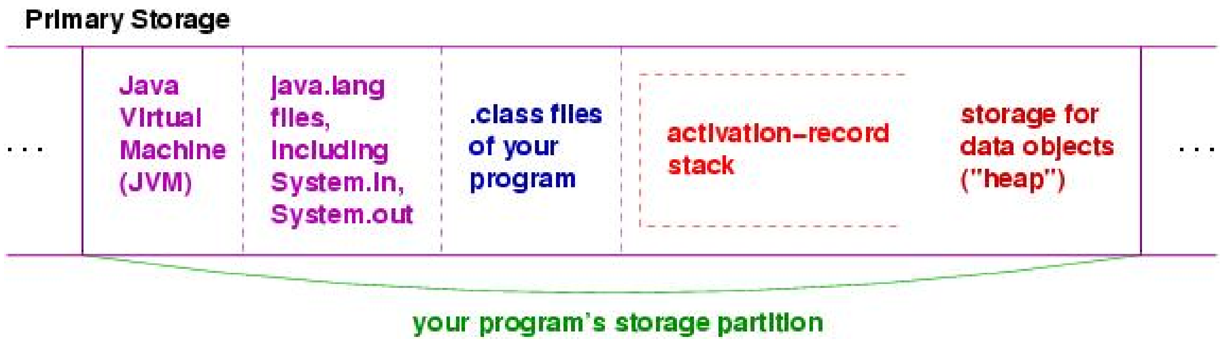
Source: http://people.cs.ksu.edu/~schmidt/300s05/Lectures/Lecture3.html

# The activation-record stack

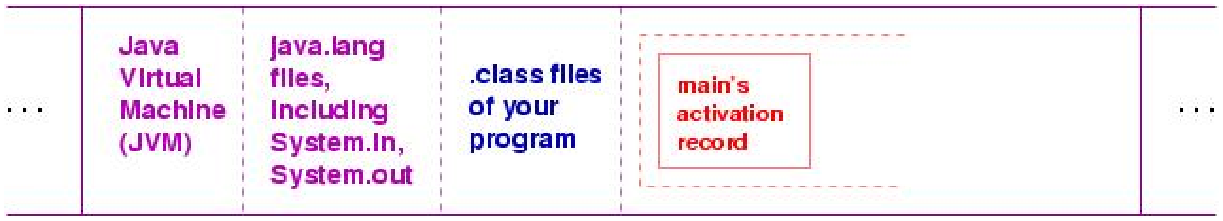
Almost every programming language that contains procedures or methods in its vocabulary is implemented with a stack structure, and this is also the case with Java.

The earlier lecture on execution semantics showed how objects are constructed within a process's storage partition. But the presentation in that lecture simplified the semantics of method call --- the lecture showed the code of an invoked method ``copied'' into the object that was the target of the invocation. In reality, no code is copied into objects; instead, an *activation record* is constructed and pushed onto the process's *activation record stack*.

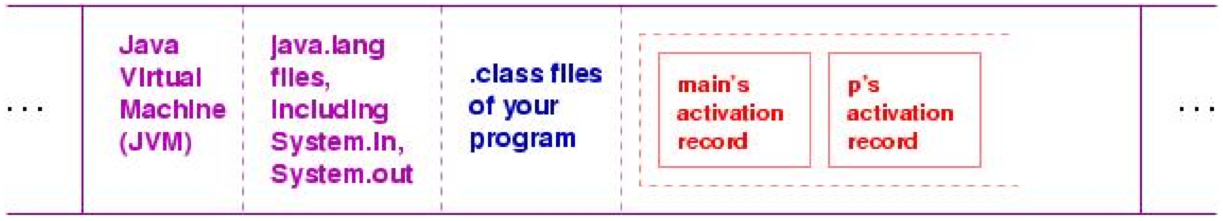
First, recall that a program's storage partition looks like this:


Primary Storage
. . .
Java Virtual Machine (JVM)
java.lang files, including System.in, System.out
.class files of your program
activation-record stack
storage for data objects ("heap")
. . .
your program's storage partition

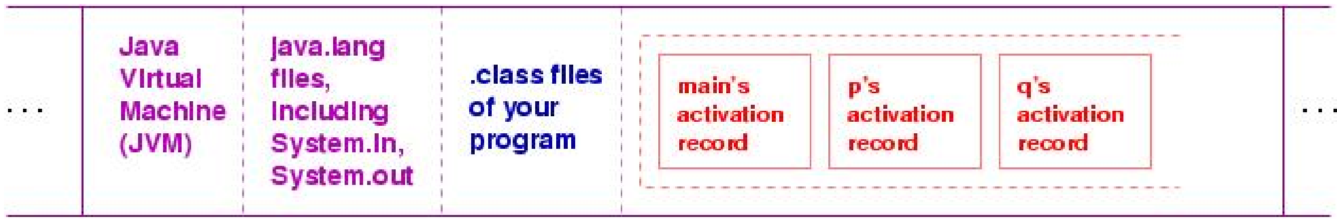
The storage used for data will be used to build a stack at the ``left end,'' and objects will be constructed at the ``right end.'' When a program's `main` method is started, the partition looks like this:


. . .
Java Virtual Machine (JVM)
java.lang files, including System.in, System.out
.class files of your program
main's activation record
. . .

A record for `main` is pushed onto the activation record stack; the record holds cells for `main`'s local variables and the return address to which the JVM should jump when `main` finishes. Say that `main` calls a method, `p`. Then, an activation record holding `p`'s local variables and return address is pushed onto the stack:


. . .
Java Virtual Machine (JVM)
java.lang files, including System.in, System.out
.class files of your program
main's activation record
p's activation record
. . .

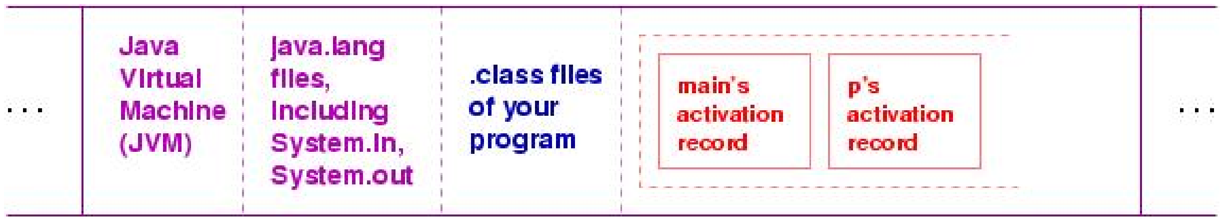
If `p` calls `q`, the same happens:


. . .
Java Virtual Machine (JVM)
java.lang files, including System.in, System.out
.class files of your program
main's activation record
p's activation record
q's activation record
. . .

The pictures show us that

- **the activation-record stack *remembers the history of incompleted method calls*, and**
- **the topmost activation record *holds the data values for the currently executing method.***

When `q` finishes, its activation record is popped, and the configuation reverts to


. . .
Java Virtual Machine (JVM)
java.lang files, including System.in, System.out
.class files of your program
main's activation record
p's activation record
. . .

Now, `p` can finish its execution from the point where it paused to invoke `q`. When `p` finishes, its record is popped, and `main` can finish.

Now we study an example to see how this concept applies to methods associated with objects.

## An example

Here is a small Java application:

```
public class Controller
{ public static void main(...)
  { int x = 2;
    Model m = new Model();
    m.set(x+1);
    System.out.println( m.get() );
} }


public class Model
{ private int val;

  public Model() { val = 0; }

  public void set(int w)
  { Model x = new Model();
    val = w; }

  public int get() { return val; }
}
```

When the Java compiler checks these two classes and translates them into .class files, it makes some small but crucial changes; the changes are marked by `//!`:

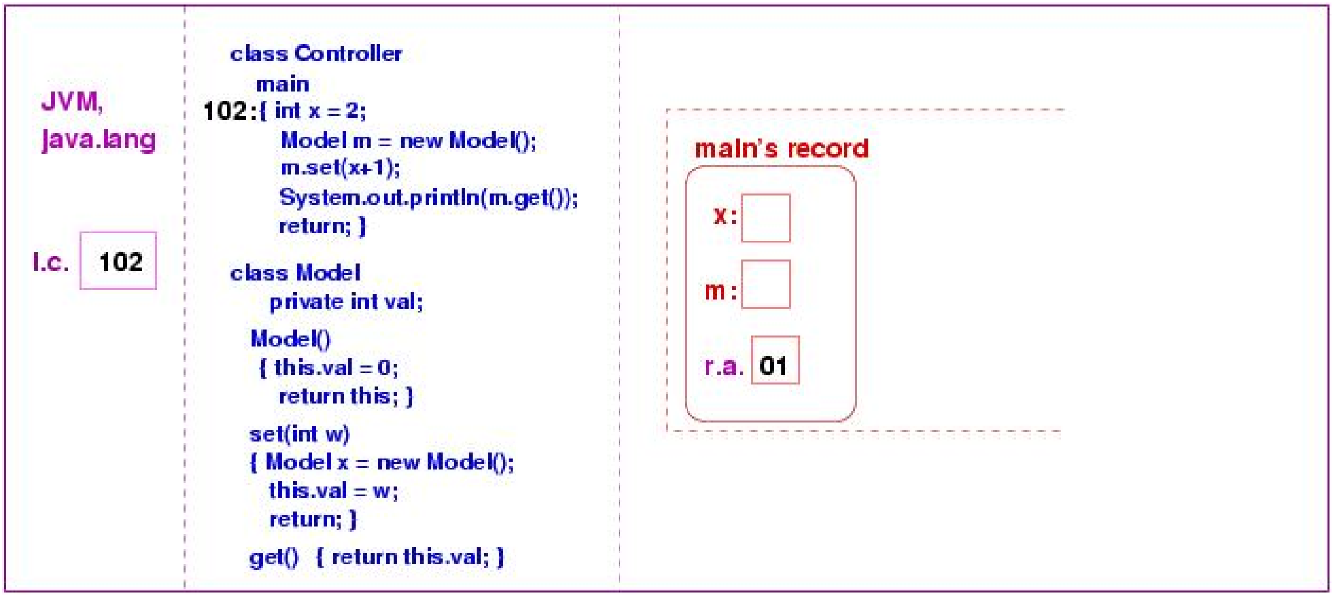
```
public class Controller
{ public static void main(...)
  { int x = 2;
    Model m = new Model();
    m.set(x+1);
    System.out.println( m.get() );
    return;  //!
  } }


public class Model
{ private int val;

  public Model()
  { this.val = 0;   //!
    return this;    //!
  }

  public void set(int w)
  { Model x = new Model();
```

```
    this.val = w;  //!
    return;  //!
  }

  public int get()
  { return this.val; } //!
}
```

First, every method is ended with an explicit `return` statement, which clarifies when control leaves the method and returns to the method's caller. Second, within each class, references to the class's fields (attributes) are prefixed by `this`. When we study the example's execution semantics, we will see that `this` is an extra local variable that helps associate method code with the object that the method manipulates.

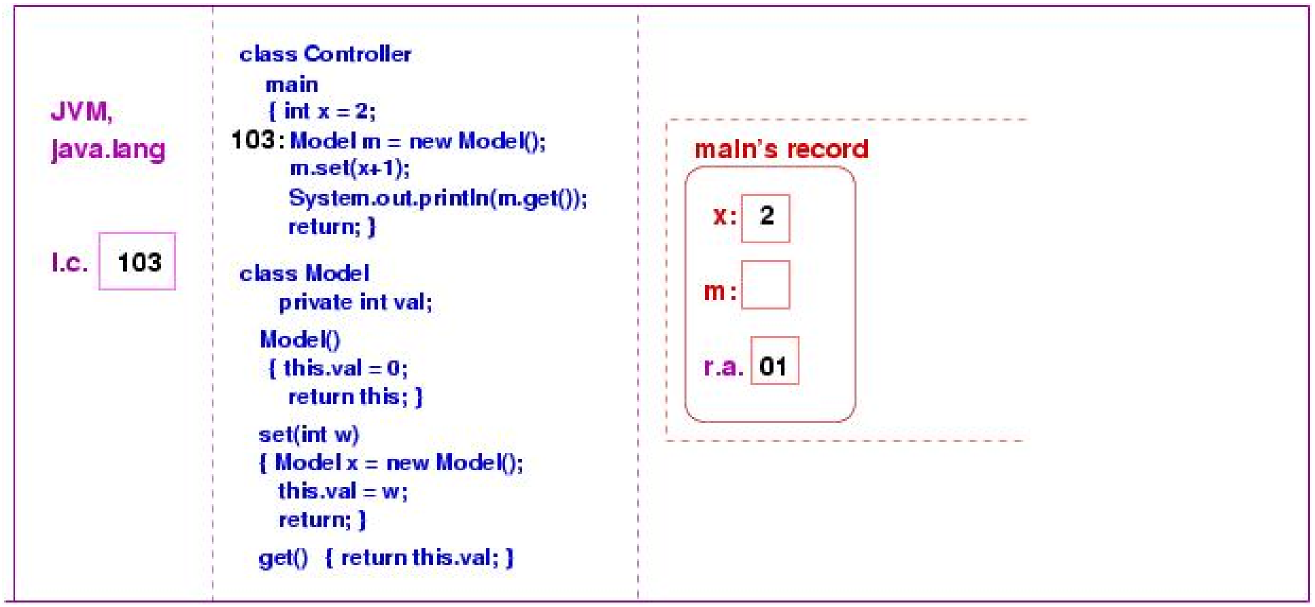
In the previous lecture, we learned that the Java compiler next reformats the code into posfix notation and then into byte code. Because byte code is difficult for humans to read, we will not use the byte-code versions of the two example classes in the example that follows.

When the program is started (`java Controller`), the JVM and `java.lang` are loaded into the partition. Then, `Controller.class` and `Model.class` are loaded, and the controller's `main` method is started: an activation record for `main` is pushed onto the activation-record stack:



As noted earlier, `main`'s record holds cells for its two local variables, `x` and `m`, as well as the return address of where execution should continue when `main` finishes and returns.

The first instruction that executes, at address 102, saves 2 in `x`'s cell:



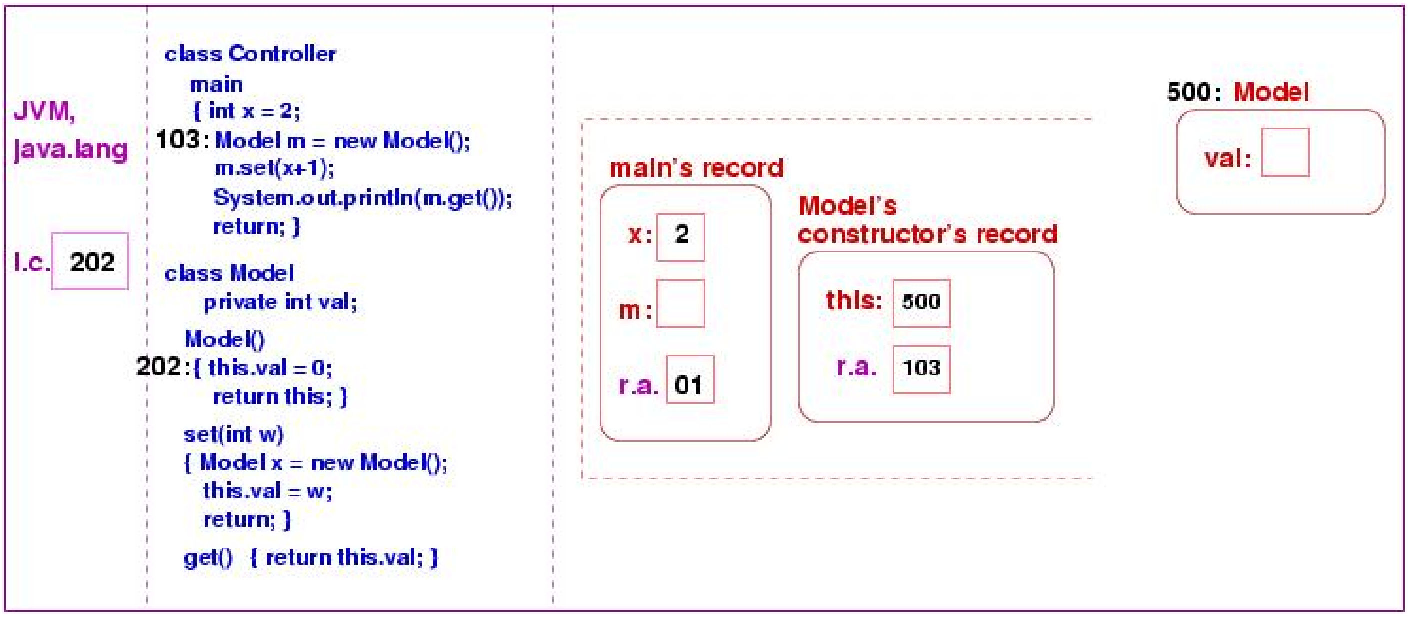
```
class Controller
   main
   { int x = 2;
103: Model m = new Model();
      m.set(x+1);
      System.out.println(m.get());
      return; }

class Model
    private int val;

  Model()
   { this.val = 0;
      return this; }

  set(int w)
  { Model x = new Model();
    this.val = w;
    return; }

  get()  { return this.val; }
```

The next instruction, at address 103, constructs a new `Model` object. Several steps must be performed:

1. A `Model` object is constructed in heap storage, and a cell for its private variable, `val`, is allocated therein.
2. The object's constructor method is immediately executed.
3. The address of the newly constructed object is returned as the result of executing the constructor method.

The picture below shows Step 1: The object is constructed, a cell is allocated for its variable, `val`, and its constructor method is started. (The instruction counter in the JVM is reset to 202, the first instruction in the constructor method.)

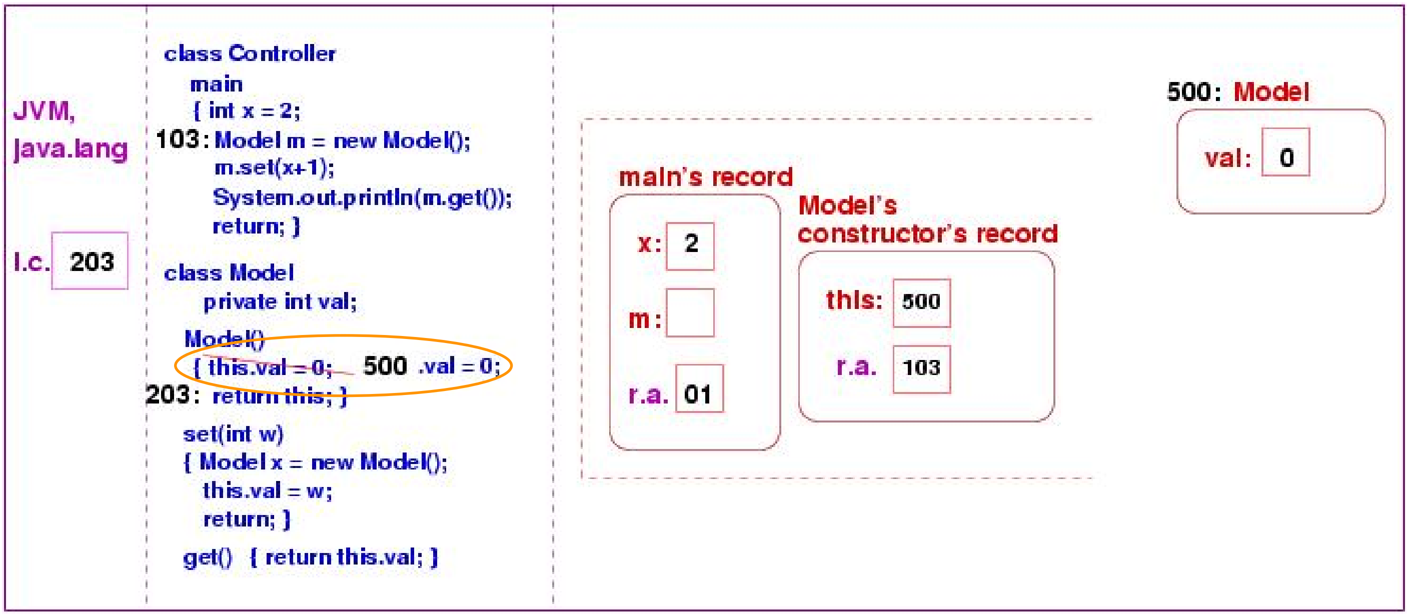
The constructor method's activation record is pushed onto the stack. It holds cells for the method's local variables (in this case, none), and it holds the return address back to `main`'s code. It holds an additional cell, `this`, which *holds the address of the newly constructed object*.



```
class Controller
   main
   { int x = 2;
103: Model m = new Model();
      m.set(x+1);
      System.out.println(m.get());
      return; }

class Model
    private int val;

  Model()
202:{ this.val = 0;
      return this; }

  set(int w)
  { Model x = new Model();
    this.val = w;
    return; }

  get()  { return this.val; }
```

The picture shows that *no code is copied into the `Model` object* --- the code stays where it is, and the instruction counter holds the code's address.

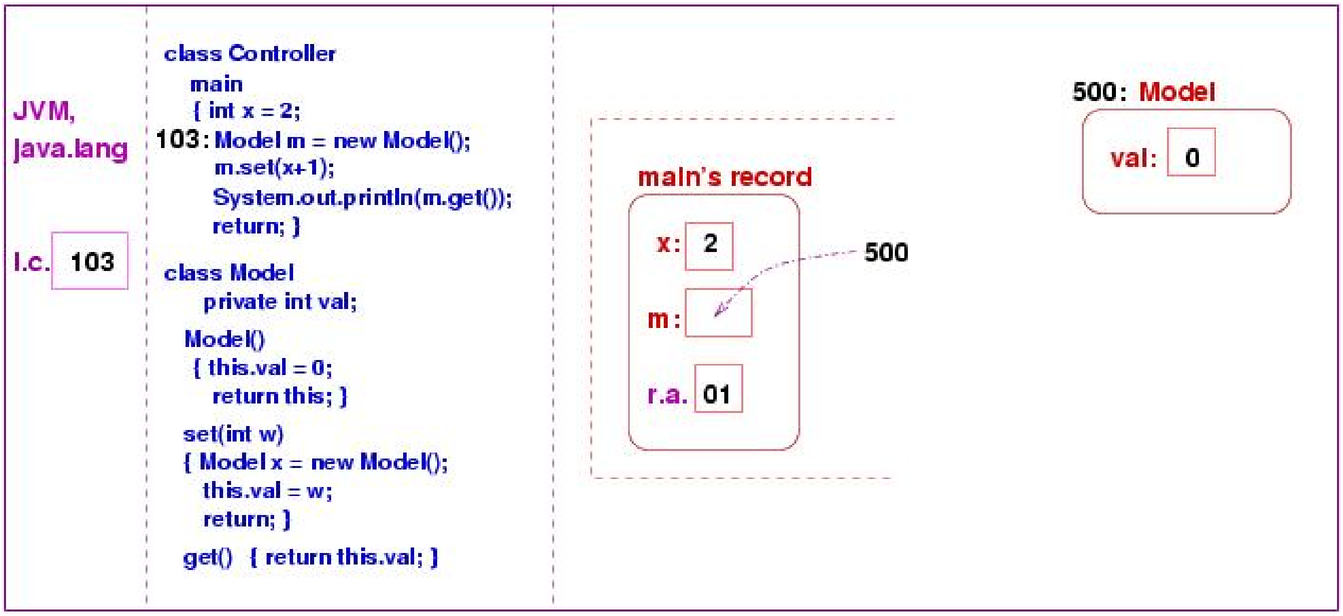
Now, we learn why the Java compiler reformatted the assignment, `val = 0`, into `this.val = 0`. The value of variable, `this`, is found within the topmost record of the activation-record stack --- the value is 500. Hence, it is the `val` variable within the object at address 500 that must be assigned zero:



```
class Controller
   main
   { int x = 2;
103: Model m = new Model();
     m.set(x+1);
     System.out.println(m.get());
     return; }

class Model
   private int val;

  Model()
   { this.val = 0;   500 .val = 0;
203: return this; }

  set(int w)
  { Model x = new Model();
    this.val = w;
    return; }

  get()  { return this.val; }
```

The `this` variable removes the need to copy method code into objects.

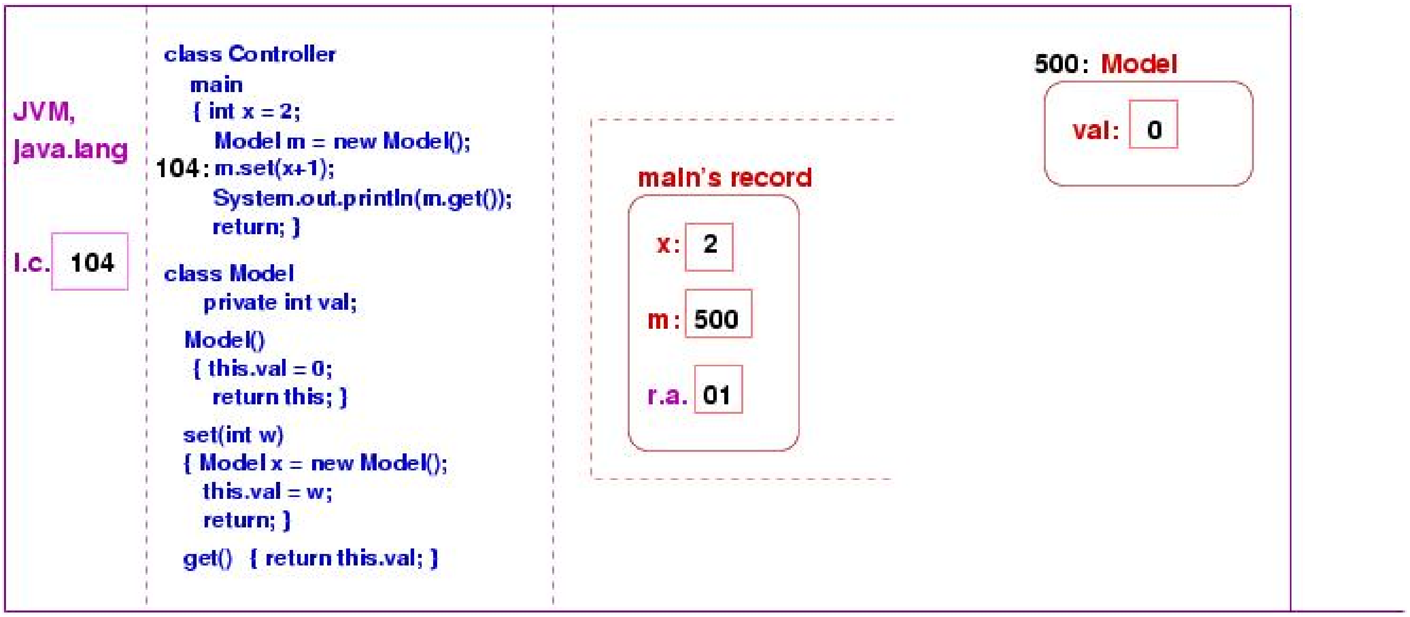
Now, it is time to return from the constructor method. The `return this` instruction causes the value in the return-address cell to be copied into the instruction counter and also the value in `this`'s cell to be returned to its destination in `main`. (In reality, the value of `this` is copied into a register in the CPU and later it is copied into `main`'s variable `m`.)



```
class Controller
   main
   { int x = 2;
103: Model m = new Model();
     m.set(x+1);
     System.out.println(m.get());
     return; }

class Model
   private int val;

  Model()
   { this.val = 0;
     return this; }

  set(int w)
  { Model x = new Model();
    this.val = w;
    return; }

  get()  { return this.val; }
```

The activation record for the constructor method is erased.

Now, the assignment to `m` is completed:

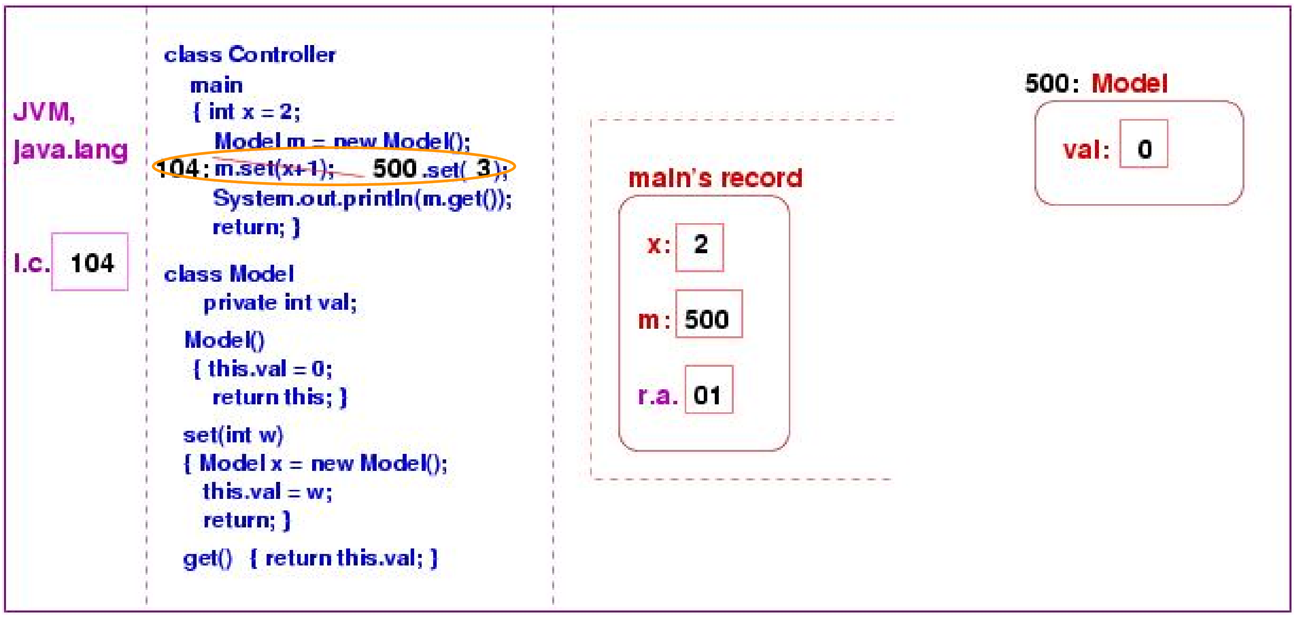


```
class Controller
   main
   { int x = 2;
      Model m = new Model();
104: m.set(x+1);
      System.out.println(m.get());
      return; }
class Model
     private int val;
   Model()
    { this.val = 0;
      return this; }
   set(int w)
   { Model x = new Model();
     this.val = w;
     return; }
   get()  { return this.val; }
```

Next, it is time to execute the method invocation, `m.set(x+1)`. The evaluation of the invocation proceeds from left to right:

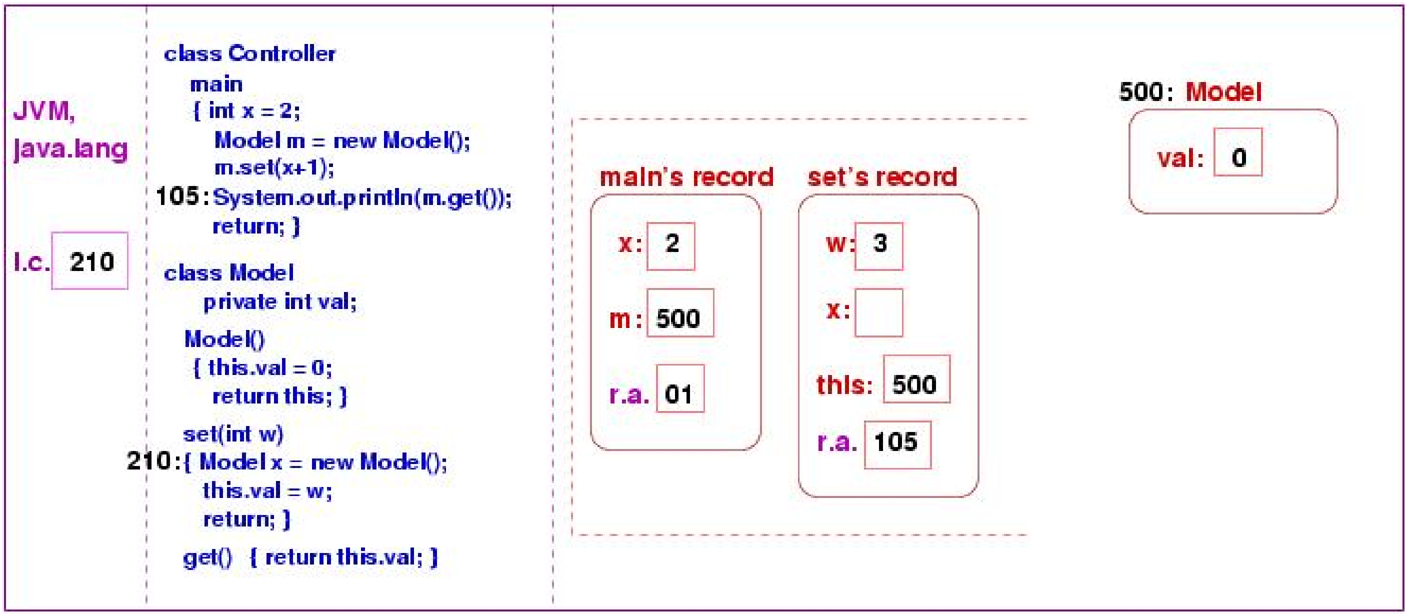
1. determine the target object's (`m`'s) address. (Here, it is 500.)
2. determine the value of the argument (actual parameter). Here, it is `3`.
3. start the invoked method.

Steps 1 and 2 are shown below:

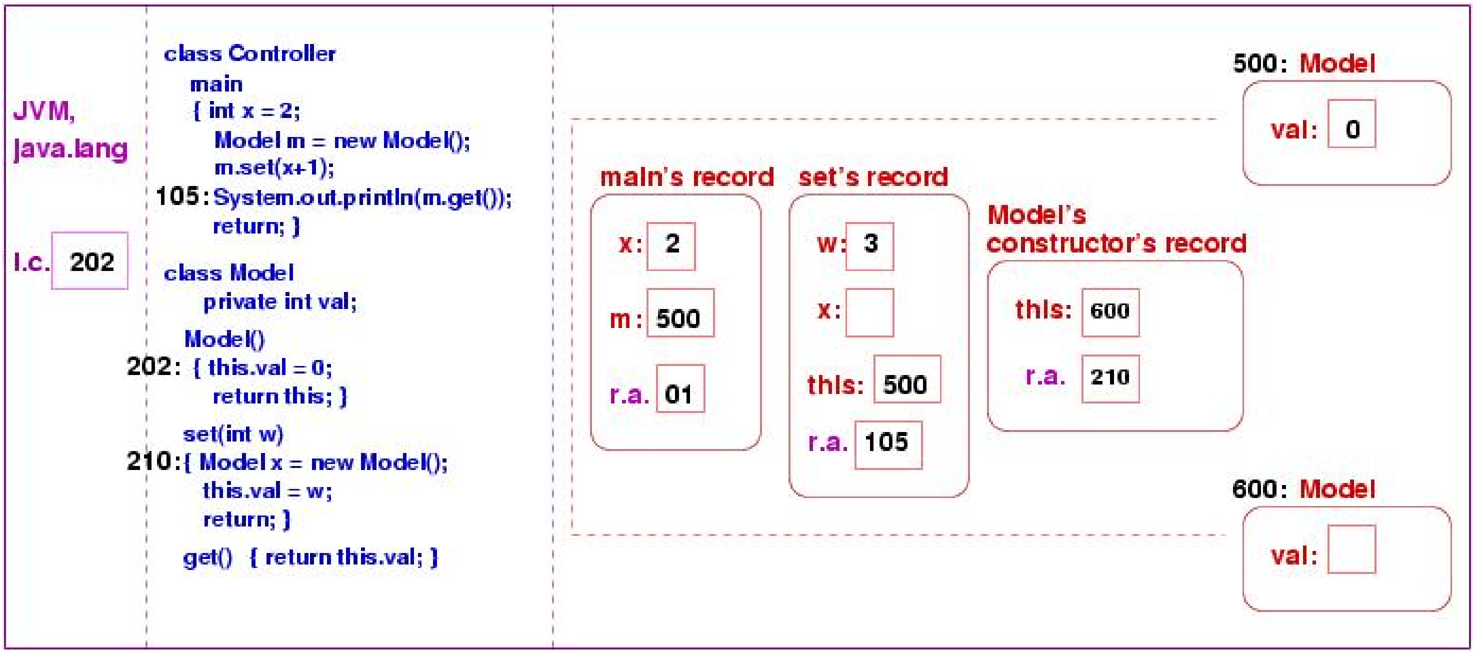


```
class Controller
   main
   { int x = 2;
      Model m = new Model();
104: m.set(x+1);  500 .set( 3);
      System.out.println(m.get());
      return; }
class Model
     private int val;
   Model()
    { this.val = 0;
      return this; }
   set(int w)
   { Model x = new Model();
     this.val = w;
     return; }
   get()  { return this.val; }
```

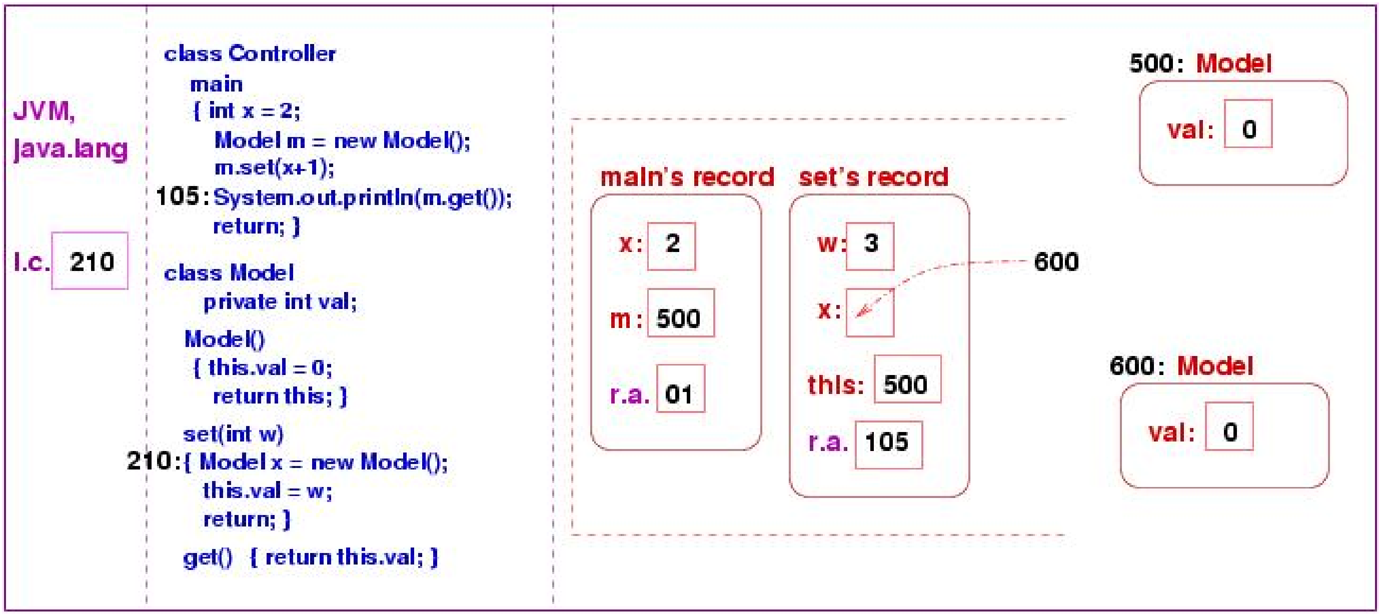
And here is the start of Step 3 --- an activation record for method `set` is pushed, where its `this` variable is initialized to 500. Notice that its argument is saved in the variable for formal parameter, `w`. And, the return address is saved. The instruction counter is reset to the first instruction within the invoked method:



The next instruction constructs a second `Model` object, and the steps seen a moment ago are repeated. We see a new object constructed and fresh activation record pushed for `Model`'s constructor method:

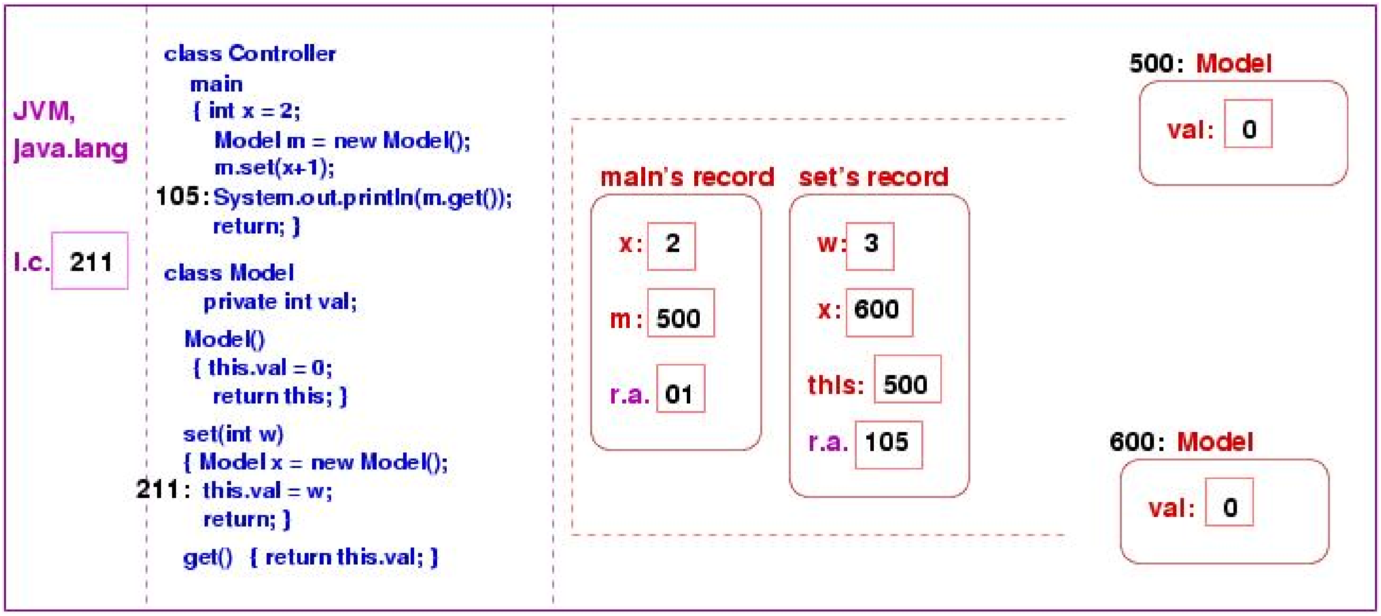


The constructor executes as seen before, using the same instructions as before, but since `this`'s cell holds 600, the new object is correctly initialized. The constructor returns its address to its caller, and its activation record disappears:



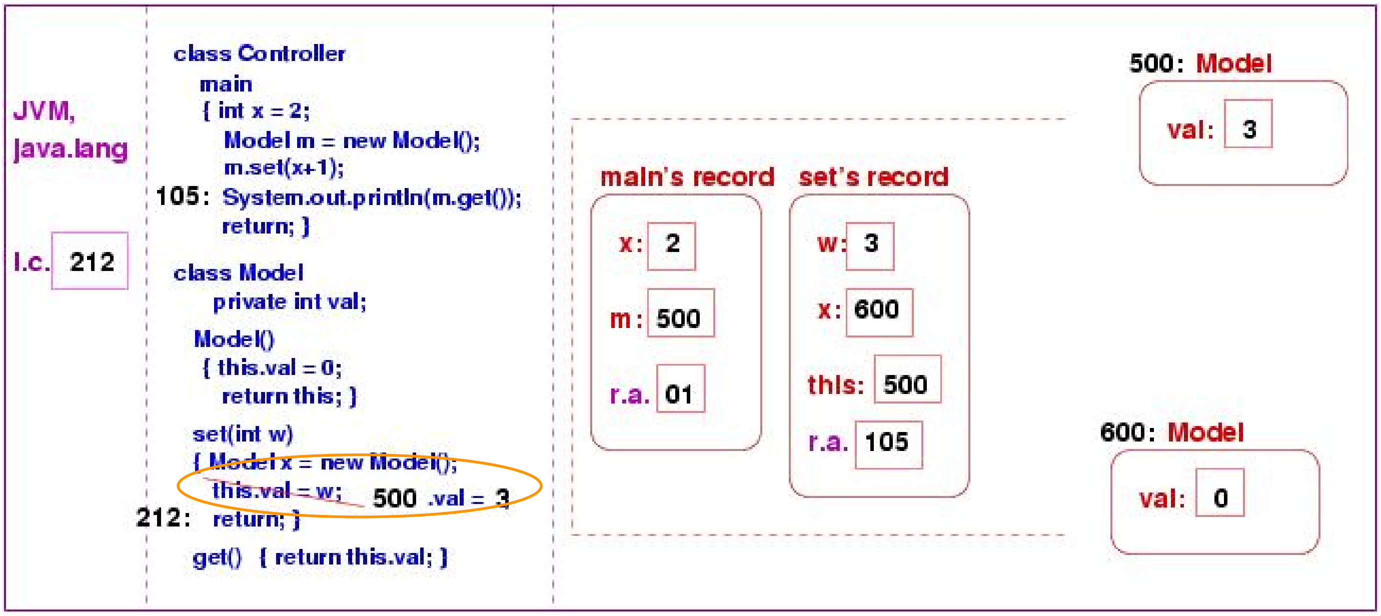
```
class Controller
  main
  { int x = 2;
    Model m = new Model();
    m.set(x+1);
105:System.out.println(m.get());
    return; }

class Model
  private int val;

  Model()
  { this.val = 0;
    return this; }

  set(int w)
210:{ Model x = new Model();
    this.val = w;
    return; }

  get()  { return this.val; }
```

Because the execution has returned to the code for `set`, and because the topmost activation record holds the variables for `set`, variable `x` is correctly assigned:

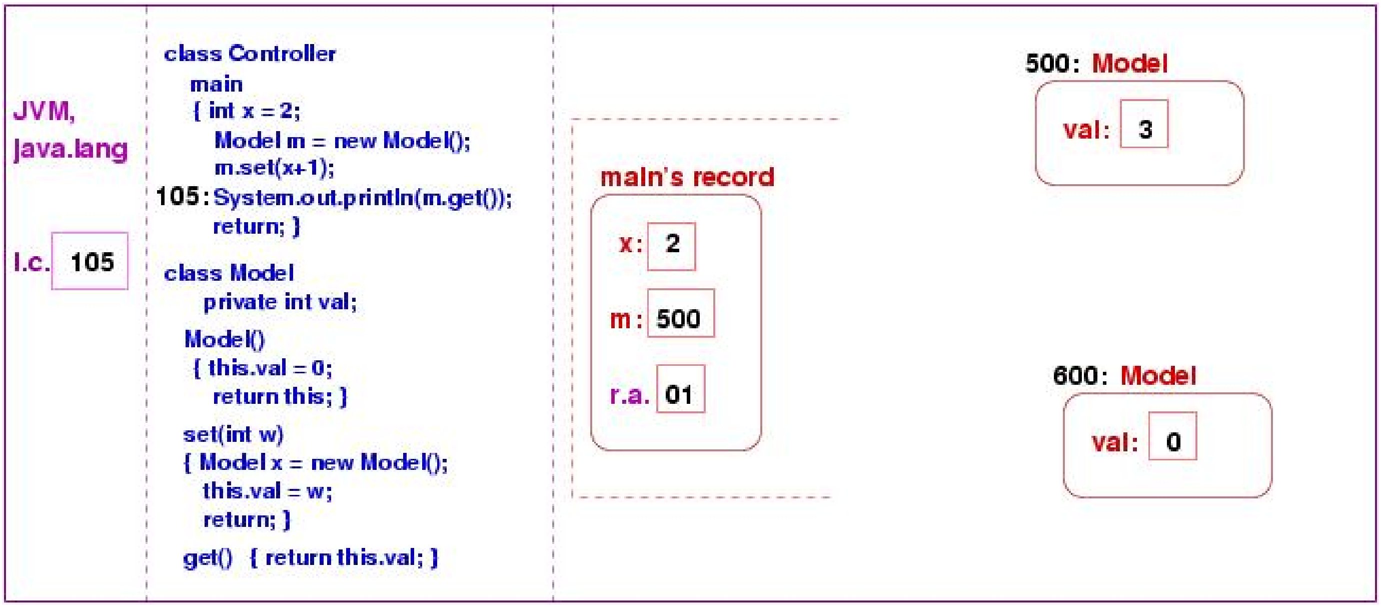


```
class Controller
  main
  { int x = 2;
    Model m = new Model();
    m.set(x+1);
105:System.out.println(m.get());
    return; }

class Model
  private int val;

  Model()
  { this.val = 0;
    return this; }

  set(int w)
  { Model x = new Model();
211: this.val = w;
    return; }

  get()  { return this.val; }
```

and the correct `val` field is reset:



Now, `set` is finished, and execution returns to `main`:



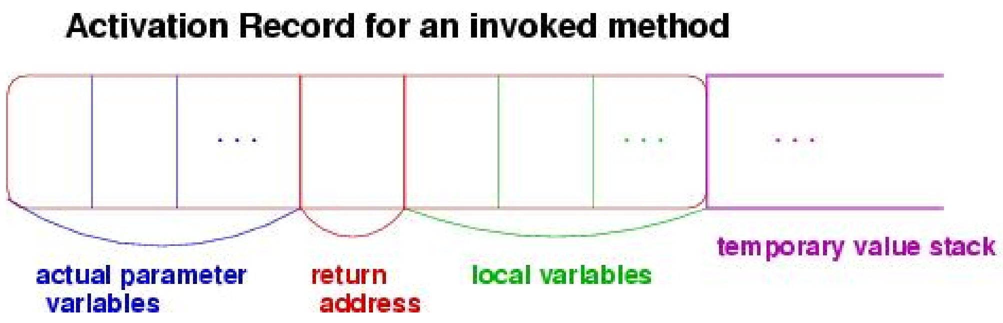
Notice that the object at address 600 still rests in storage, even though it is impossible for the application to reference it; the object is *garbage*, and at a later point in the execution, the *garbage collector* program within the JVM will examine all of storage and erase all such unreachable objects. (In contrast, languages like C and C++ lack garbage collectors, and the programmer must insert code to explictly erase unneeded objects.)

The next instruction, `System.out.println(m.get())`, triggers an invocation of `get` whose `this` cell holds 500. Once `get` returns 3, the `println` method is invoked. This finishes the application's execution.

## The temporary-value stack

The previous example emphasized how the activation-record stack remembers the local variables and return address for each method that is invoked. But within a method, there might be instructions that compute arithmetic expressions. We saw in the earlier lecture that arithmetic expressions are computed with the assistance of a stack; the stack that holds arithmetic values is called the *temporary-value stack*.

Although it was not drawn in the above diagrams, each activation record holds its own temporary-value stack for computing arithmetic. If we examine the precise structure of a method's activation record, we would find this:


Activation Record for an invoked method
. . .
. . .
. . .
actual parameter variables
return address
local variables
temporary value stack

The temporary-value stack literally grows ``out of the right end'' of the activation record; this lets the temporary-value stack grow as needed to evaluate complicated arithmetic expressions. When a function is invoked in the middle of evaluating a complex arithmetic expression, the activation record for the invoked function is constructed just as if it is resting ``on the top'' of the temporary value stack. This makes it easy to return from the invoked function and finish evaluating the expression.