Programming Languages and Techniques (CIS120)

Lecture 26

March 23, 2016

Inheritance and Dynamic Dispatch

Chapter 24

Inheritance Example

```
public class Counter {
    private int x;
    public Counter () { x = 0; }
    public void incBy(int d) { x = x + d; }
    public int get() { return x; }
}
class Decr extends Counter {
    private int y;
    public Decr (int initY) { y = initY; }
    public void dec() { incBy(-y); }
}
// … somewhere in main:
Decr d = new Decr(2);
d.dec();
int x = d.get();
```

What is the value of x at the end of this computation?

1. -2
2. -1
3. 0
4. 1
5. 2
6. NPE
7. Doesn't type check

Answer: -2

Announcements

- Exam grades will be available (late) Friday

- Homework 6 available, due Tuesday

Subtype Polymorphism*

- Main idea:

Anywhere an object of type A is needed, an object that is a subtype of A can be provided.

```
// in class C
public static void times2(Counter c) {
    c.incBy(c.get());
 }
// somewhere else
C.times2(new Decr(3));
```

- If B is a subtype of A, it provides all of A's (public) methods.
- Due to dynamic dispatch, the behavior of a method depends on B's implementation.
  - Simple inheritance means B's method is inherited from A
  - Otherwise, behavior of B should be "compatible" with A's behavior

*polymorphism = many shapes

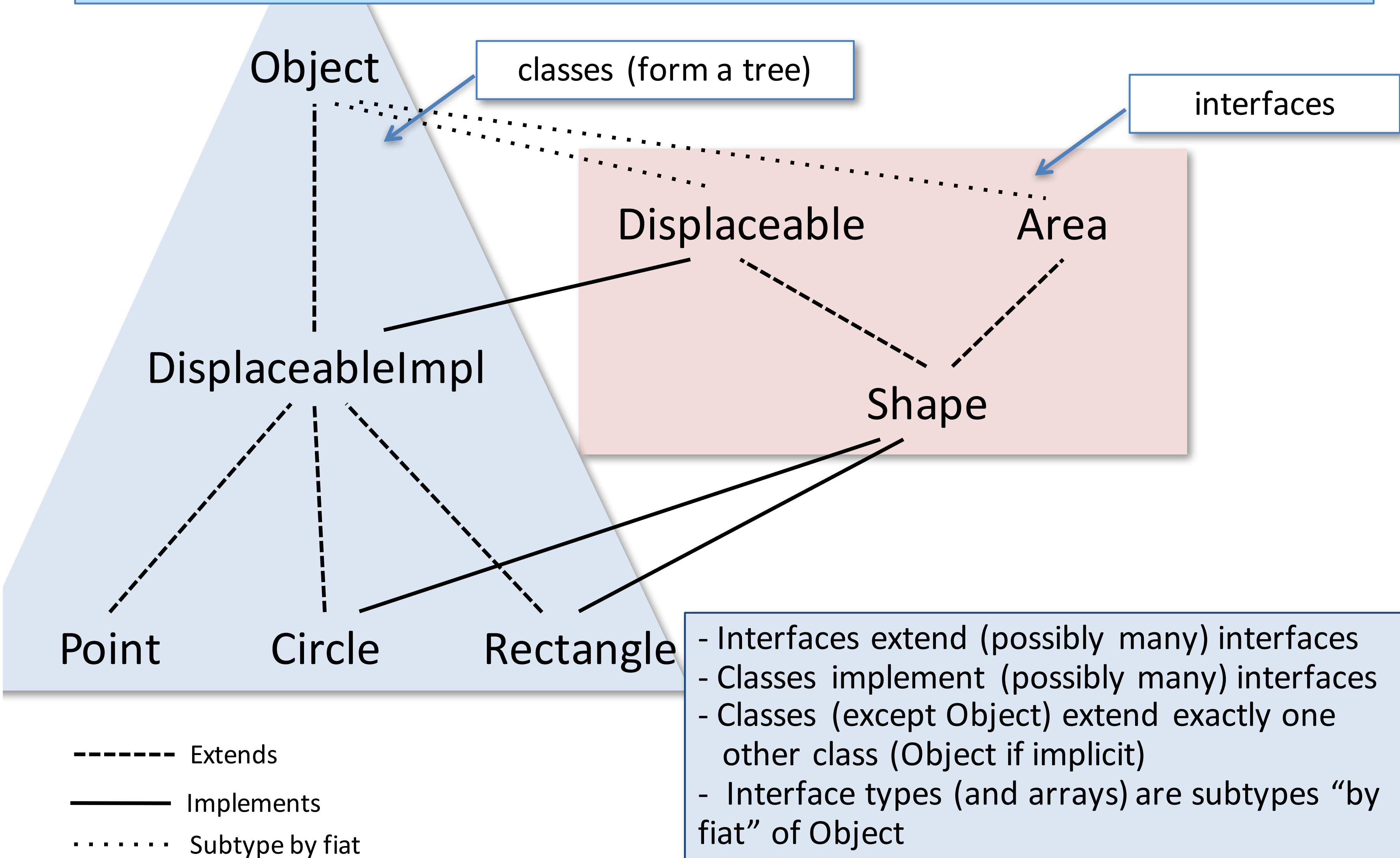
The Object Class

Object

```
public class Object {
  boolean equals(Object o) {
    … // test for equality
  }
  String toString() {
    … // return a string representation
  }
  …  // other methods omitted
}
```

- Object is the root of the class tree.
  - Classes that leave off the “extends” clause *implicitly* extend Object
  - Arrays also implement the methods of Object
  - This class provides methods useful for *all* objects to support
- Object is the highest type in the subtyping hierarchy.

Recap: Subtyping



- Interfaces extend (possibly many) interfaces
- Classes implement (possibly many) interfaces
- Classes (except Object) extend exactly one other class (Object if implicit)
- Interface types (and arrays) are subtypes "by fiat" of Object

When do constructors execute?
How are fields accessed?
What code runs in a method call?

Revenge of the Son
of the
Abstract Stack Machine

How do method calls work?

- What code gets run in a method invocation?

```
o.move(3,4);
```

- When that code is running, how does it access the fields of the object that invoked it?

```
x = x + dx;
```

- When does the code in a constructor get executed?

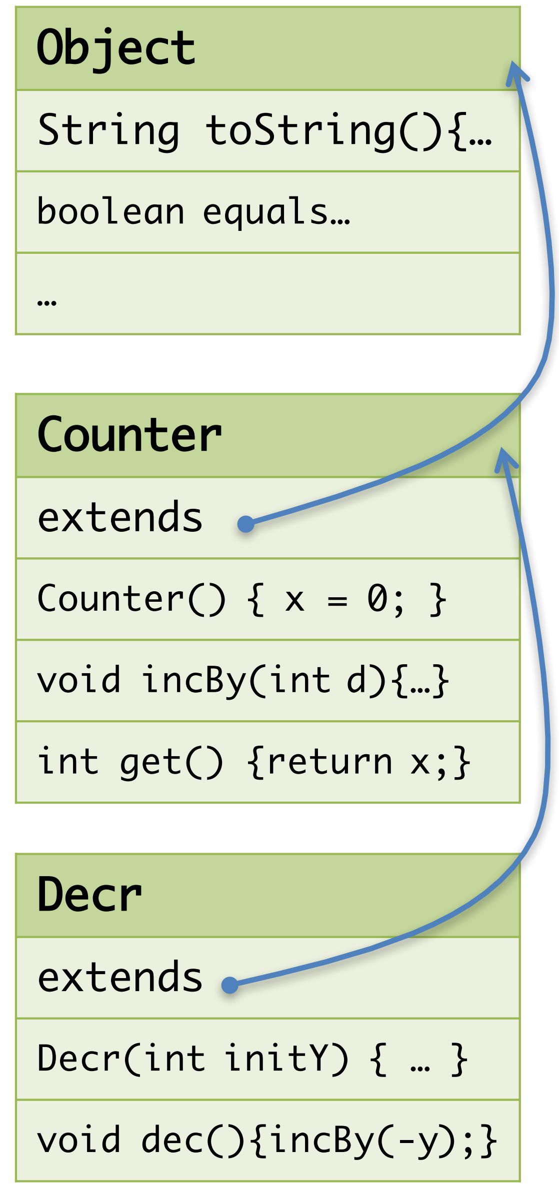
- What if the method was inherited from a superclass?

ASM refinement: The Class Table

```java
public class Counter {
   private int x;
   public Counter () { x = 0; }
   public void incBy(int d) { x = x + d; }
   public int get() { return x; }
}

public class Decr extends Counter {
   private int y;
   public Decr (int initY) { y = initY; }
   public void dec() { incBy(-y);  }
}
```

Class Table



The class table contains:

- the code for each method,
- references to each class's parent, and
- the class's static members.

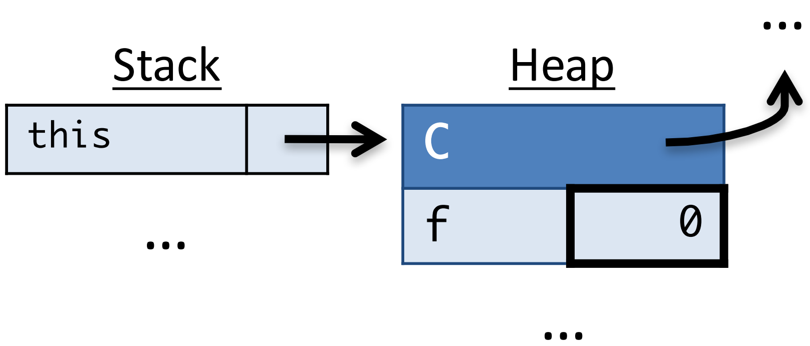
`this`

- Inside a non-static method, the variable `this` is a reference to the object on which the method was invoked.

- References to local fields and methods have an implicit "`this.`" in front of them.

```
class C {
    private int f;

    public void copyF(C other) {
        this.f = other.f;
    }
}
```



An Example

```
public class Counter {
  private int x;
  public Counter () { x = 0; }
  public void incBy(int d) { x = x + d; }
  public int get() { return x; }
}

public class Decr extends Counter {
  private int y;
  public Decr (int initY) { y = initY; }
  public void dec() { incBy(-y); }
}

// … somewhere in main:
Decr d = new Decr(2);
d.dec();
int x = d.get();
```

…with Explicit this and super

```
public class Counter extends Object {
  private int x;
  public Counter () { super(); this.x = 0; }
  public void incBy(int d) { this.x = this.x + d; }
  public int get() { return this.x; }
}

public class Decr extends Counter {
  private int y;
  public Decr (int initY) { super(); this.y = initY; }
  public void dec() { this.incBy(-this.y);  }
}

// … somewhere in main:
Decr d = new Decr(2);
d.dec();
int x = d.get();
```

Constructing an Object

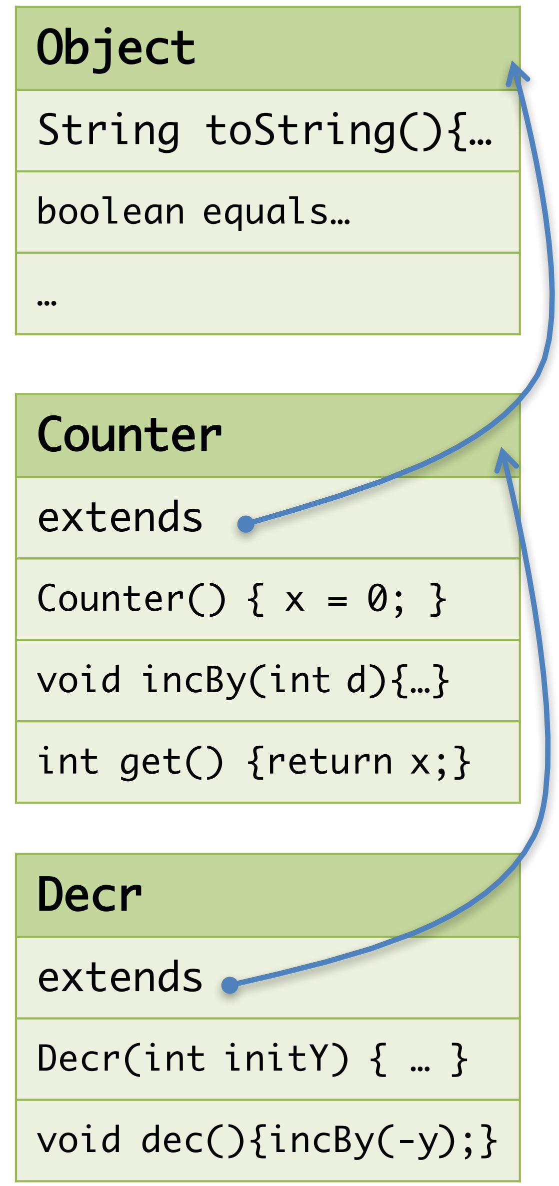
Workspace

```
Decr d = new Decr(2);
d.dec();
int x = d.get();
```

Stack

Heap

Class Table



Allocating Space on the Heap

Workspace

```
super();
this.y = initY;
```

Stack

```
Decr d = _;
d.dec();
int x = d.get();
```

this	•
initY	2

Heap

Decr	
x	0
y	0

Class Table

Object
String toString(){…
boolean equals…
…

Counter
extends Object
Counter() { x = 0; }
void incBy(int d){…}
int get() {return x;}

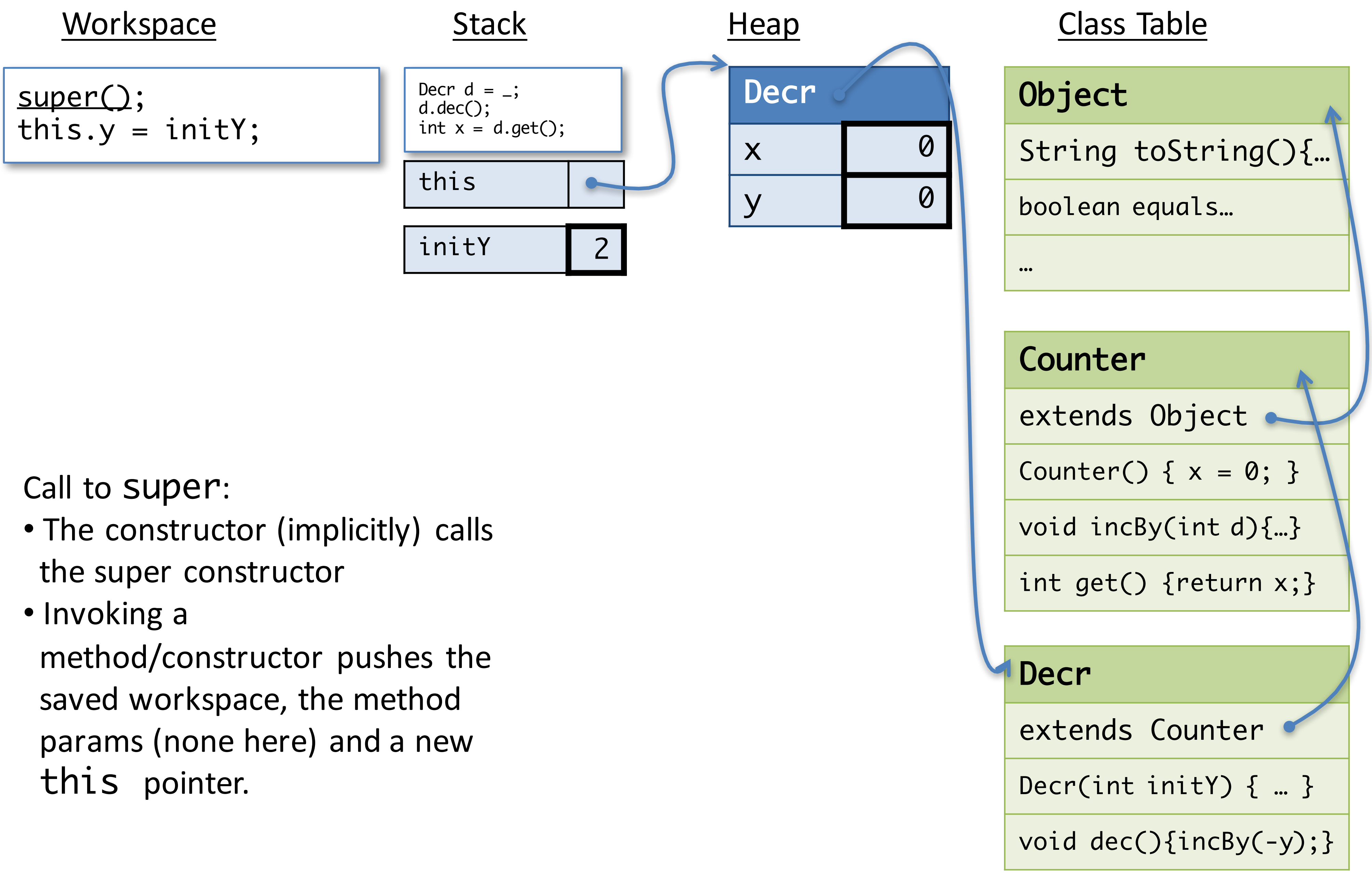
Decr
extends Counter
Decr(int initY) { … }
void dec(){incBy(-y);}

Invoking a constructor:

- allocates space for a new object in the heap
- includes slots for *all* fields of *all* ancestors in the class tree (here: x *and* y)
- creates a pointer to the class – this is the object's dynamic type
- runs the constructor body after pushing parameters and `this` onto the stack

Note: fields start with a "sensible" default
- 0 for numeric values
- `null` for references

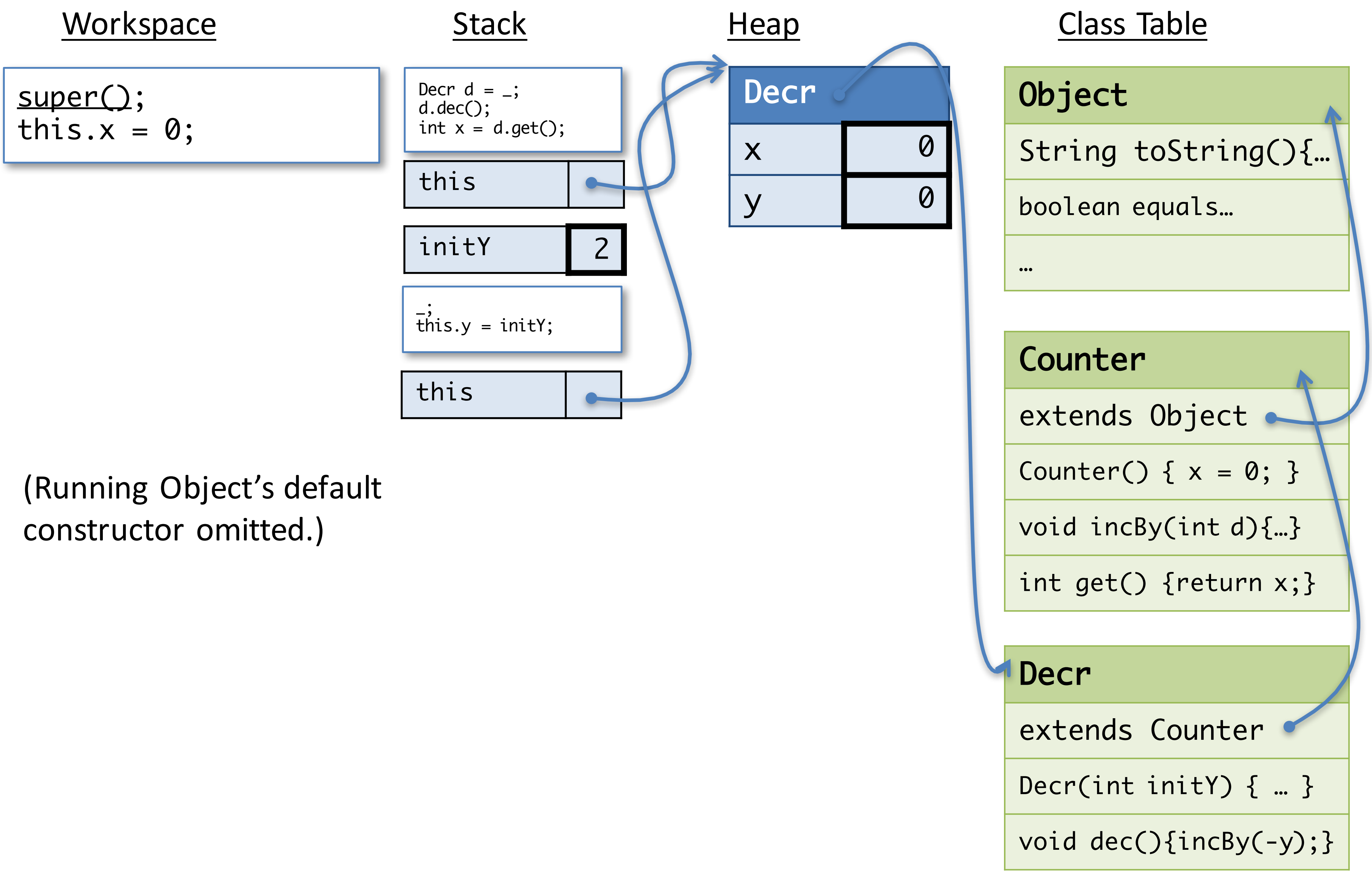
Calling super



Call to `super`:

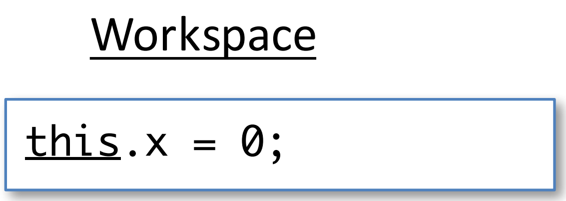
- The constructor (implicitly) calls the super constructor
- Invoking a method/constructor pushes the saved workspace, the method params (none here) and a new `this` pointer.

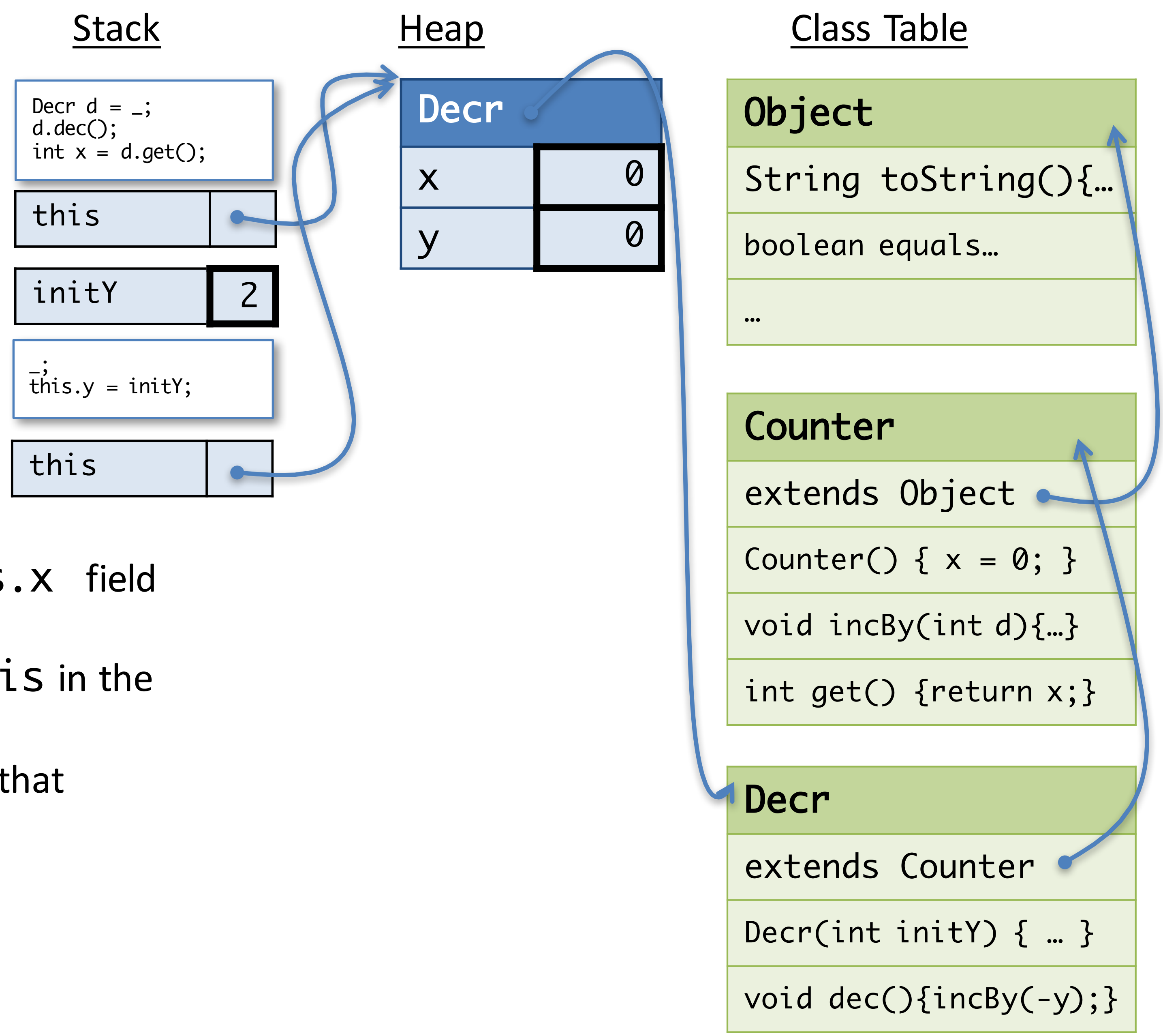
Abstract Stack Machine



(Running Object's default constructor omitted.)

Assigning to a Field

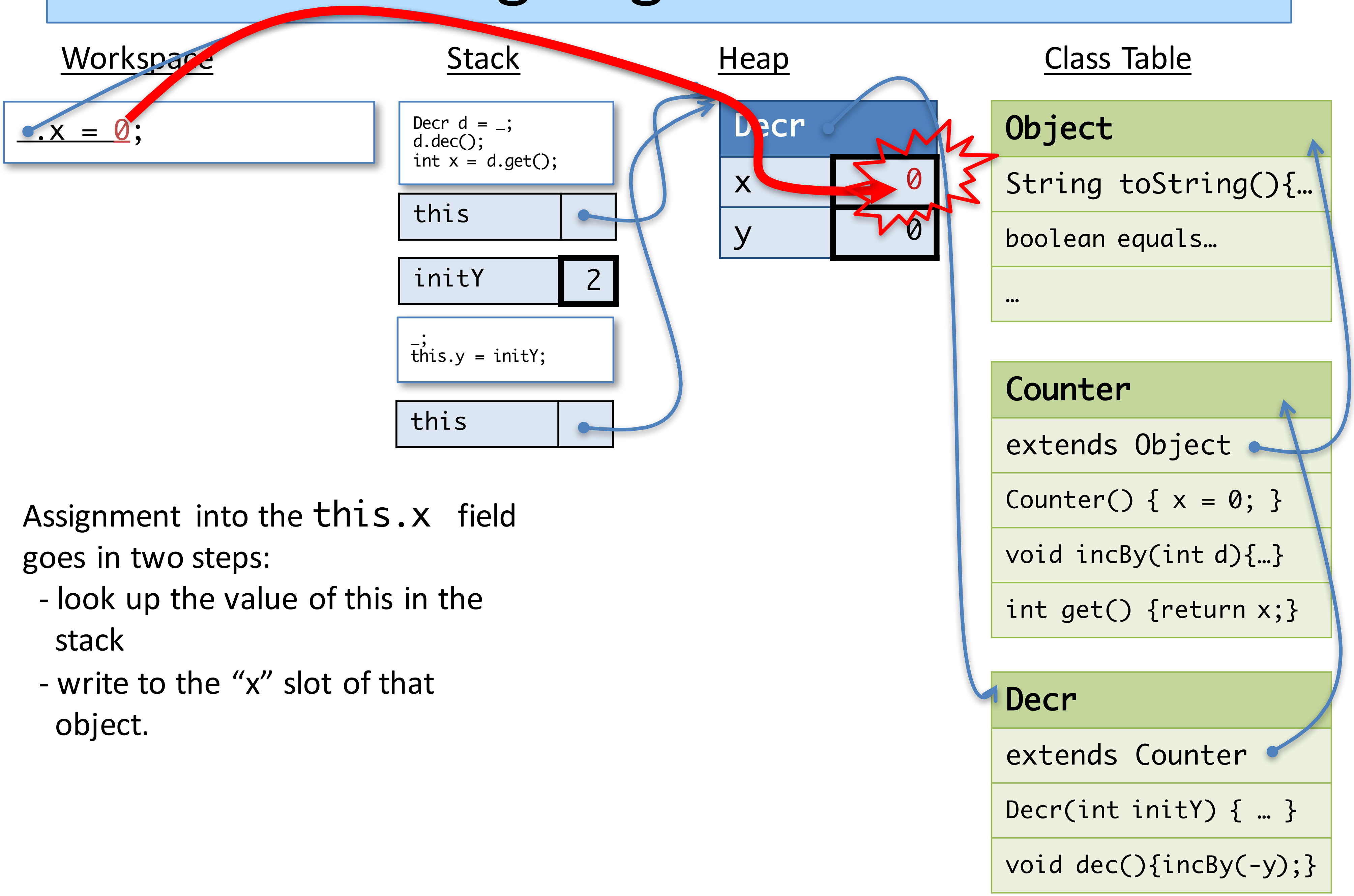




Assignment into the this.x field goes in two steps:

- look up the value of this in the stack
- write to the "x" slot of that object.

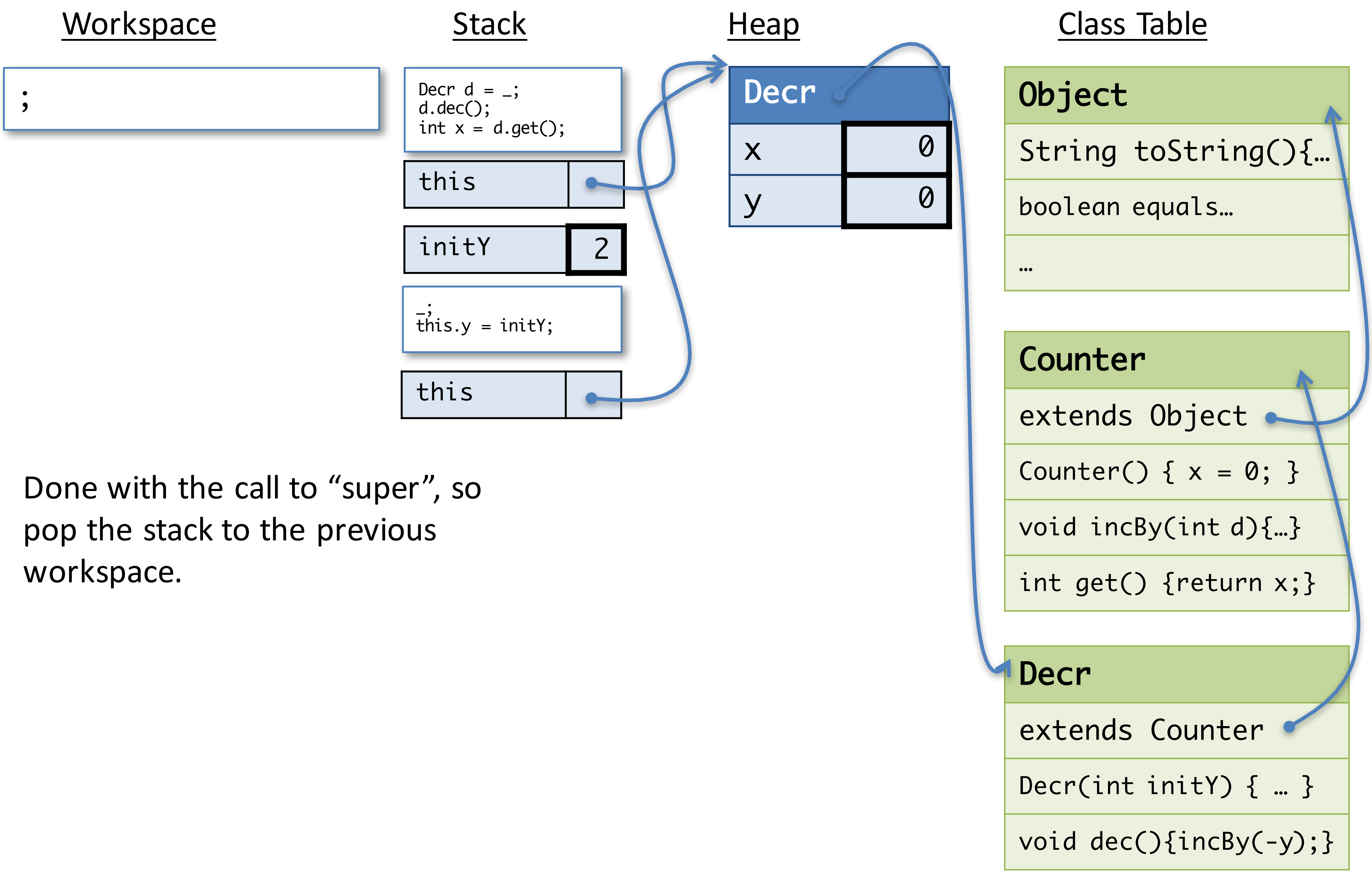
Assigning to a Field



Assignment into the `this.x` field goes in two steps:

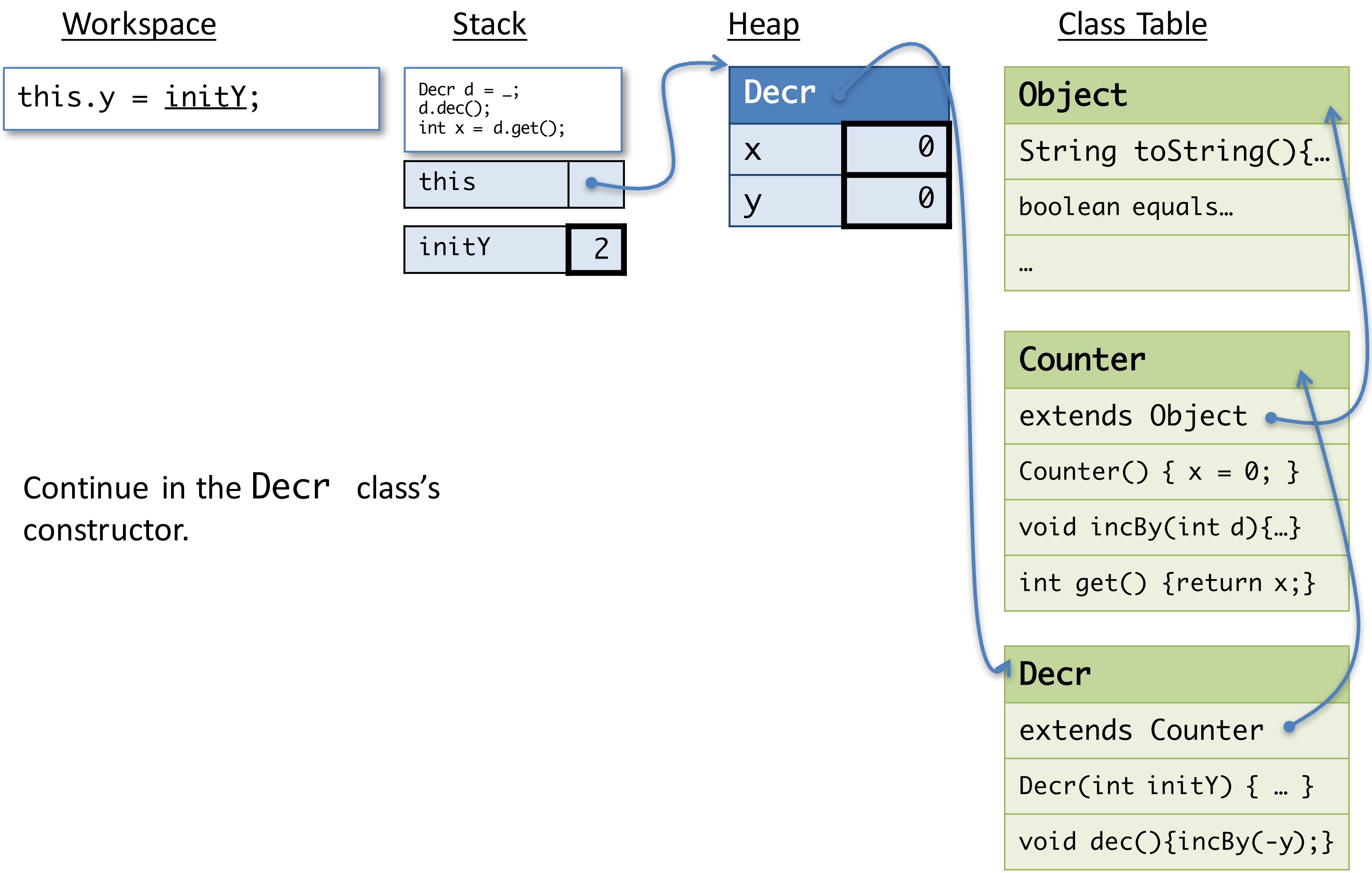
- look up the value of this in the stack
- write to the "x" slot of that object.

Done with the call



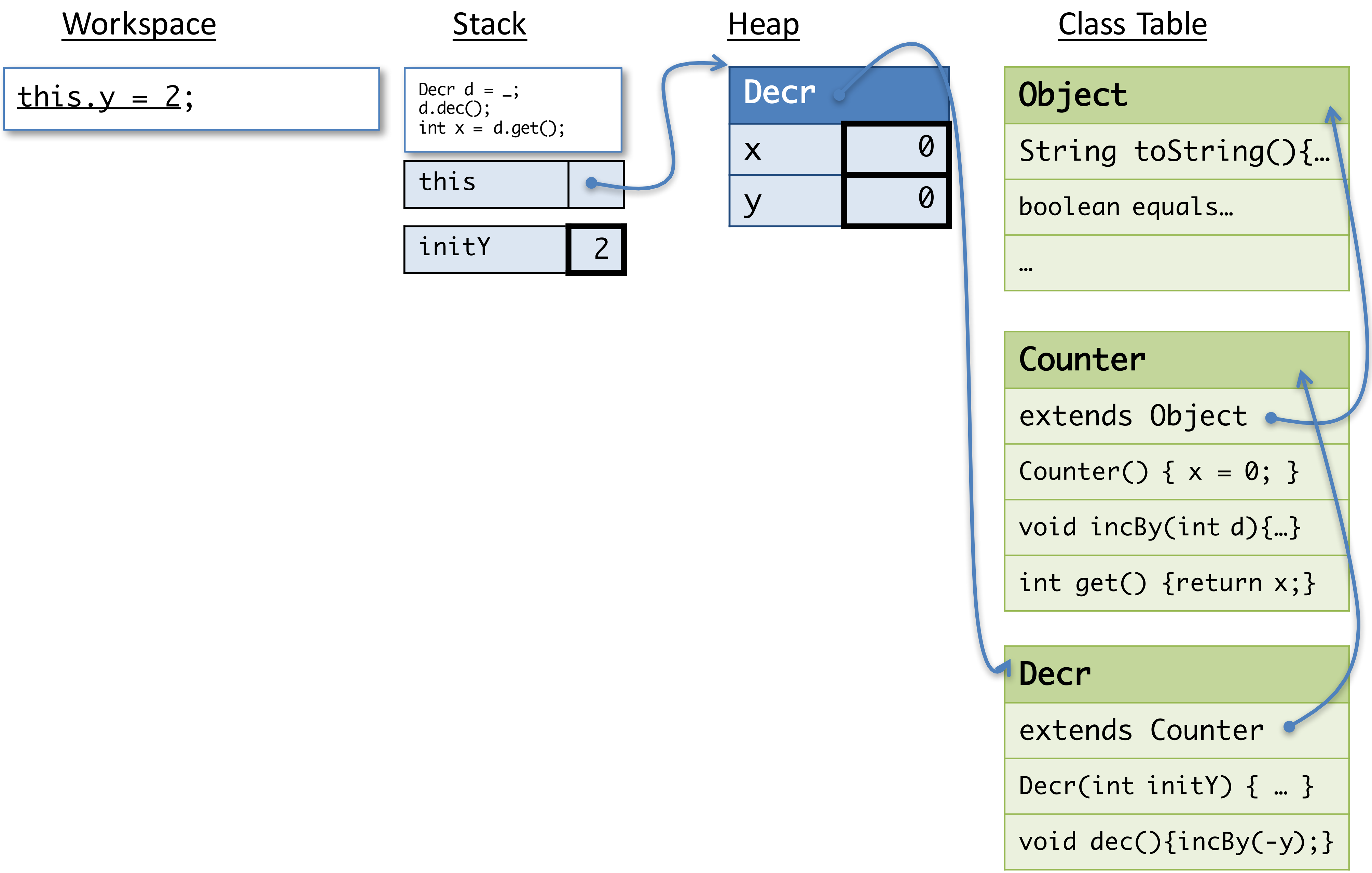
Done with the call to "super", so pop the stack to the previous workspace.

Continuing

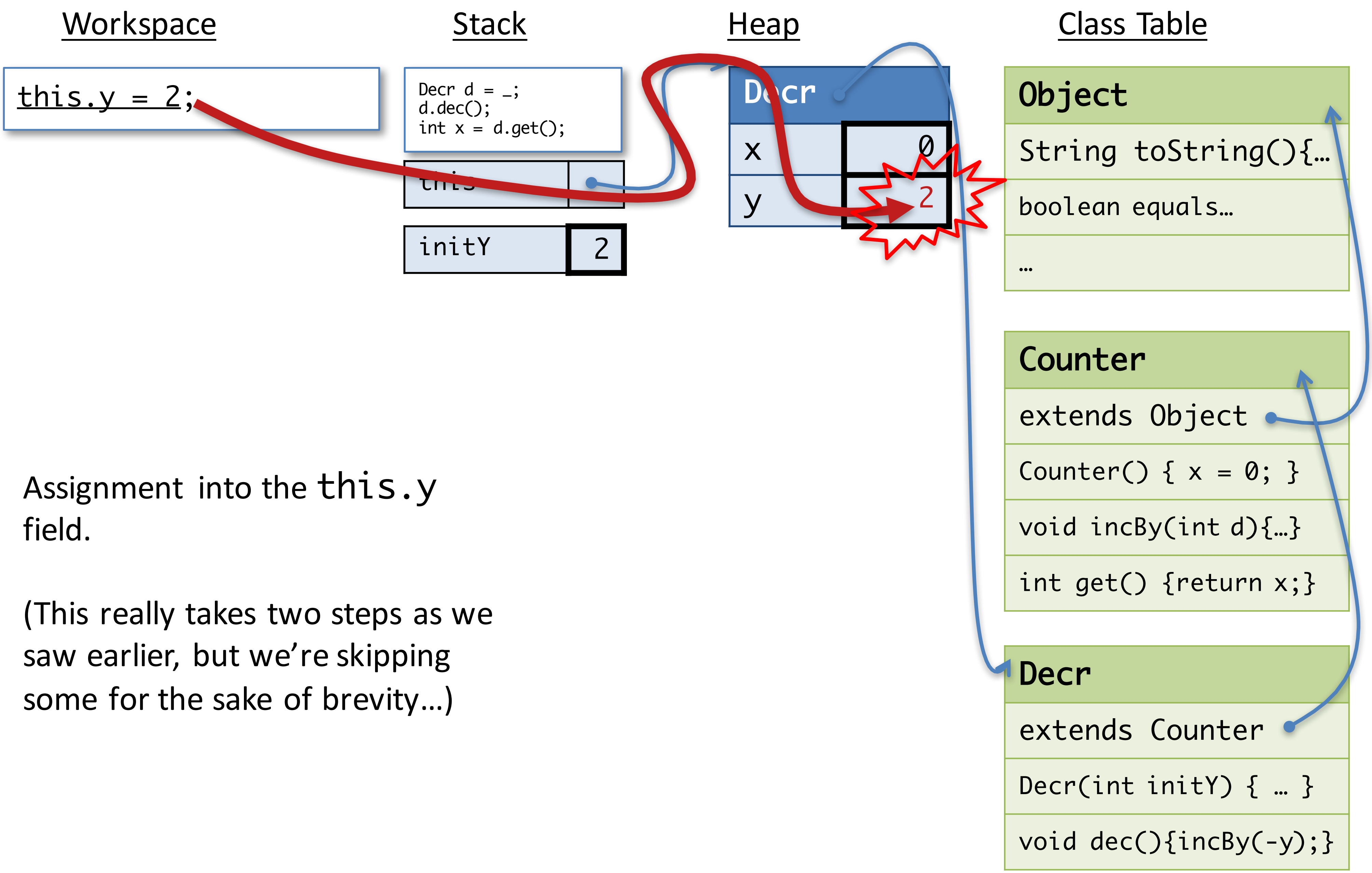


Continue in the Decr class's constructor.

Abstract Stack Machine



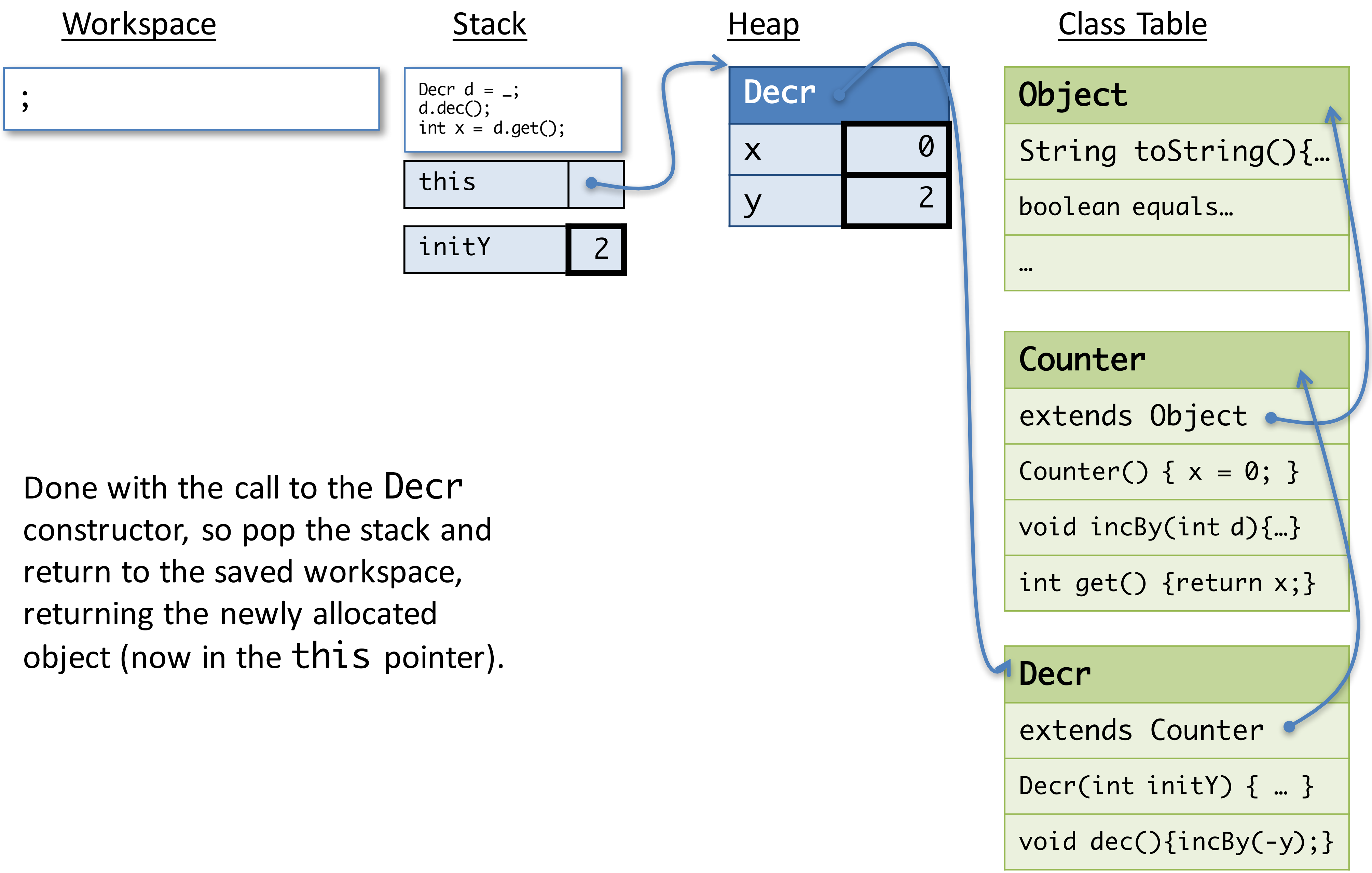
Assigning to a field



Assignment into the `this.y` field.

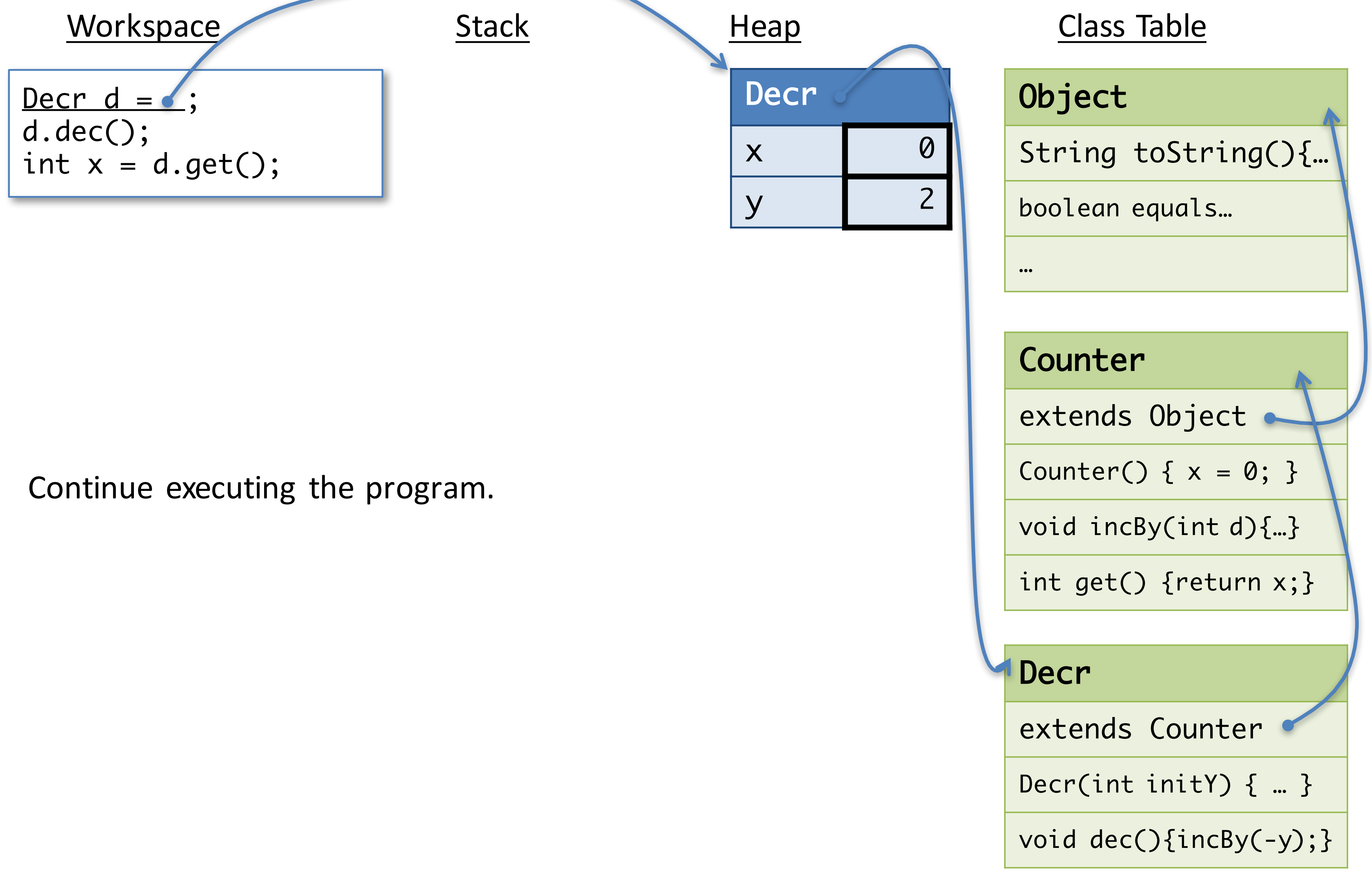
(This really takes two steps as we saw earlier, but we're skipping some for the sake of brevity…)

Done with the call



Done with the call to the `Decr` constructor, so pop the stack and return to the saved workspace, returning the newly allocated object (now in the `this` pointer).

Returning the Newly Constructed Object

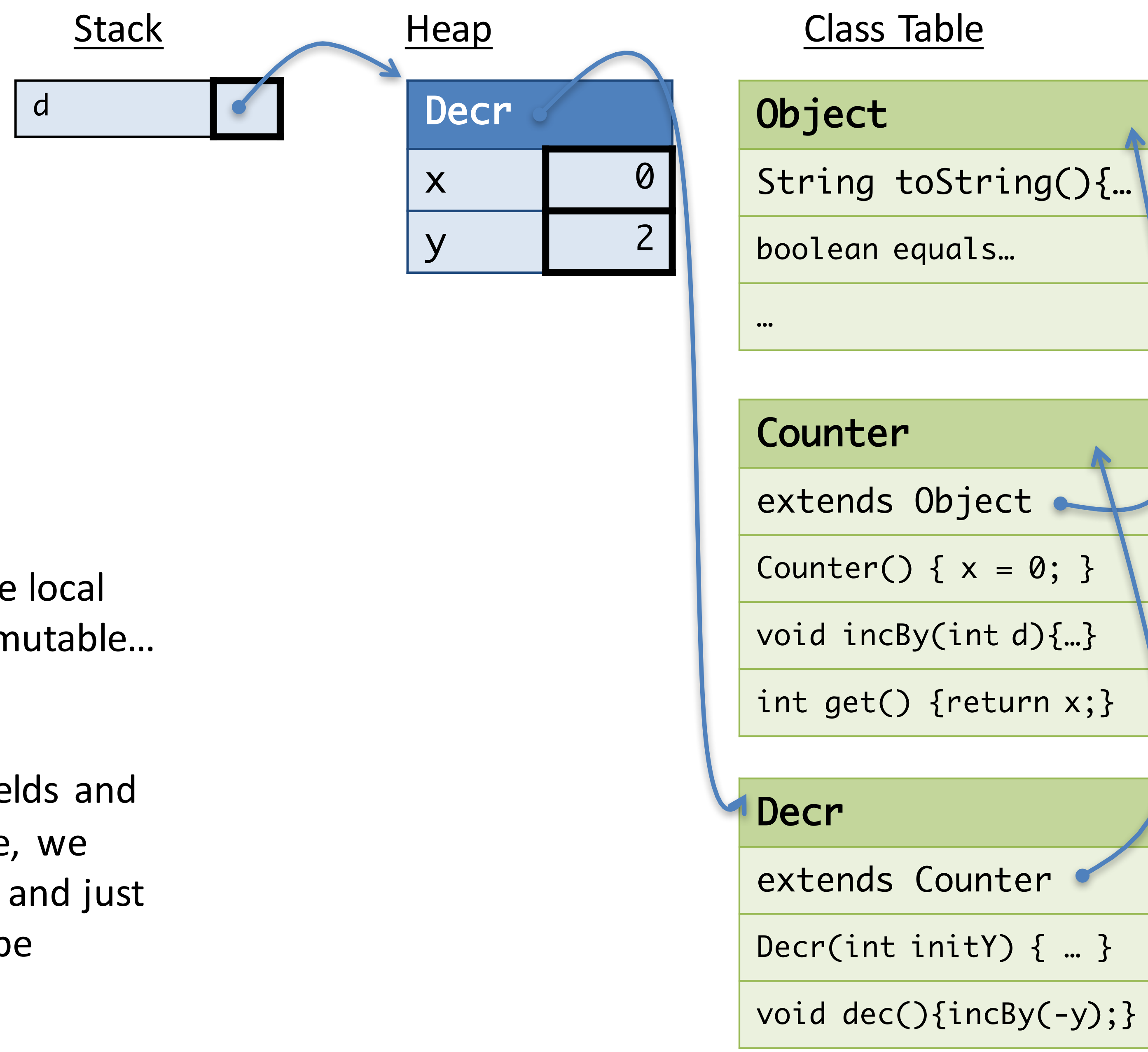


Continue executing the program.

Allocating a local variable

Workspace

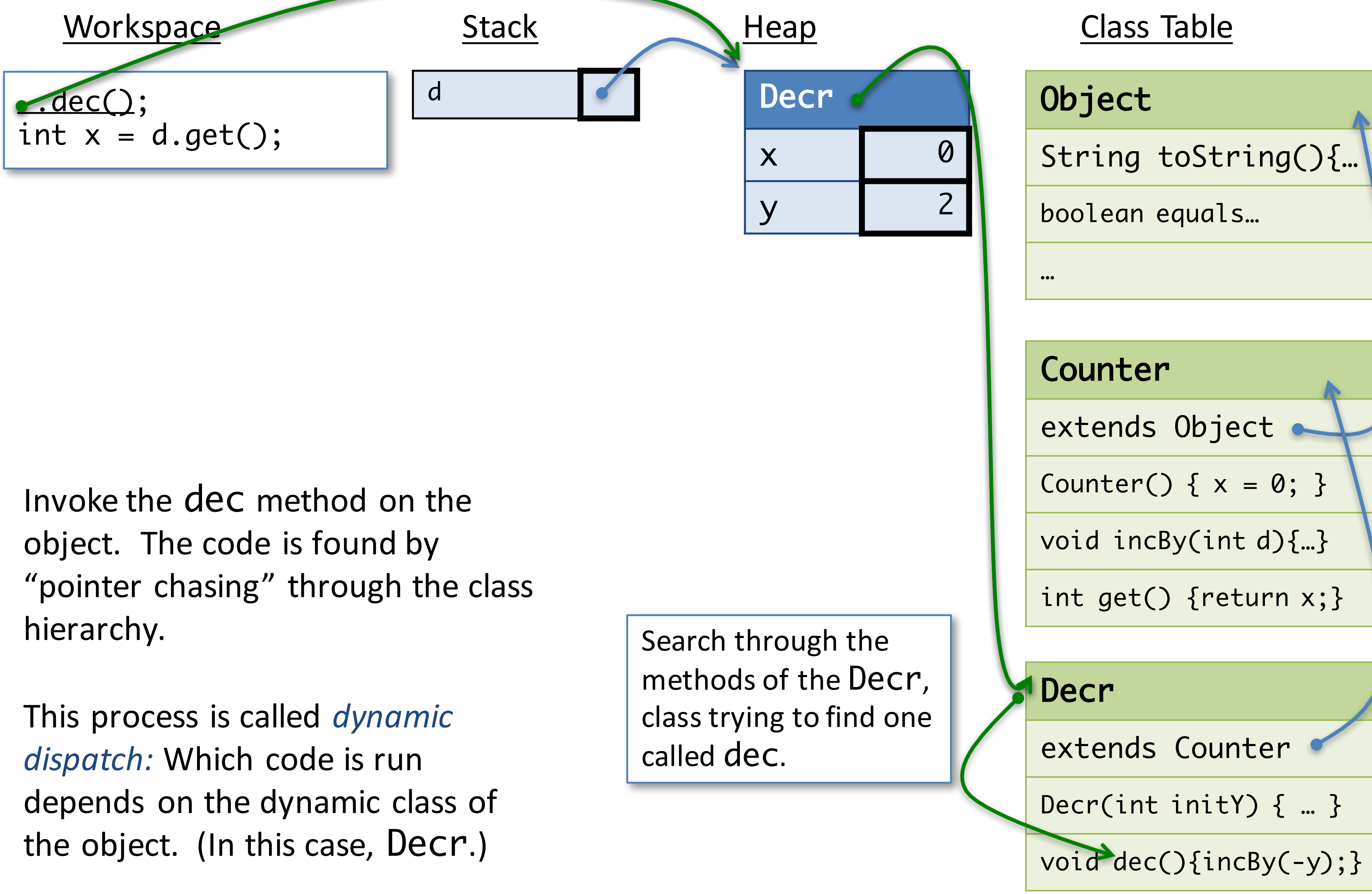
```
d.dec();
int x = d.get();
```



Allocate a stack slot for the local variable d. Note that it's mutable… (bold box in the diagram).

Aside: since, by default, fields and local variables are mutable, we often omit the bold boxes and just assume the contents can be modified.

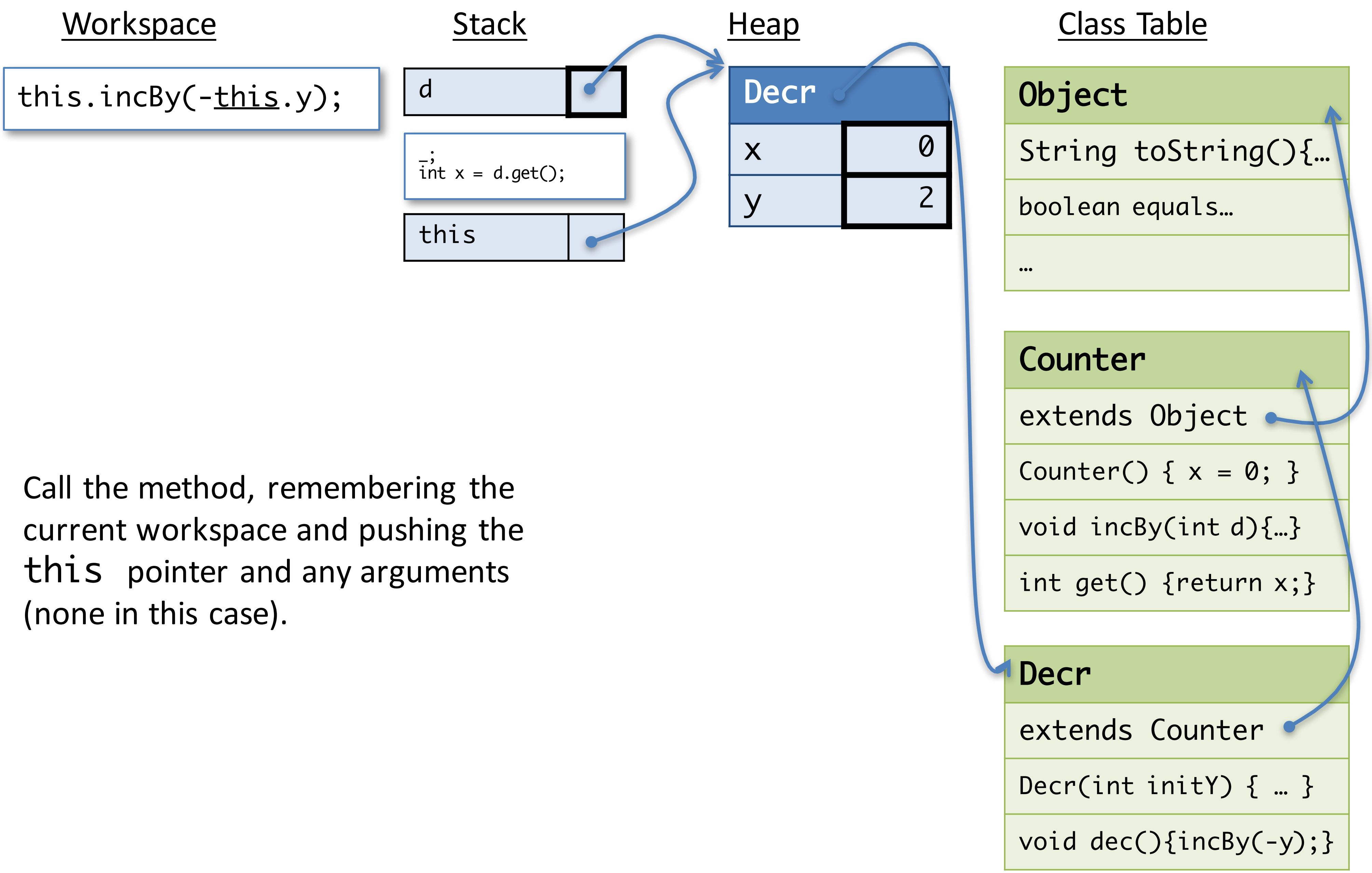
Dynamic Dispatch: Finding the Code



Invoke the dec method on the object. The code is found by "pointer chasing" through the class hierarchy.

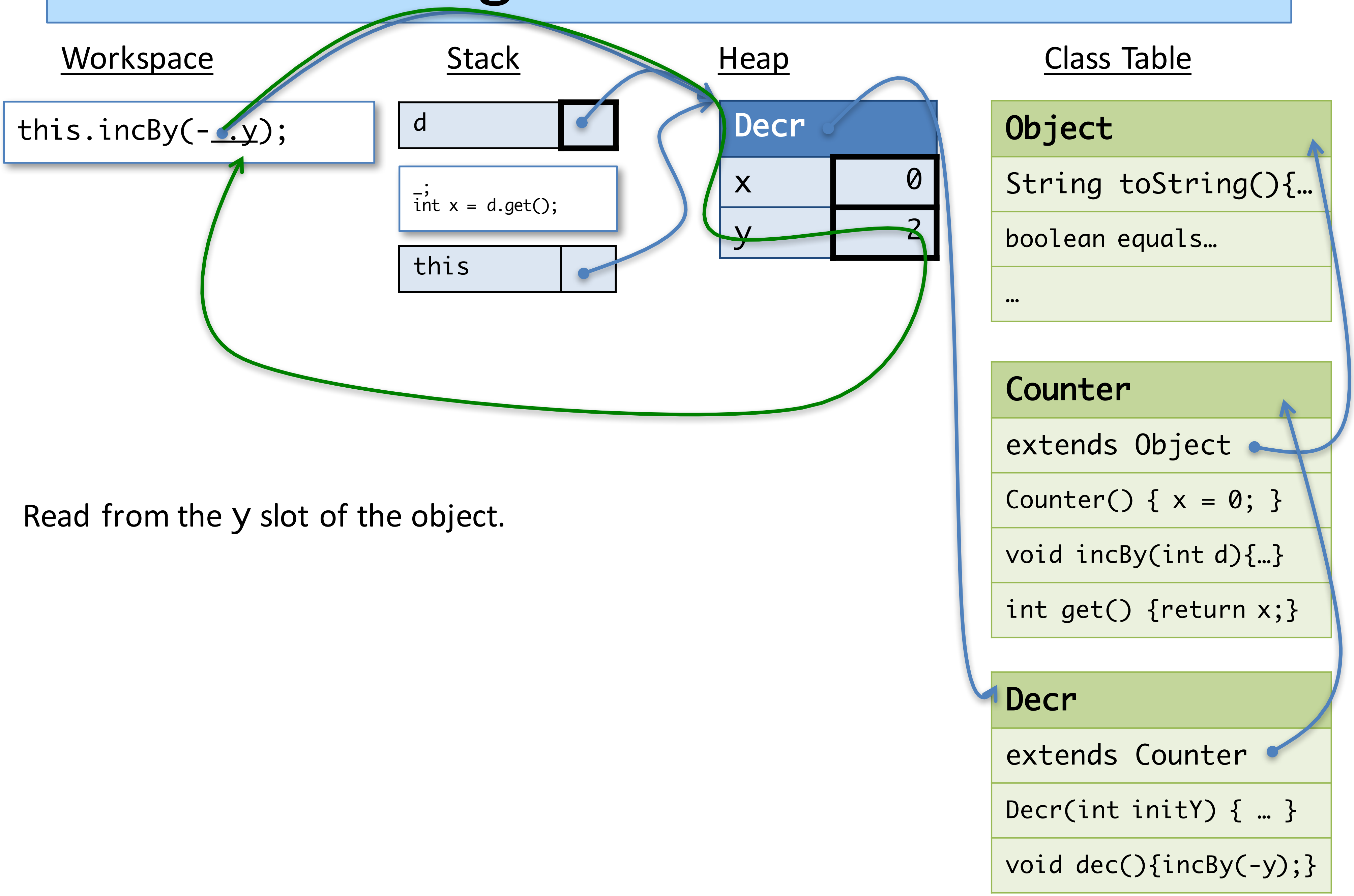
This process is called *dynamic dispatch:* Which code is run depends on the dynamic class of the object. (In this case, Decr.)

Dynamic Dispatch: Finding the Code



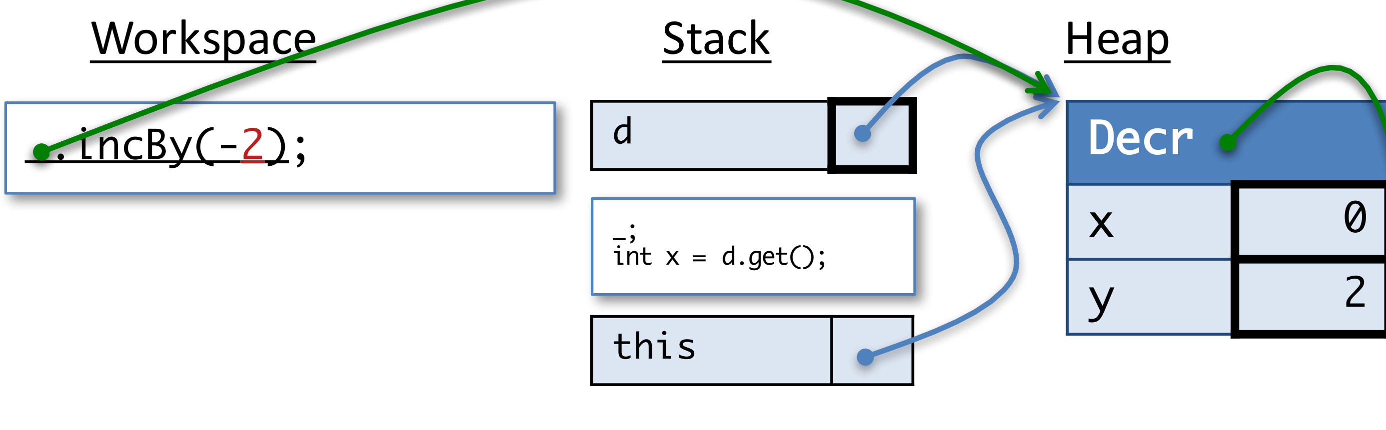
Call the method, remembering the current workspace and pushing the `this` pointer and any arguments (none in this case).

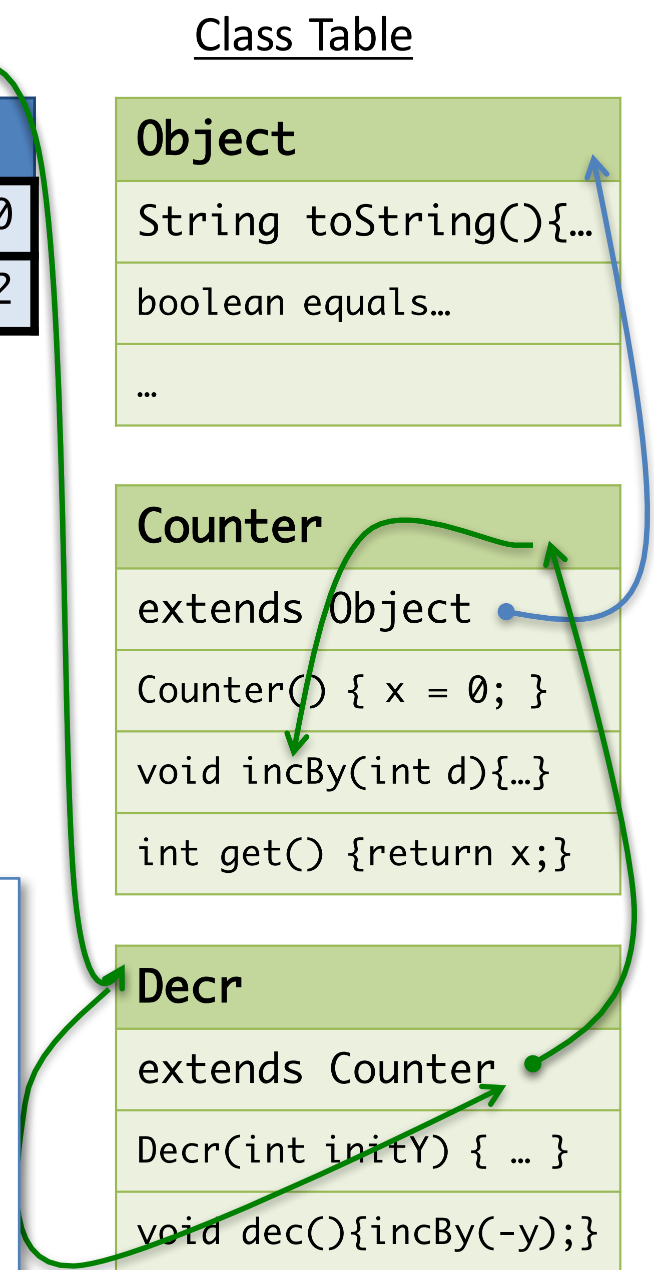
Reading A Field’s Contents



Read from the y slot of the object.

Dynamic Dispatch, Again





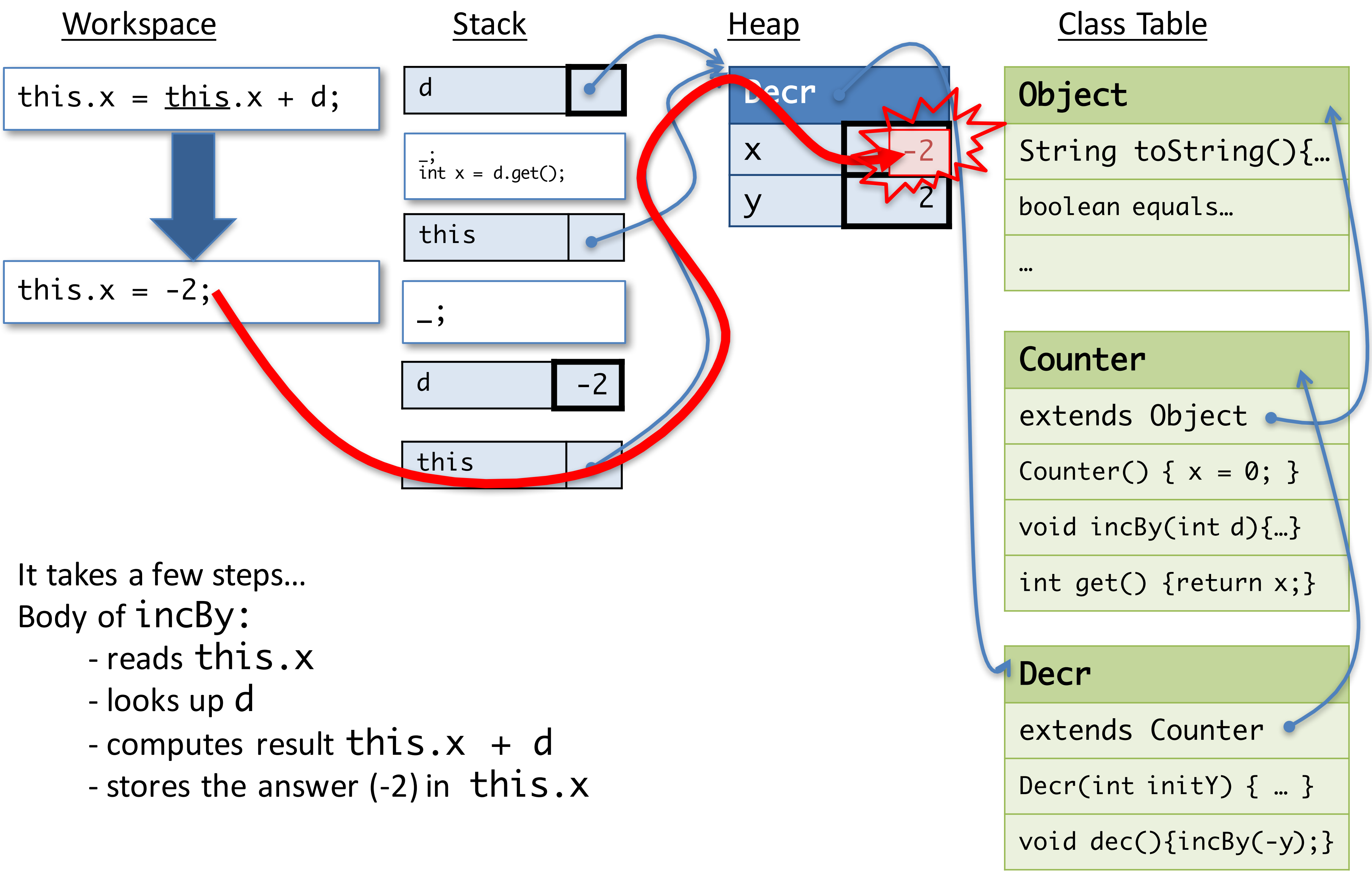
Invoke the incBy method on the object via dynamic dispatch.

In this case, the incBy method is *inherited* from the parent, so dynamic dispatch must search up the class tree, looking for the implementation code.

The search is guaranteed to succeed – Java's static type system ensures this.

Search through the methods of the Decr, class trying to find one called incBy.
If the search fails, recursively search the parent classes.

Running the body of incBy

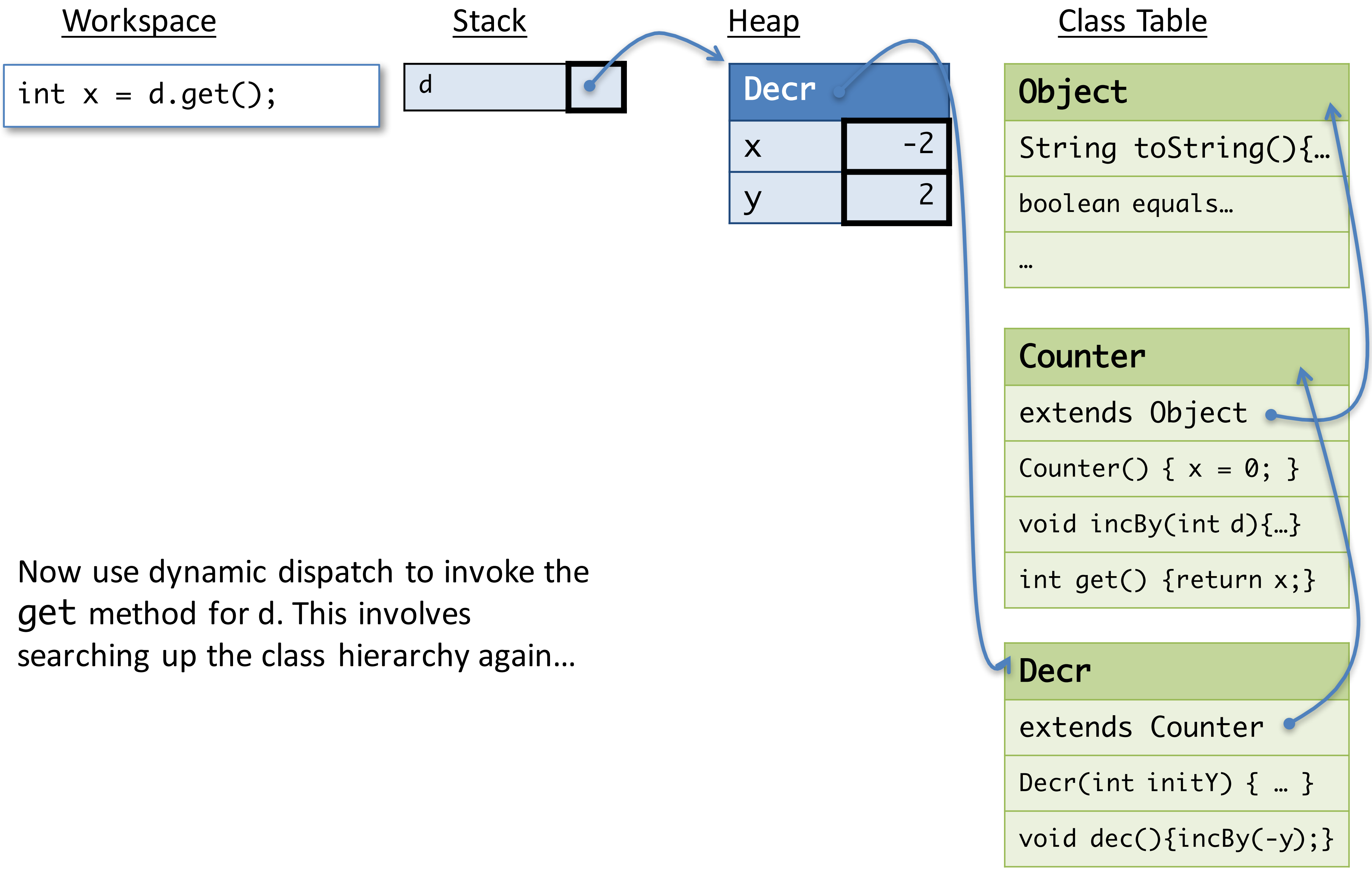


It takes a few steps…

Body of incBy:

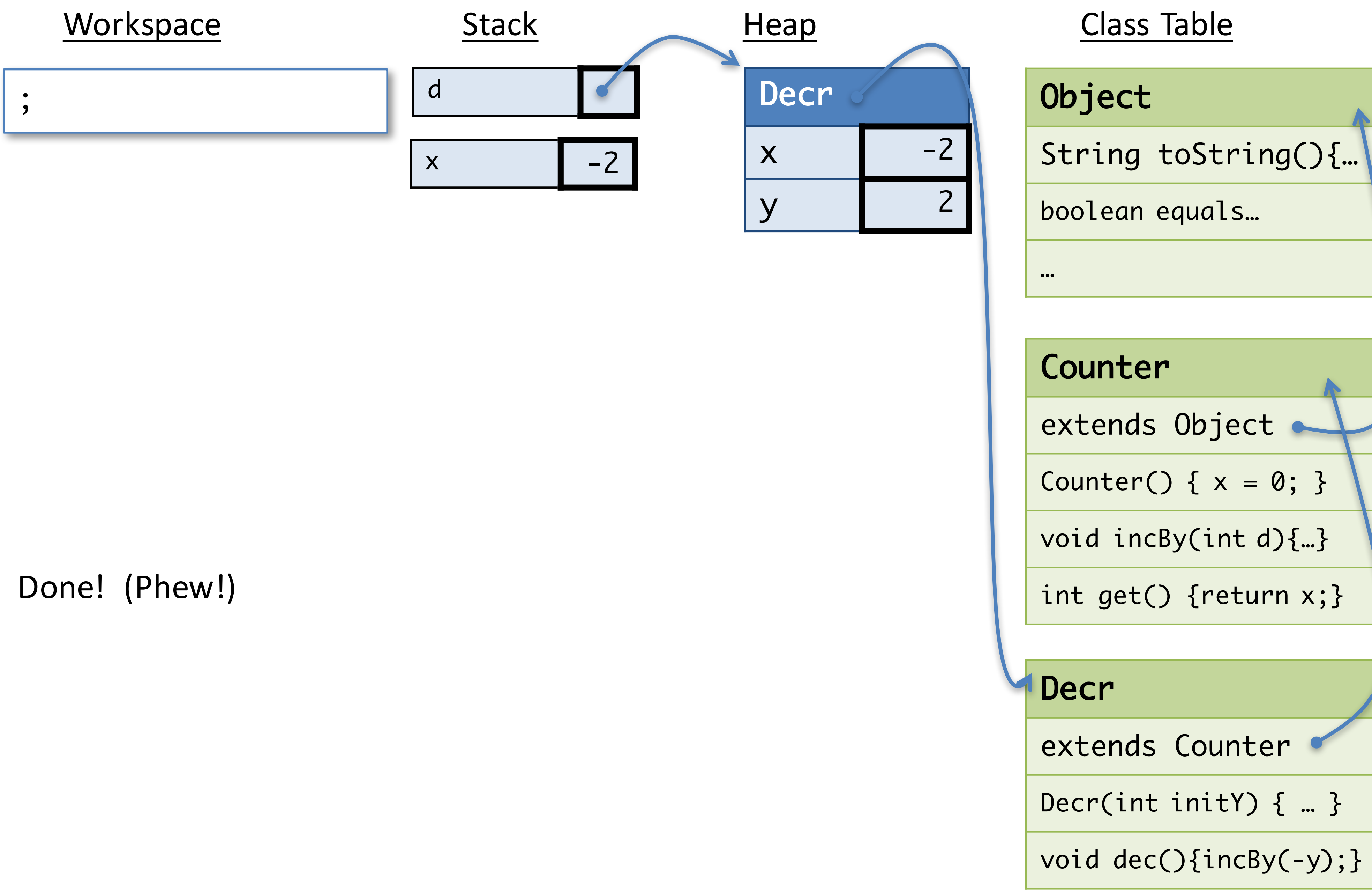
- reads this.x
- looks up d
- computes result this.x + d
- stores the answer (-2) in this.x

After a few more steps…



Now use dynamic dispatch to invoke the `get` method for d. This involves searching up the class hierarchy again…

After yet a few more steps…



Done! (Phew!)

Summary: `this` and dynamic dispatch

- When object's method is invoked, as in `o.m()`, the code that runs is determined by `o`'s *dynamic* class.
  - The dynamic class, represented as a pointer into the class table, is included in the object structure in the heap
  - If the method is inherited from a superclass, determining the code for `m` might require searching up the class hierarchy via pointers in the class table
  - This process of *dynamic dispatch* is the heart of OOP!

- Once the code for m has been determined, a binding for `this` is pushed onto the stack.
  - The `this` pointer is used to resolve field accesses and method invocations inside the code.

Static members & Java ASM

Based on your understanding of the ‘this’ parameter, is it possible to refer to ‘this’ in a static method?

1. No
2. Yes
3. I’m not sure

Static Members

- Classes in Java can also act as *containers* for code and data.
- The modifier `static` means that the field or method is associated with the class and *not* instances of the class.

```
public class C {
  public static int x = 23;
  public static int someMethod(int y) { return C.x + y; }
  public static void main(String args[]) {
     …
  }
}

C.x = C.x + 1;
C.someMethod(17);
```

You can do a static assignment to initialize a static field.

Access to the static member uses the class name `C.x` or `C.foo()`

Example of Statics

- The java.lang.Math library provides static fields/methods for many common arithmetic operations:

- `Math.PI == 3.141592653589793`
- `Math.sin, Math.cos`
- `Math.sqrt`
- `Math.pow`
- etc.

Class Table Associated with C

- The class table entry for C has a field slot for x.
- Updates to C.x modify the contents of this slot: `C.x = 17;`

C	
extends Object	
static x	23
static int someMethod(int y) { return x + y; }	
static void main(String args[]) {…}	

- A static field is a *global* variable
  - There is only one heap location for it (in the class table)
  - Modifications to such a field are globally visible (if the field is public)
  - Generally not a good idea!

Static Methods (Details)

- Static methods do *not* have access to the `this` pointer
  - Why? There isn't an instance to dispatch through.
  - Therefore, static methods may only directly call other static methods.
  - Similarly, static methods can only directly read/write static fields.
  - Of course a static method can create instance of objects (via `new`) and then invoke methods on those objects.

- Gotcha: It is possible (but confusing) to invoke a static method as though it belongs to an object instance.
  - e.g. `o.someMethod(17)` where `someMethod` is static
  - Eclipse will issue a warning if you try to do this.