Programming Languages and Techniques (CIS120)

Lecture 25

March 18, 2013

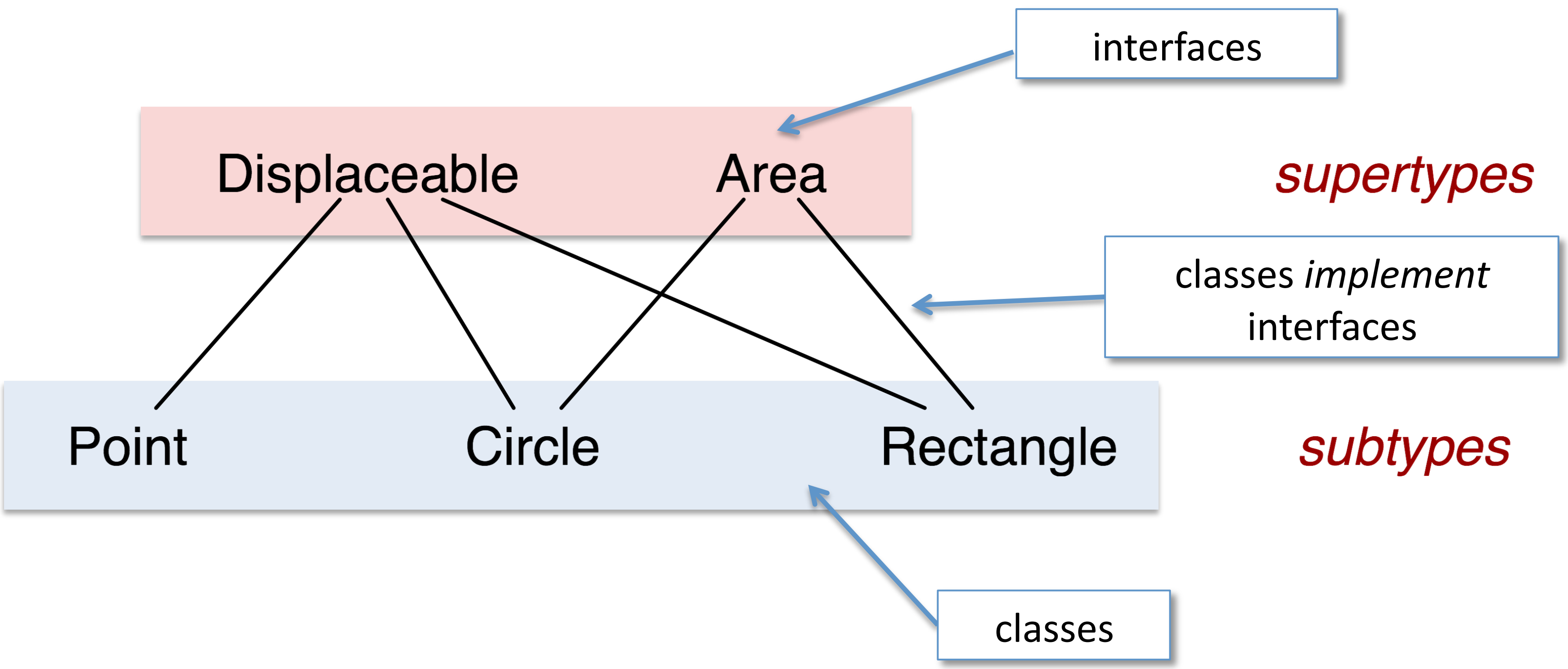
Subtyping and Dynamic Dispatch

Announcements

- HW07 due tonight at midnight
  - Weirich OH cancelled today
  - Help your TAs make the most effective use of OH
- HW08 (Text Adventure) is due March 25th at 11:59:59pm
- *Midterm 2 is Friday, March 29th in class*
  - Mutable state (in OCaml and Java)
  - Objects (in OCaml and Java)
  - ASM (in OCaml and Java)
  - Reactive programming (in OCaml)
  - Arrays in (Java)
  - Subtyping & Inheritance (in Java)

Subtypes and Supertypes

- An interface represents a *point of view* about an object
- Classes can implement *multiple* interfaces



Types can have many different supertypes / subtypes

Extension

Sharing declarations and definitions
between related types

Interface Extension

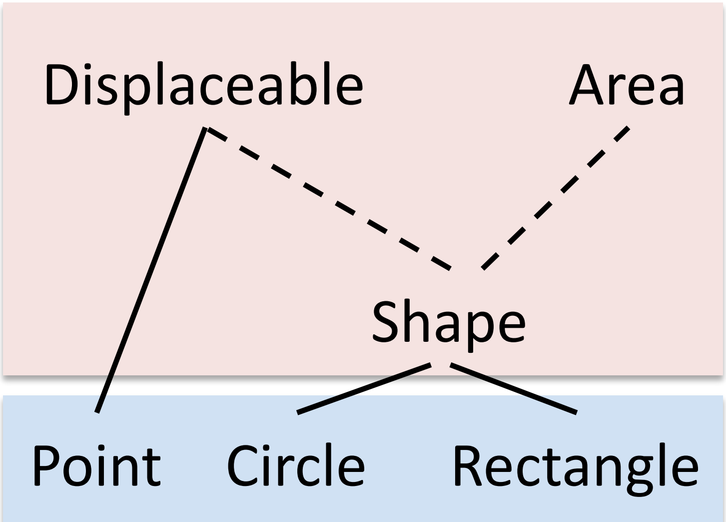
- Build rich interface hierarchies by *extending* existing interfaces.

```
public interface Displaceable {
   double getX();
   double getY();
   void move(double dx, double dy);
}

public interface Area {
   double getArea();
}

public interface Shape extends Displaceable, Area {
     Rectangle getBoundingBox();
}
```

The Shape type includes all the methods of Displaceable and Area, plus the new getBoundingBox method.

Note the use of the “extends” keyword.

Interface Hierarchy




```
class Point implements Displaceable {
   … // omitted
}
class Circle implements Shape {
   … // omitted
}
class Rectangle implements Shape {
   … // omitted
}
```

- Shape is a *subtype* of both Displaceable and Area.
- Circle and Rectangle are both subtypes of Shape, and, by *transitivity*, both are also subtypes of Displaceable and Area.
- Note that one interface may extend *several* others.
  - Interfaces do not necessarily form a tree, but the hierarchy has no cycles.

Interface Extension Demo

See: Main1.java

Class Extension: Inheritance

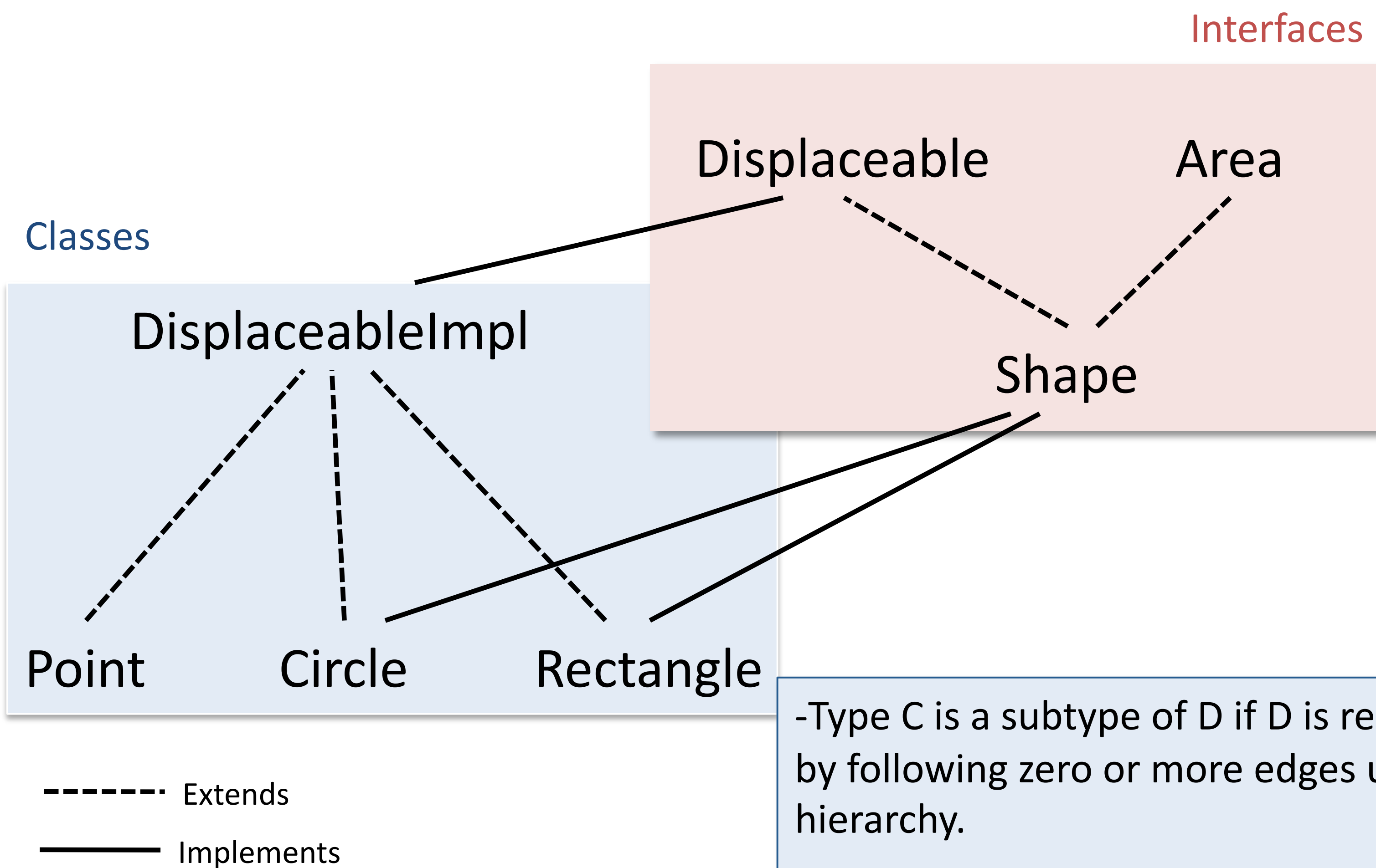
- Classes, like interfaces, can also extend one another.
  - Unlike interfaces, a class can extend only *one* other class.
- The extending class *inherits* all of the fields and methods of its *superclass*, and may include additional fields or methods.

```
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); }
}
```

Simple Inheritance

- In *simple inheritance*, the subclass only *adds* new fields or methods
- Use simple inheritance to *share common code* among related classes
  - Example: Point, Circle, and Rectangle have *identical* code for getX(), getY(), and move() methods when implementing Displaceable
  - Share this common code in a class "DisplaceableImpl". The classes Point, Circle, Rectangle should inherit fields and methods from this class (see Main2.java)
- Inheritance captures the "is a" relationship between objects (e.g. a Car is a Vehicle)
  - Class extension should *never* be used when "is a" does not relate the subtype to the supertype

Subtyping with Inheritance



-Type C is a subtype of D if D is reachable from C by following zero or more edges upwards in the hierarchy.

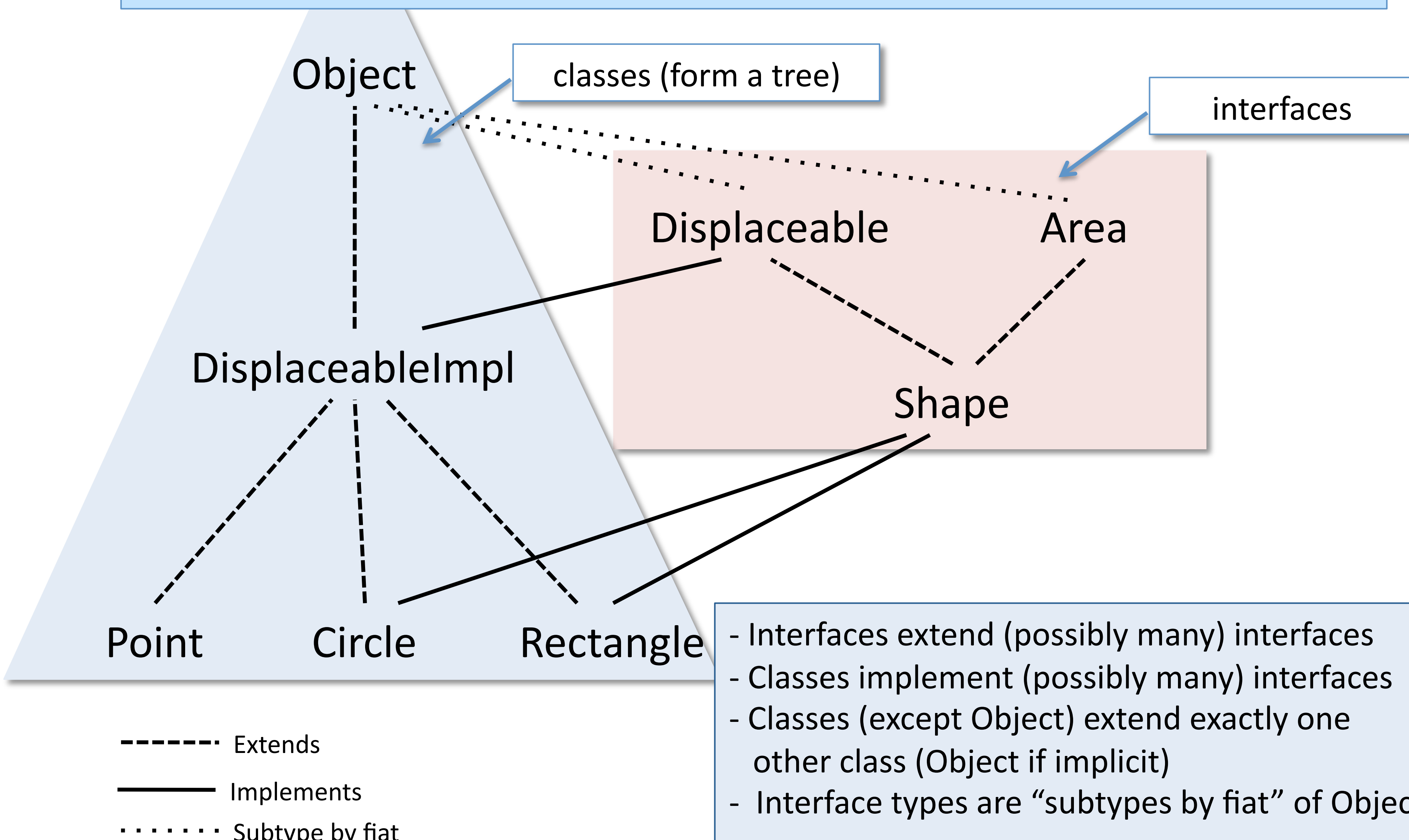
- e.g. Circle is a subtype of Area, but Point is not

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 (override these!)
- Object is also the top type of the subtyping hierarchy.

Subtyping



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

Example of Simple Inheritance

See: Main2.java

Inheritance: Constructors

- Contructors *cannot* be inherited (they have the wrong names!)
  - Instead, a subclass invokes the constructor of its super class using the keyword 'super'.
  - Super *must* be the first line of the subclass constructor, unless the parent class constructor takes no arguments, in which it is OK to omit the call to super (it is called implicitly).

```
class D {
  private int x;
  private int y;
  public D (int initX, int initY) { x = initX; y = initY; }
  public int addBoth() { return x + y; }
}

class C extends D {
  private int z;
  public C (int initX, int initY, int initZ) {
    super(initX, initY);
    z = initZ;
  }
  public int addThree() {return (addBoth() + z); }
}
```

Other forms of inheritance

- Java has other features related to inheritance (some of which we will discuss later in the course):
  - A subclass might *override* (re-implement) a method already found in the superclass.
  - A class might be *abstract* – i.e. it does not provide implementations for all of its methods (its subclasses must provide them instead)
- These features are hard to use properly and the need for them arises in special cases
  - Making reusable libraries
  - Special methods: equals and toString
- We recommend avoiding all forms of inheritance (even "simple inheritance") when possible – prefer interfaces and composition (see Main3.java).

  Especially avoid overriding.

The Java Abstract Stack Machine

1. Class tables
2. Constructors and “this”
3. Dynamic dispatch

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;
```

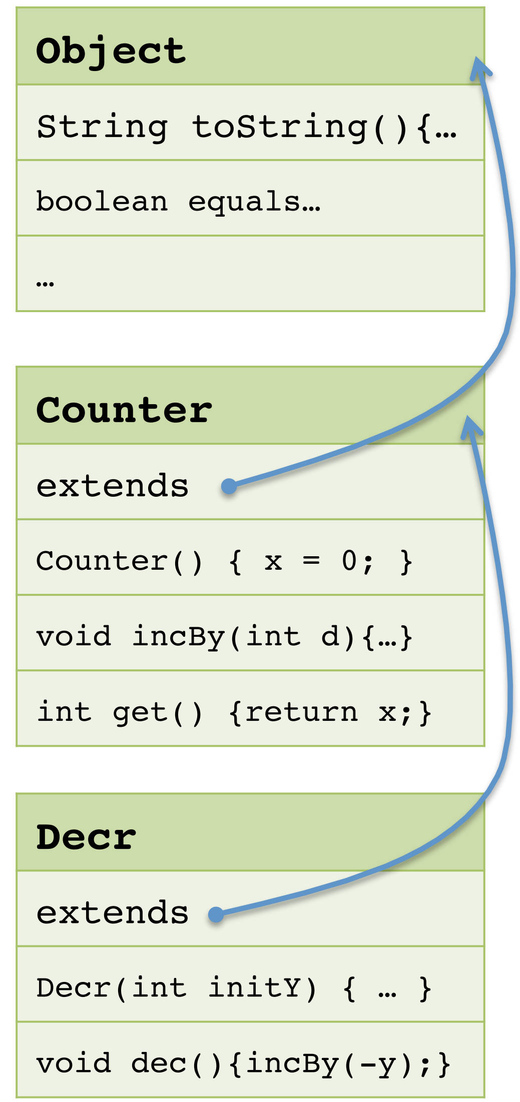
- When does the code in a constructor get executed?

- What if the method was inherited from a superclass?

ASM refinement: The Class Table

```
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:

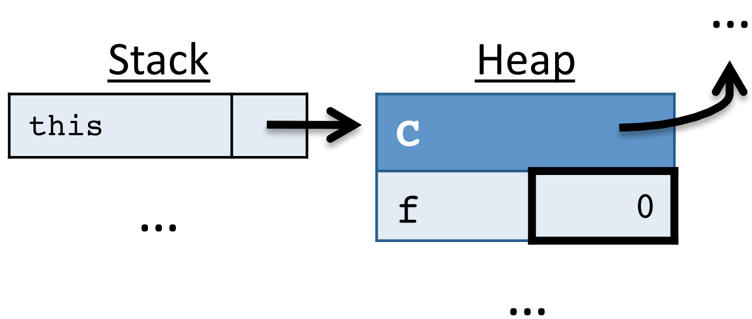
- The code for each method,
- Back pointers to each class's parent, and
- The class's static members.

The ‘`this`’ Reference

- Inside a non-static method, the variable `this` is a reference to the object itself.

- 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();
```

Example 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

Object
`String toString(){…`
`boolean equals…`
…

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

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

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

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…
…

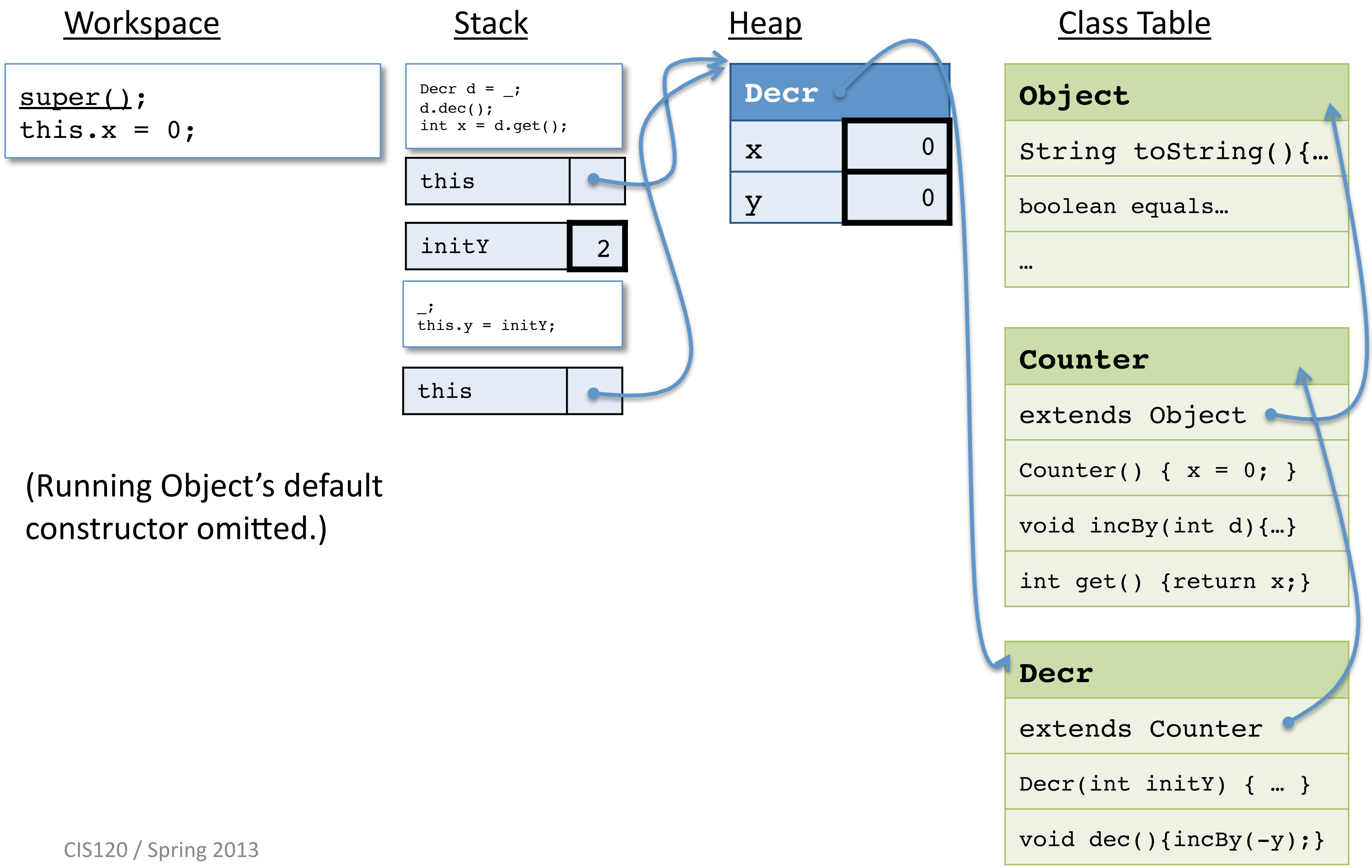
Counter
extends Object
Counter() { x = 0; }
void incBy(int d){…}
int get() {return x;}

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

Call to super:

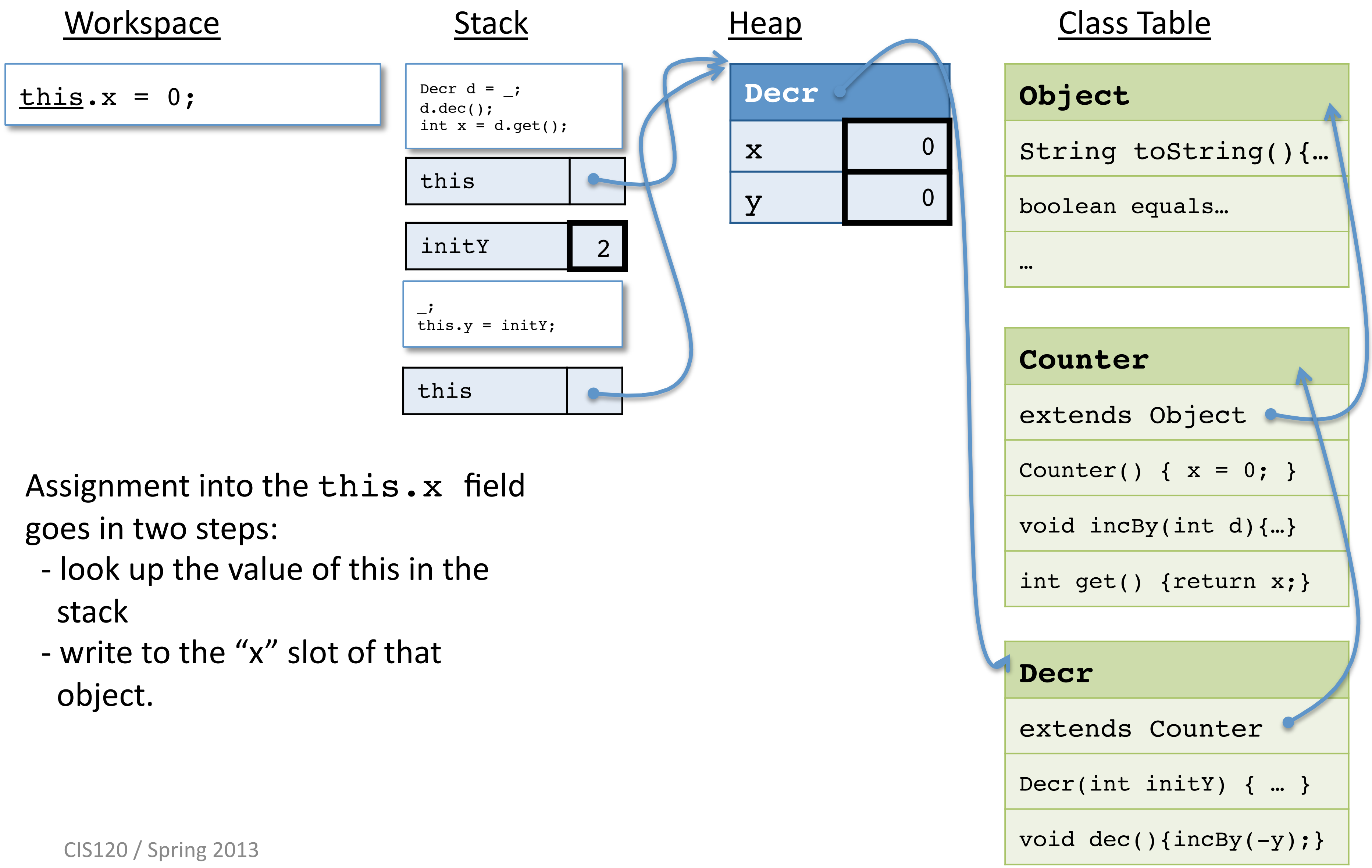
- The constructor (implicitly) calls the super constructor
- Invoking a method/constructor pushes the saved workspace, the method params (none here) and a new this pointer.

Abstract Stack Machine



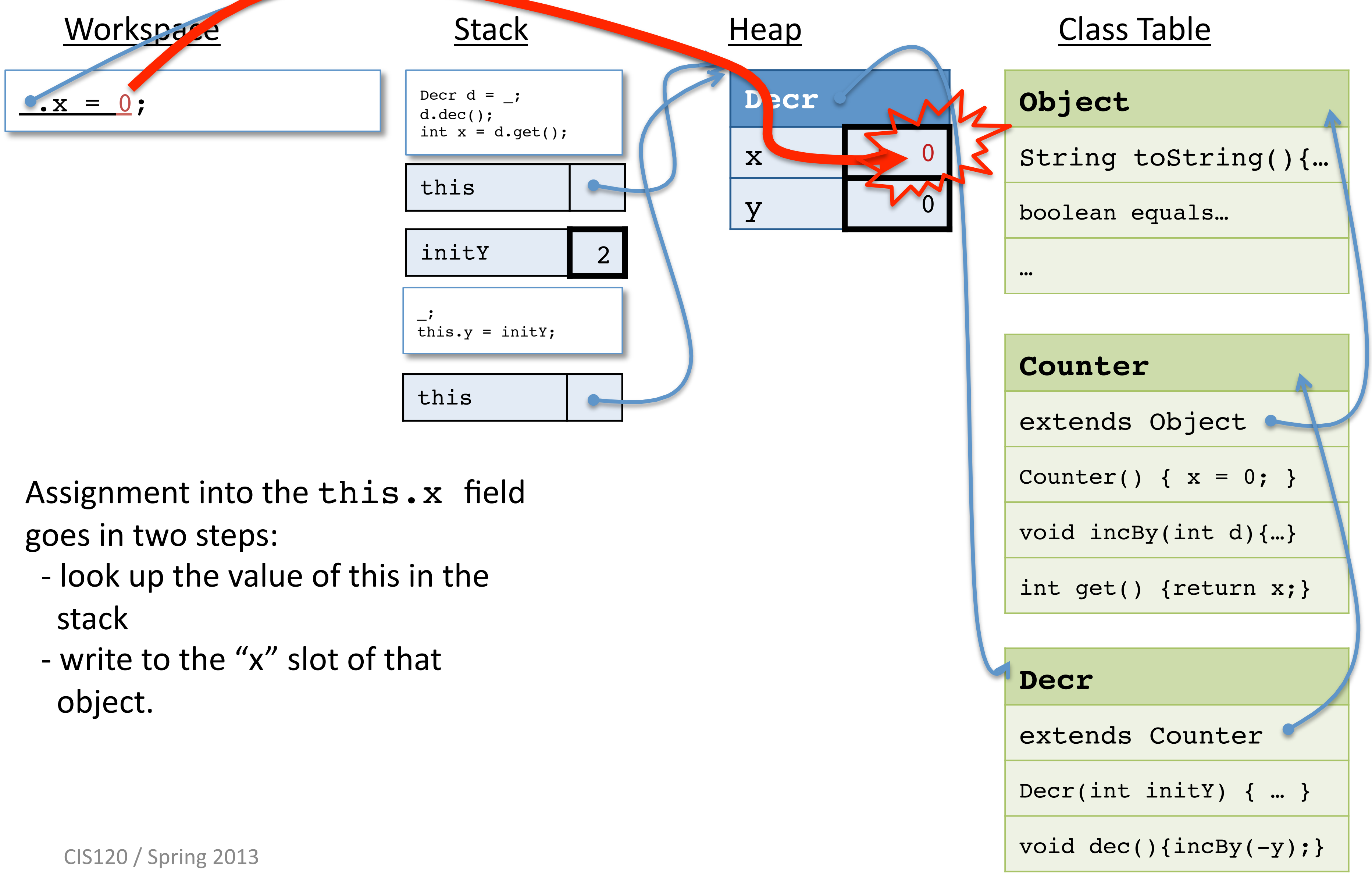
(Running Object's default constructor omitted.)

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.

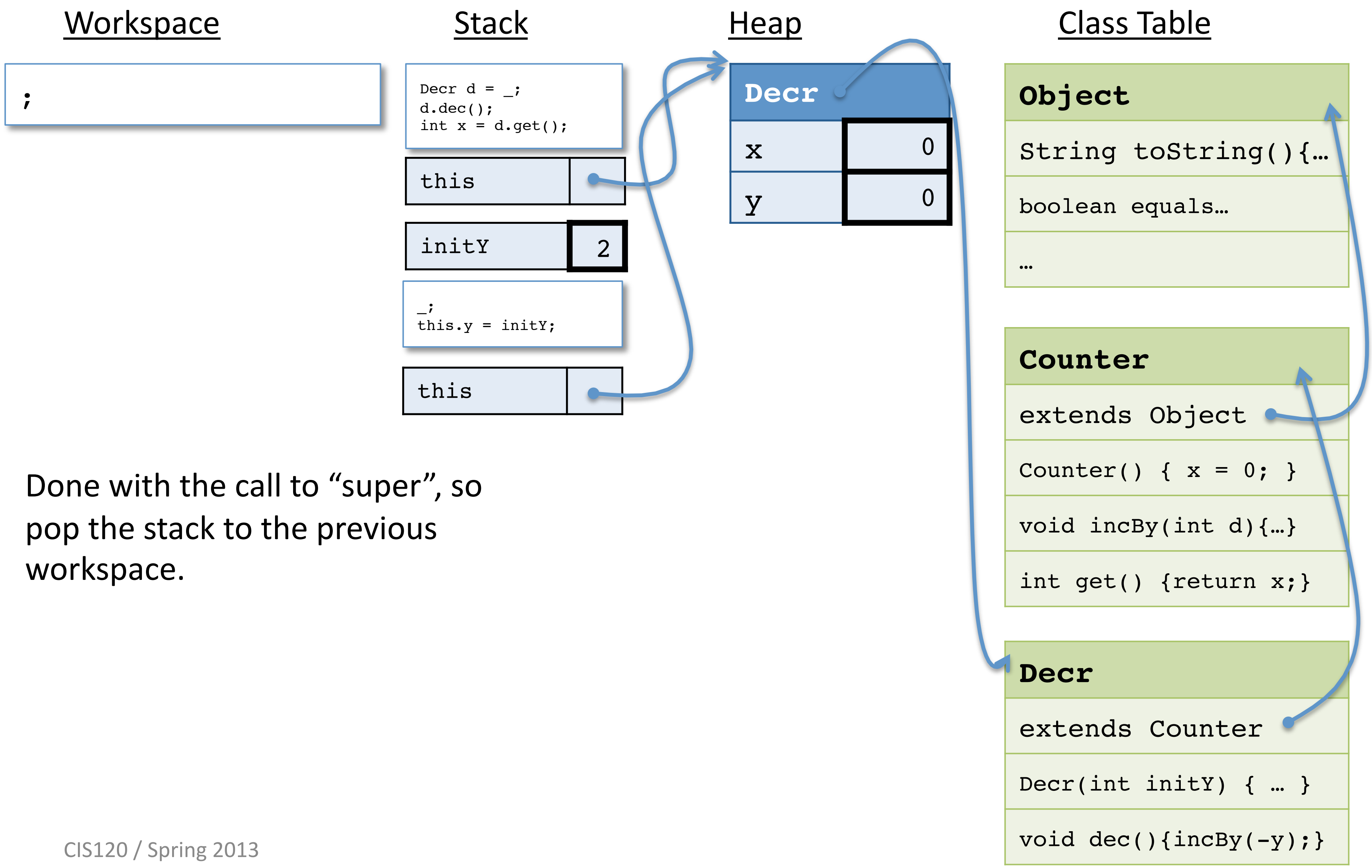
Assigning to a Field



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

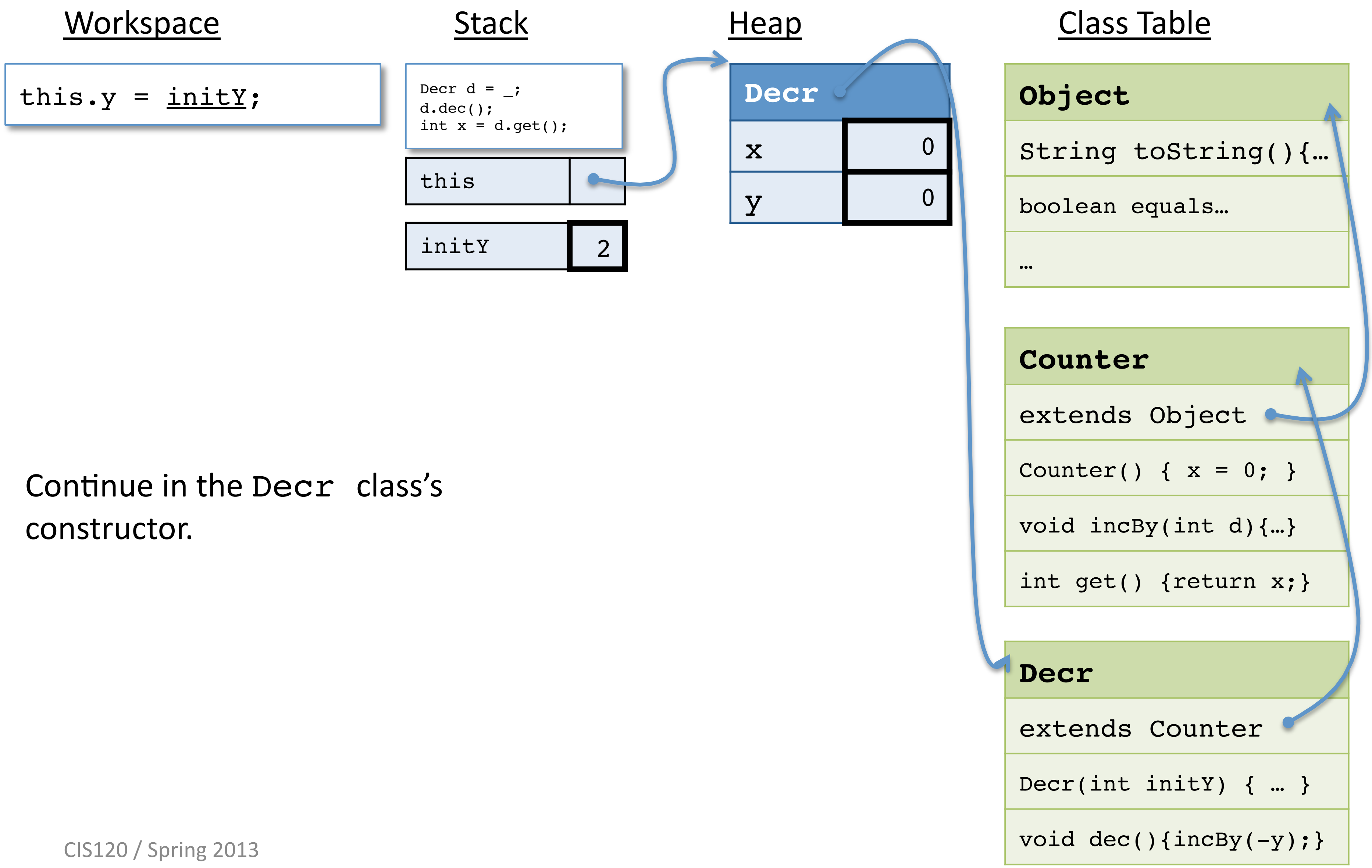
- look up the value of this in the stack
- write to the "x" slot of that object.

Done with the call



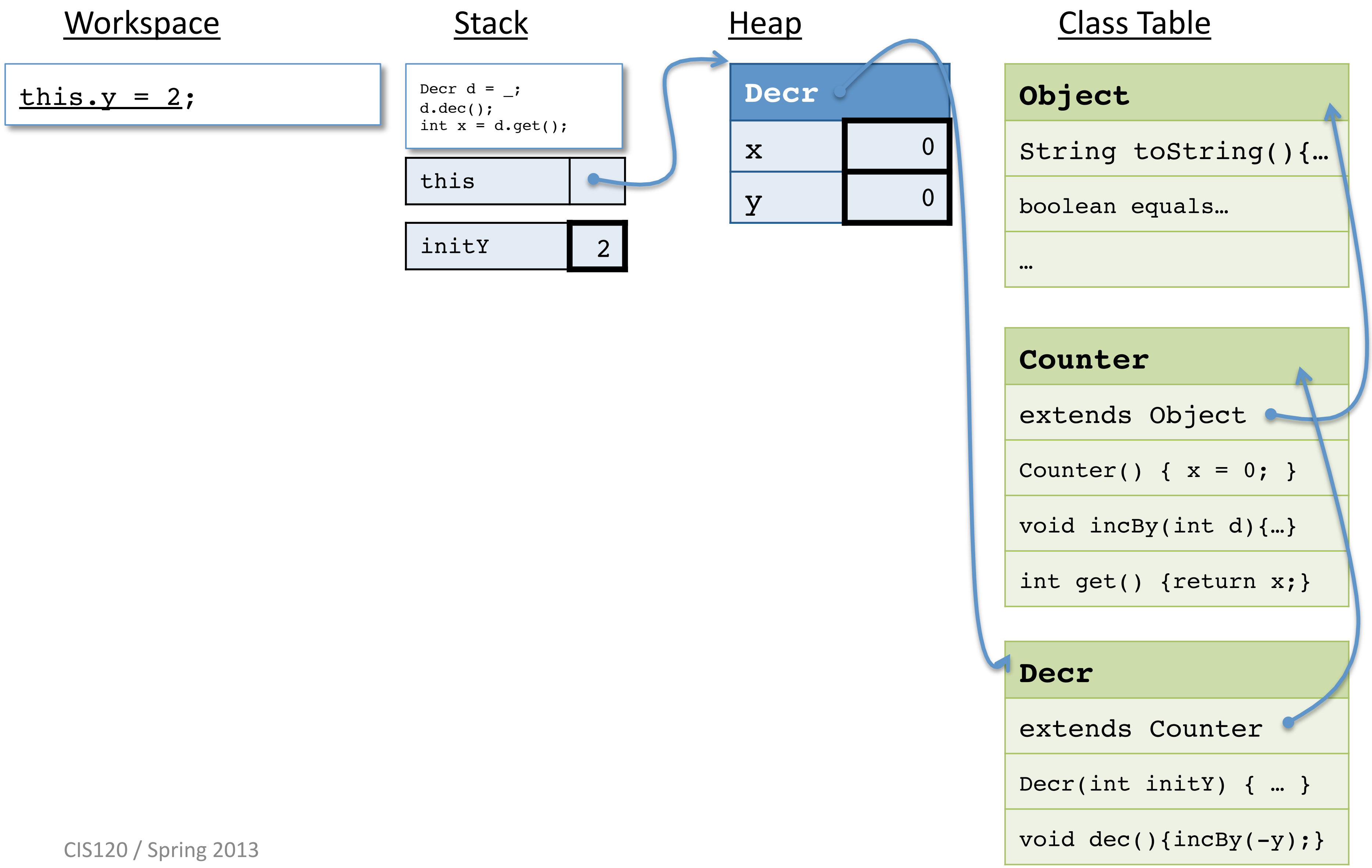
Done with the call to "super", so pop the stack to the previous workspace.

Continuing

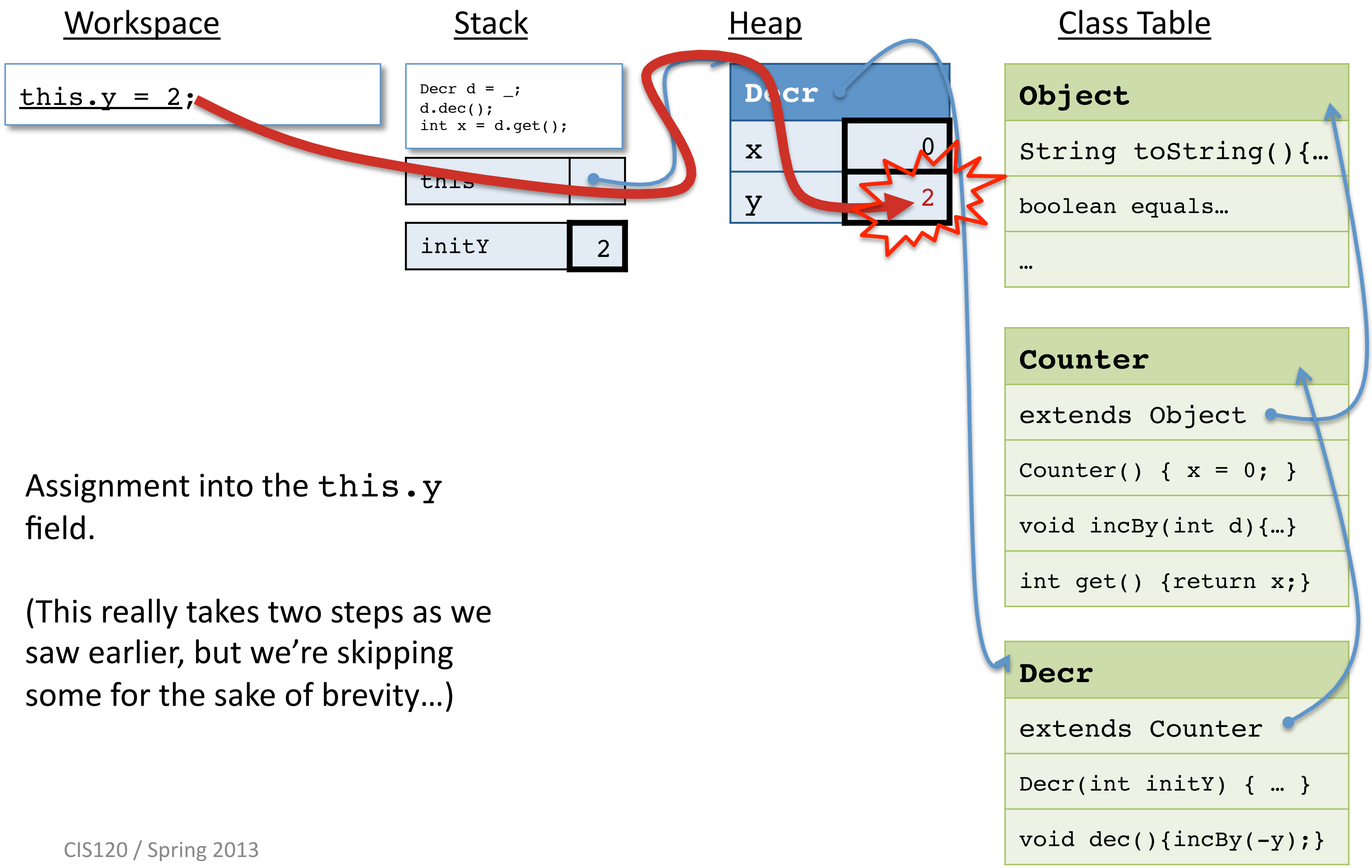


Continue in the `Decr` class's constructor.

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

Workspace

```
;
```

Stack

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

this	
initY	2

Heap

Decr	
x	0
y	2

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);}`

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

Workspace

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

Stack

Heap

Decr	
x	0
y	2

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);}`

Continue executing the program.

Allocating a local variable

Workspace

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

Stack

d	

Heap

Decr	
x	0
y	2

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);}

Allocate a stack slot for the local variable d. It's mutable… (see the 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.