Programming Languages and Techniques (CIS120)

Lecture 28

March 30, 2016

Collections and Equality

Chapter 26

Announcements

- Dr. Steve Zdancewic is guest lecturing today
  - He teaches CIS 120 in the Fall

- Midterm II is available for review
  - See Laura Fox in Levine 308

- Homework 7: PennPals
  - DUE: Tuesday, April 5th

Method Overriding

A Subclass can *Override* its Parent

```
public class C {
  public void printName() { System.out.println(“I’m a C”); }
}

public class D extends C {
  public void printName() { System.out.println(“I’m a D”); }
}

// somewhere in main
C c = new D();
c.printName();
```

What gets printed to the console?

1. I’m a C
2. I’m a D
3. NullPointerException
4. NoSuchMethodException

A Subclass can *Override* its Parent

```
public class C {
  public void printName() { System.out.println(“I’m a C”); }
}

public class D extends C {
  public void printName() { System.out.println(“I’m a D”); }
}

// somewhere in main
C c = new D();
c.printName();
```

- Our ASM model for dynamic dispatch already explains what will happen when we run this code.
- Useful for changing the default behavior of classes.
- But… can be confusing and difficult to reason about if not used carefully.

Overriding Example

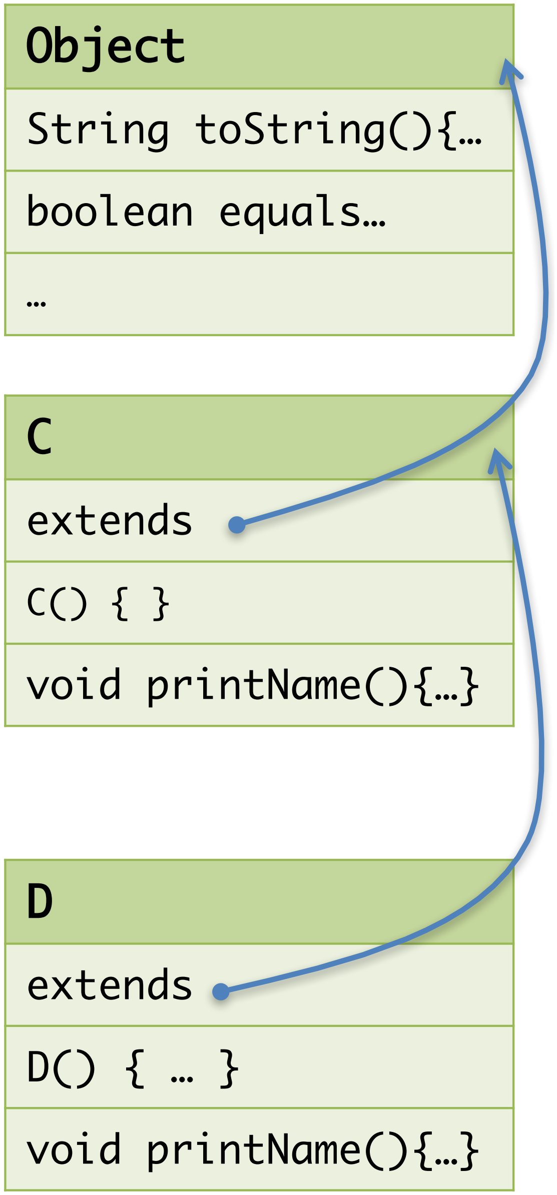
Workspace

Stack

Heap

Class Table

```
C c = new D();
c.printName();›
```



Object

String toString(){…

boolean equals…

…

C

extends

C() { }

void printName(){…}

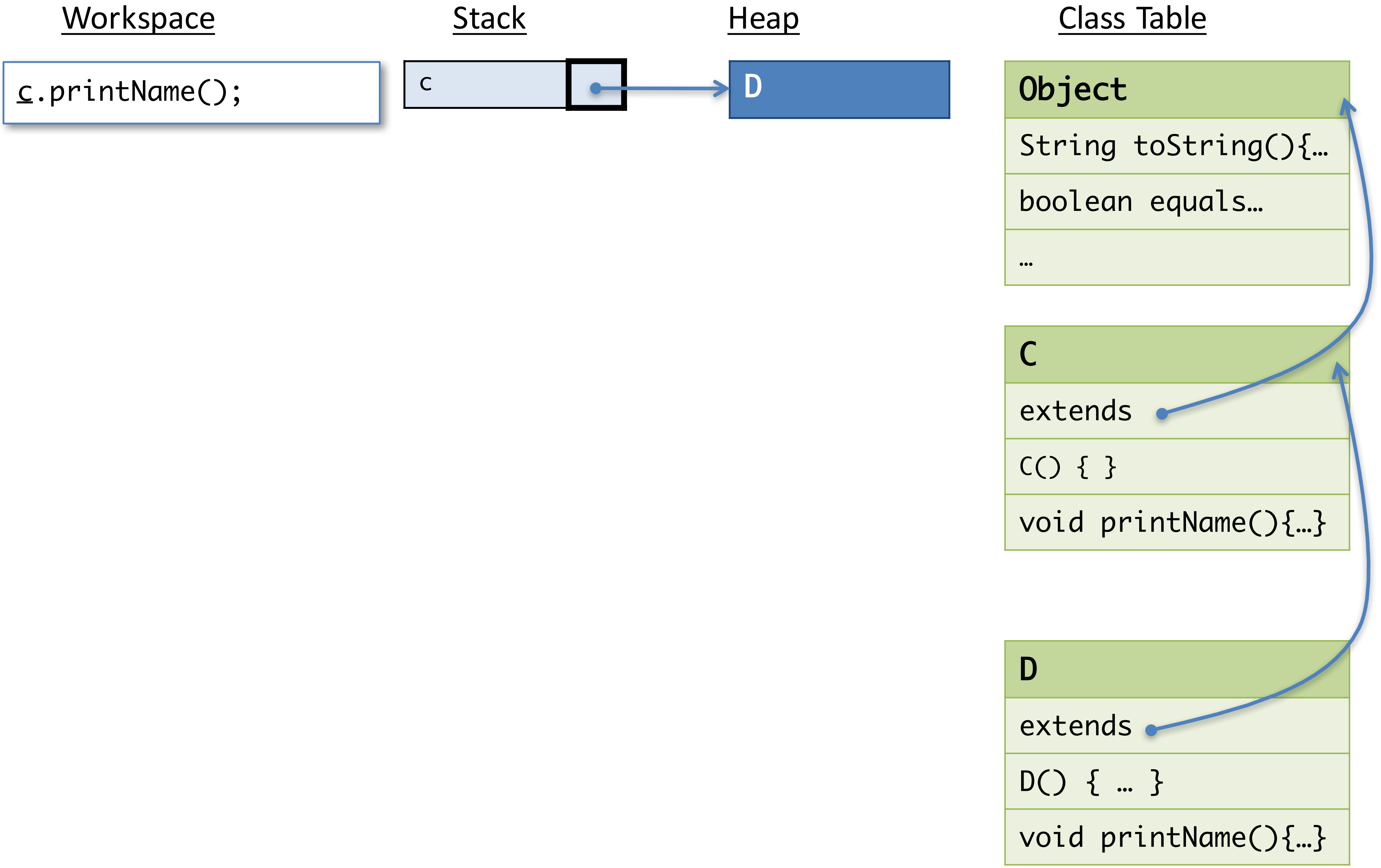
D

extends

D() { … }

void printName(){…}

Overriding Example



Workspace

c.printName();

Stack

c

Heap

D

Class Table

Object

String toString(){…

boolean equals…

…

C

extends

C() { }

void printName(){…}

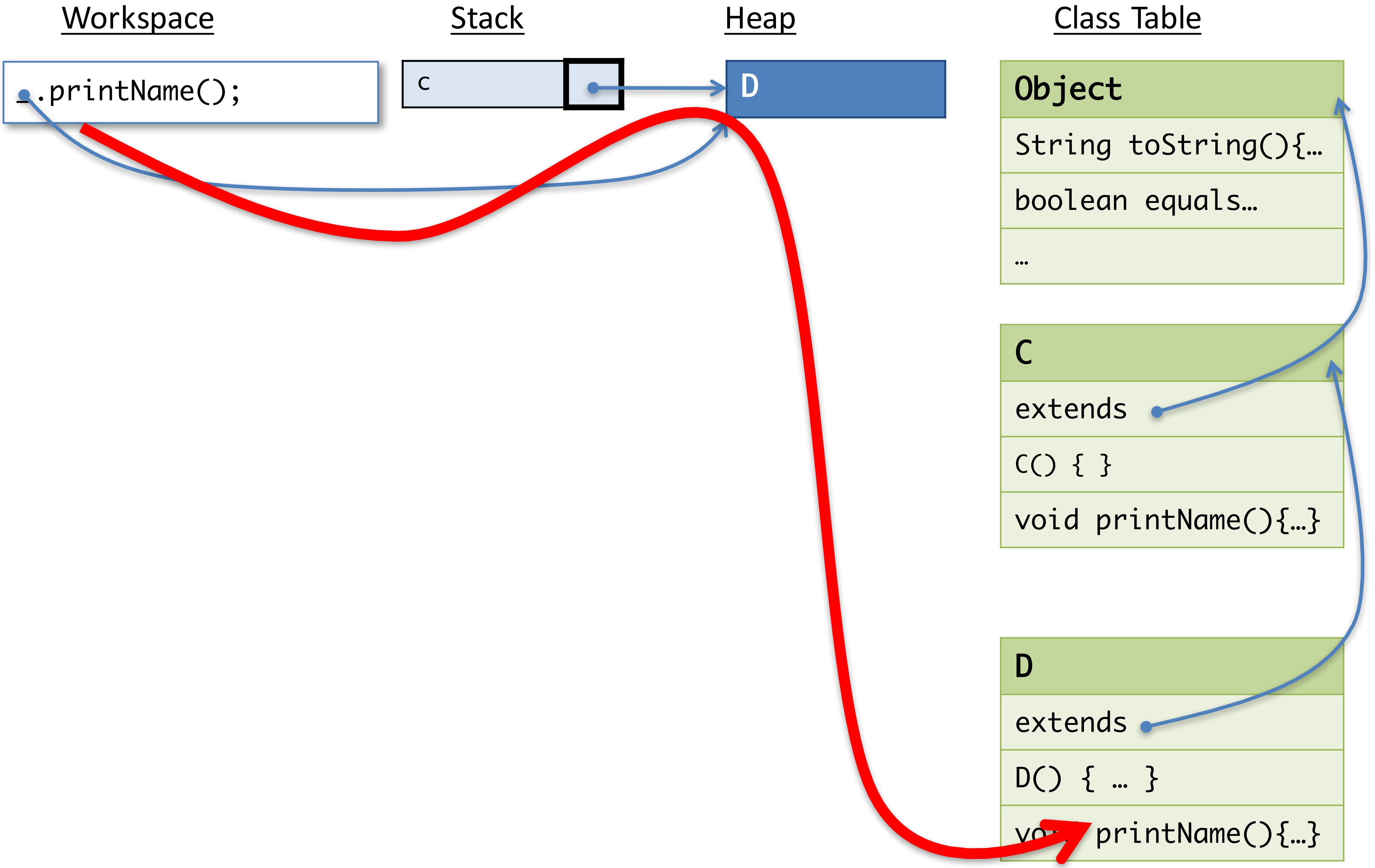
D

extends

D() { … }

void printName(){…}

Overriding Example



Workspace

_.printName();

Stack

c

Heap

D

Class Table

Object

String toString(){…

boolean equals…

…

C

extends

C() { }

void printName(){…}

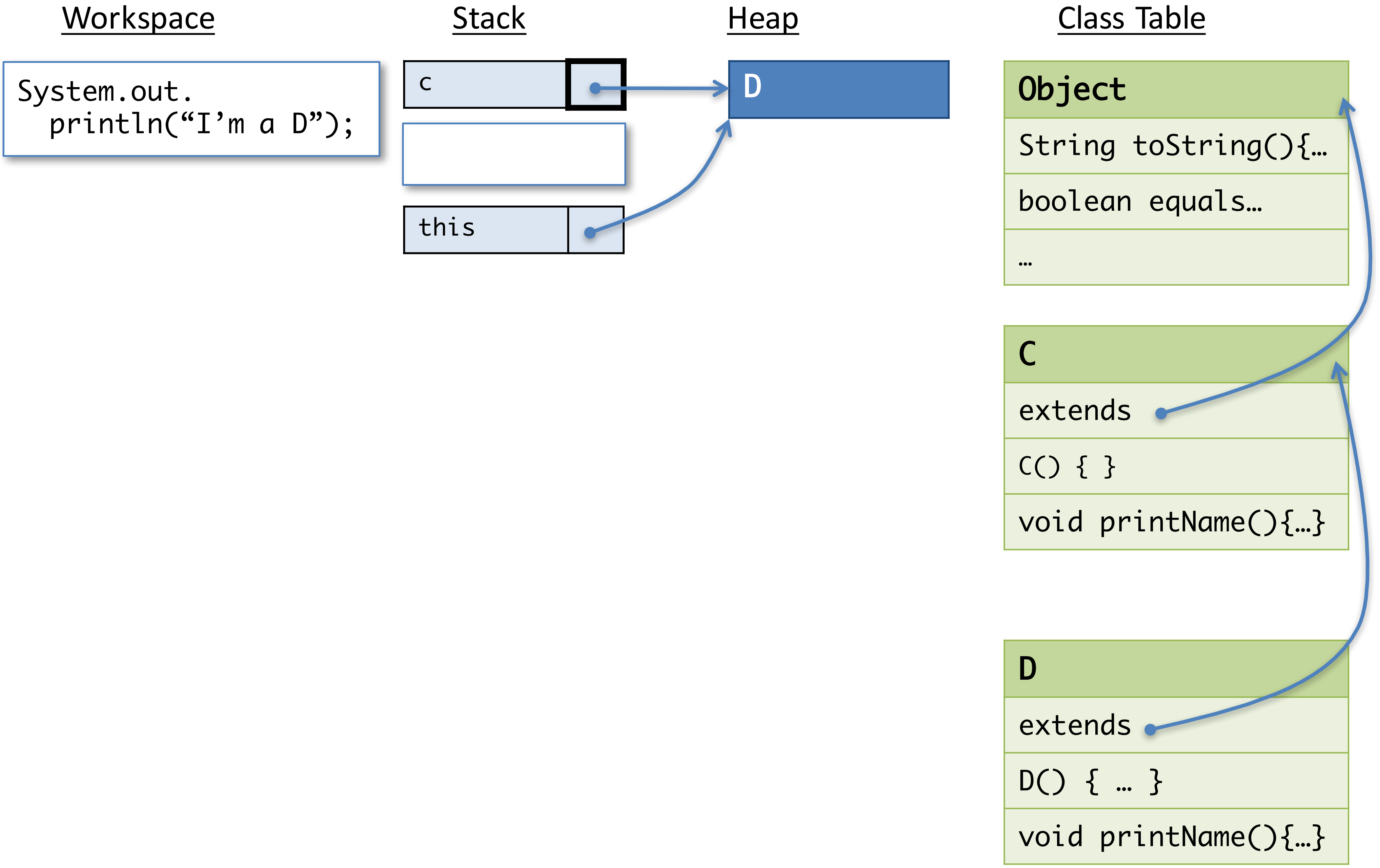
D

extends

D() { … }

vo printName(){…}

Overriding Example



Workspace

```
System.out.
  println("I'm a D");
```

Stack

Heap

Class Table

Difficulty with Overriding

```java
class C {

  public void printName() {
    System.out.println("I'm a " + getName());
  }

  public String getName() {
    return "C";
  }
}

class E extends C {

  public String getName() {
    return "E";
  }
}

// in main
C c = new E();
c.printName();
```

What gets printed to the console?

1. I’m a C
2. I’m a E
3. NullPointerException

Difficulty with Overriding

```
class C {

  public void printName() {
    System.out.println("I'm a " + getName());
  }

  public String getName() {
    return "C";
  }
}

class E extends C {

  public String getName() {
    return "E";
  }
}

// in main
C c = new E();
c.printName();
```

The C class might be in another package, or a library…

Whoever wrote E might not be aware of the implications of changing getName.

Overriding the method causes the behavior of printName to change!

- Overriding can break invariants/abstractions relied upon by the superclass.

Case study: Equality

Consider this example

```
public class Point {
    private final int x;
    private final int y;
    public Point(int x, int y) { this.x = x; this.y = y;
}
    public int getX() { return x; }
    public int getY() { return y; }
}

// somewhere in main…
List<Point> l = new LinkedList<Point>();
l.add(new Point(1,2));
System.out.println(l.contains(new Point(1,2)));
```

What gets printed to the console?

1. true
2. false

Why?

Answer: 2

When to override equals

- In classes that represent immutable *values*
  - String already overrides equals
  - Our Point class is a good candidate

- When there is a “logical” notion of equality
  - The collections library overrides equality for Sets (e.g. two sets are equal if and only if they contain equal elements)

- Whenever instances of a class might need to serve as *elements of a set* or as *keys in a map*
  - The collections library uses `equals` internally to define set membership and key lookup
  - (This is the problem with the example code)

When *not* to override equals

- When each instance of a class is inherently unique
  - *Often* the case for mutable objects (since its state might change, the only sensible notion of equality is identity)
  - Classes that represent “active” entities rather than data (e.g. threads, gui components, etc.)

- When a superclass already overrides equals and provides the correct functionality.
  - Usually the case when a subclass is implemented by adding only new methods, but not fields

How to override equals

*See the very nicely written article “How to write an Equality Method in Java” by Oderski, Spoon, and Venners (June 1, 2009) at http://www.artima.com/lejava/articles/equality.html

The contract for equals

- The equals method implements an *equivalence relation* on non-null objects.
- It is *reflexive*:
  - for any non-null reference value x, x.equals(x) should return true
- It is *symmetric*:
  - for any non-null reference values x and y, x.equals(y) should return true if and only if y.equals(x) returns true
- It is *transitive*:
  - 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.
- It is consistent:
  - 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 object is modified
- For any non-null reference x, x.equals(null) should return false.

Directly from: http://docs.oracle.com/javase/7/docs/api/java/lang/Object.html#equals(java.lang.Object)

First attempt

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {this.x = x; this.y = y;}
  public int getX() { return x; }
  public int getY() { return y; }
  public boolean equals(Point that) {
    return (this.getX() == that.getX() &&
            this.getY() == that.getY());
  }
}
```

Gocha: *overloading*, vs. *overriding*

```
public class Point {
  …
  // overloaded, not overridden
  public boolean equals(Point that) {
    return (this.getX() == that.getX() &&
            this.getY() == that.getY());
  }
}
Point p1 = new Point(1,2);
Point p2 = new Point(1,2);
Object o = p2;
System.out.println(p1.equals(o));
// prints false!
System.out.println(p1.equals(p2));
// prints true!
```

The type of equals as declared in Object is:

```
  public boolean equals(Object o)
```

The implementation above takes a Point *not* an Object!

Overriding equals, take two

Properly overridden equals

```
public class Point {
    …
    @Override
    public boolean equals(Object o) {
        // what do we do here???
    }
}
```

- Use the `@Override` annotation when you *intend* to override a method so that the compiler can warn you about accidental overloading.

- Now what? How do we know whether the o is even a Point?
  - We need a way to check the *dynamic* type of an object.

instanceof

- The instanceof operator tests the *dynamic* type of any object

```
Point p = new Point(1,2);
Object o1 = p;
Object o2 = "hello";
System.out.println(p instanceof Point);
       // prints true
System.out.println(o1 instanceof Point);
       // prints true
System.out.println(o2 instanceof Point);
       // prints false
System.out.println(p instanceof Object);
       // prints true
```

- But… use instanceof judiciously – usually dynamic dispatch is better.

Type Casts

- We can test whether o is a Point using instanceof

```
@Override
public boolean equals(Object o) {
  boolean result = false;
     if (o instanceof Point) {
        // o is a point - how do we treat it as such?
     }
   return result;
}
```

Check whether o is a Point.

- Use a type *cast*: `(Point) o`
  - At compile time: the expression `(Point) o` has type `Point`.
  - At runtime: check whether the dynamic type of o is a subtype of `Point`, if so evaluate to o, otherwise raise a `ClassCastException`
  - As with instanceof, use casts judiciously – i.e. almost never. Instead use generics

Refining the equals implementation

```
@Override
public boolean equals(Object o) {
    boolean result = false;
    if (o instanceof Point) {
        Point that = (Point) o;
        result = (this.getX() == that.getX() &&
                  this.getY() == that.getY());
    }
    return result;
}
```

This cast is guaranteed to succeed.

What about subtypes?

Equality and Subtypes

Suppose we extend Point like this

```
public class ColoredPoint extends Point {
  private final int color;
  public ColoredPoint(int x, int y, int color) {
    super(x,y);
    this.color = color;
  }

  @Override
  public boolean equals(Object o) {
    boolean result = false;
    if (o instanceof ColoredPoint) {
      ColoredPoint that = (ColoredPoint) o;
      result = (this.color == that.color &&
                super.equals(that));
    }
    return result;
  }
}
```

This version of equals is suitably modified to check the color field too.

Keyword super is used to invoke overridden methods.

Broken Symmetry

```
Point p = new Point(1,2);
ColoredPoint cp = new ColoredPoint(1,2,17);
System.out.println(p.equals(cp));
    // prints true
System.out.println(cp.equals(p));
    // prints false
```

What gets printed? (1=true, 2=false)

- The problem arises because we mixed Points and ColoredPoints, but ColoredPoints have more data that allows for finer distinctions.
- Should a Point *ever* be equal to a ColoredPoint?

Suppose Points *can* equal ColoredPoints

```
public class ColoredPoint extends Point {
  …
  public boolean equals(Object o) {
     boolean result = false;
     if (o instanceof ColoredPoint) {
        ColoredPoint that = (ColoredPoint) o;
        result = (this.color == that.color &&
                  super.equals(that));
     } else if (o instanceof Point) {
        result = super.equals(o);
     }
     return result;
  }
}
```

I.e., we repair the symmetry violation by checking for Point explicitly

Does this really work? (1=yes, 2=no)

Broken Transitivity

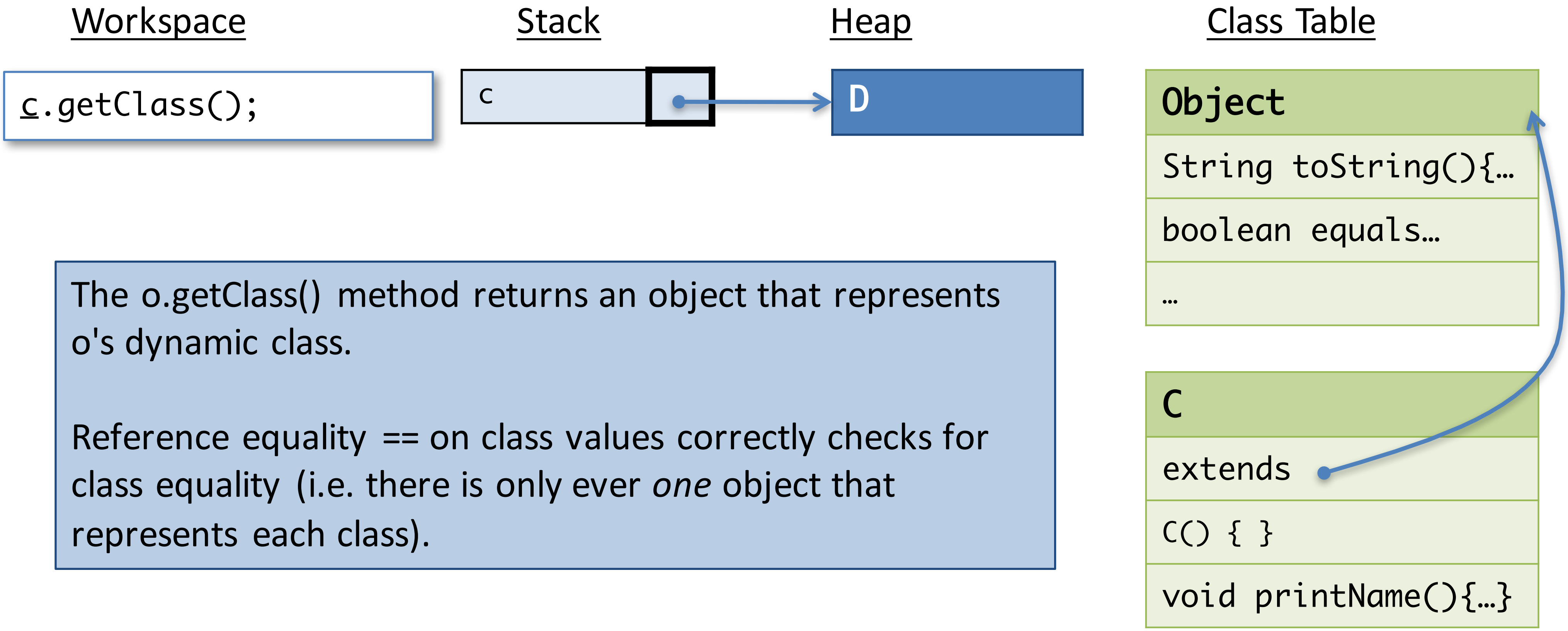
```
Point p = new Point(1,2);
ColoredPoint cp1 = new ColoredPoint(1,2,17);
ColoredPoint cp2 = new ColoredPoint(1,2,42);
System.out.println(p.equals(cp1));
    // prints true
System.out.println(cp1.equals(p));
    // prints true(!)
System.out.println(p.equals(cp2));
    // prints true
System.out.println(cp1.equals(cp2));
    // prints false(!!)
```

- We fixed symmetry, but broke transitivity!
- Should a Point *ever* be equal to a ColoredPoint?

No!

Should equality use `instanceof`?

- To correctly account for subtyping, we need the classes of the two objects to match *exactly*.
- instanceof only lets us ask about the subtype relation
- How do we access the dynamic class?



Workspace

`c.getClass();`

Stack

c

Heap

D

Class Table

Object

`String toString(){…`

`boolean equals…`

…

C

`extends`

`C() { }`

`void printName(){…}`

The o.getClass() method returns an object that represents o's dynamic class.

Reference equality == on class values correctly checks for class equality (i.e. there is only ever *one* object that represents each class).

Correct Implementation: Point

```java
@Override
    public boolean equals(Object obj) {
        if (this == obj)
            return true;
        if (obj == null)
            return false;
        if (getClass() != obj.getClass())
            return false;
        Point other = (Point) obj;
        if (x != other.x)
            return false;
        if (y != other.y)
            return false;
        return true;
    }
```

Check whether obj is a Point.

Equality and Hashing

- Whenever you override equals you ***must*** *also* override hashCode in a compatible way
  - hashCode is used by the HashSet and HashMap collections

- Forgetting to do this can lead to extremely puzzling bugs!

Overriding Equality in Practice

- Eclipse can autogenerate equality methods of the kind we developed.
  - But you need to specify which fields should be taken into account.
  - and you should know why some comparisons use == and some use .equals