Programming Languages and Techniques (CIS1200)

Lecture 27

Java Generics and Collections

Chapter 25

Announcements (1)

- HW07: PennPals
  - Programming with Java Collections
  - Due Tuesday, November 12 at 11.59pm

- Midterm 2: Friday, November 15th
  - Similar to Midterm 1
  - Content: HW 4 – 6, Chapters 11-21 (Java Arrays) and Chapter 32 (Encapsulation) of lecture notes

Announcements (2)

- Midterm 2: Friday, November 15
  - Coverage: up to Monday, Oct. 28 (Chapters 11-21, 32)
  - During lecture (001 @ 10.15am, 002 @ noon)
    Last names: A – Z Meyerson Hall B1
  - 60 minutes; closed book, closed notes
  - Review Material
    - old exams on the web site ("schedule" tab)
  - Review Session
    - TBA

Announcements (3)

Vote

Static members and the Java ASM

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* with instances of the class.

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

 // Elsewhere:
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()`

26: Based on your understanding of *this*, is it possible to refer to *this* in a static method?

0

No

0%

Yes

0%

I'm not sure

0%

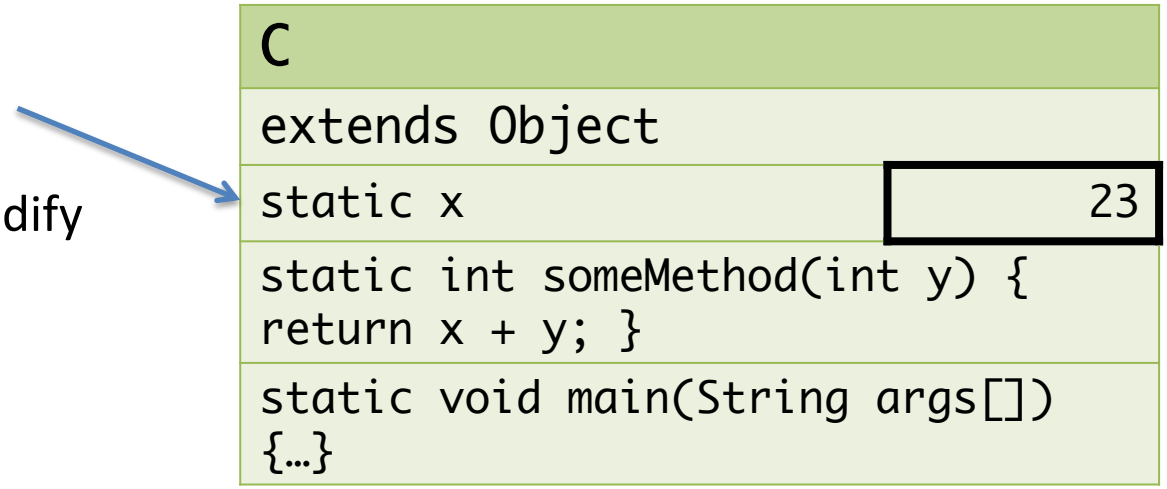
Based on your understanding of ‘this’, is it possible to refer to ‘this’ in a static method?

1. No
2. Yes
3. I’m not sure

Class Table Entry for a Class C

The class table entry associated with a class C has a field slot for x.

- Updates to `C.x` modify the contents of this slot: `C.x = 17;`



- 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 visible everywhere the field is
    - if the field is public, this means *everywhere*
  - Use with care!

Static Methods (Details)

- Static methods do *not* have access to a `this` reference
  - Why? Because there isn't any 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 also create instance of objects, via `new`, for example) 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

Java Generics

Subtype Polymorphism

vs.

Parametric Polymorphism

Review: Subtype Polymorphism*

- Main idea:

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

- If B is a subtype of A, it provides all of A's (public) methods.

*polymorphism = many shapes

Is subtype polymorphism enough?

Mutable Queue Interface in OCaml

```
module type QUEUE =
sig
  (* type of the data structure *)
  type 'a queue

  (* Make a new, empty queue *)
  val create : unit -> 'a queue

  (* Add a value to the end of the queue *)
  val enq : 'a -> 'a queue -> unit

  (* Remove the front value and return it (if any) *)
  val deq : 'a queue -> ‘a

  (* Determine if the queue is empty *)
  val is_empty : ‘a queue -> bool
end
```

How can we translate this interface to Java?

Java Interface using Subtyping

```
module type QUEUE =
sig

  type 'a queue

  val create : unit -> 'a queue

  val enq : 'a -> 'a queue -> unit

  val deq : 'a queue -> 'a

  val is_empty : 'a queue -> bool

end
```

OCaml

```
interface ObjQueue {


    // (no separate type)

    // (no constructors
    // in an interface)
    public void enq(Object elt);

    public Object deq();

    public boolean isEmpty();

}
```

Java

Subtype Polymorphism

```
interface ObjQueue {
    public void enq(Object elt);
    public Object deq();
    public boolean isEmpty();
}
```

```
ObjQueue q = …;

q.enq(" CIS 1200 ");
__A__  x = q.deq();
```

What type should we write for A?

1. String
2. Object
3. ObjQueue
4. None of the above

ANSWER: Object

Subtype Polymorphism

```
interface ObjQueue {
    public void enq(Object elt);
    public Object deq();
    public boolean isEmpty();
}
```

```
ObjQueue q = …;

q.enq(" CIS 1200 ");
Object  x = q.deq();
System.out.println(x.trim());
```

trim is a method of the String class (removes extra spaces)

← Does this line type check

1. Yes
2. No
3. It depends

ANSWER: No

Subtype Polymorphism

```
interface ObjQueue {
    public void enq(Object elt);
    public Object deq();
    public boolean isEmpty();
}
```

```
ObjQueue q = …;

q.enq(" CIS 1200 ");
Object  x = q.deq();
//System.out.println(x.trim());
q.enq(new Point(0.0,0.0));
___B___  y = q.deq();
```

What type for B?

1. Point
2. Object
3. ObjQueue
4. None of the above

ANSWER: Object

Parametric Polymorphism (a.k.a. Generics)

- Main idea:

> Parameterize a definition (i.e. interface, class or method) by a type (i.e. interface or class)

```
public interface Queue<E> {
  void enq(E o);
  E deq();
  boolean isEmpty();
}
```

- The implementation of a parametric polymorphic interface cannot depend on the type parameter
  - the implementation of enq can only invoke methods on 'o' that are inherited from Object
  - i.e. the **only** thing we know about E inside of enq is that it is a subtype of Object

Generics (Parametric Polymorphism)

```
public interface Queue<E> {
  void enq(E o);
  E deq();
  boolean isEmpty();
  …
}
```

```
Queue<String> q = …;

q.enq(" CIS 1200 ");
String x = q.deq();                 // What type is x?   String
System.out.println(x.trim());       // Is this valid?    Yes!
q.enq(new Point(0.0,0.0));          // Is this valid?    No!
```

Subtyping and Generics

Subtyping and Generics*

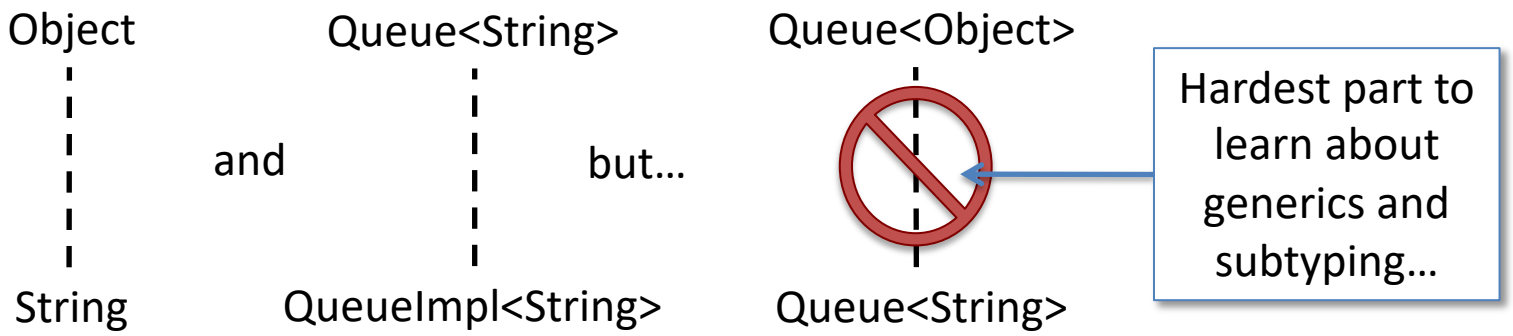
```
Queue<String> qs = new QueueImpl<>();
Queue<Object> qo = qs;

qo.enq(new Object());
String s = qs.deq();
```

Ok? Sure!
Ok? Let's see…

Ok? I guess
Ok? Noooo!

- Java generics are *invariant*:
  - Subtyping of *arguments* to generic types does not imply subtyping between the instantiations:



* Subtyping and generics interact in other ways too. Java supports *bounded polymorphism* and *wildcard types*, but those are beyond the scope of CIS 1200.

27: Subtyping with Generics

0

1

0%

2

0%

3

0%

4

0%

Subtyping and Generics

Which of these are true, assuming that class QueueImpl<E> implements interface Queue<E>?

1. QueueImpl<Queue<String>> is a subtype of Queue<Queue<String>>
2. Queue<QueueImpl<String>> is a subtype of Queue<Queue<String>>
3. Both
4. Neither

Answer: 1

The Java Collections Library

A case study in subtyping and generics...

that is also very useful...

(And presents many pitfalls and Java idiosyncrasies!)

Java Packages

- Java code can be organized into *packages* that provide namespace management.
  - Somewhat like OCaml's modules
  - Packages contain groups of related classes and interfaces.
  - Packages are organized hierarchically in a way that mimics the file system's directory structure.
- A Java source file can *import* (parts of) packages that it needs access to:

```
import org.junit.Test;     // just the Test class from JUnit
import java.util.*;        // everything in java.util
```

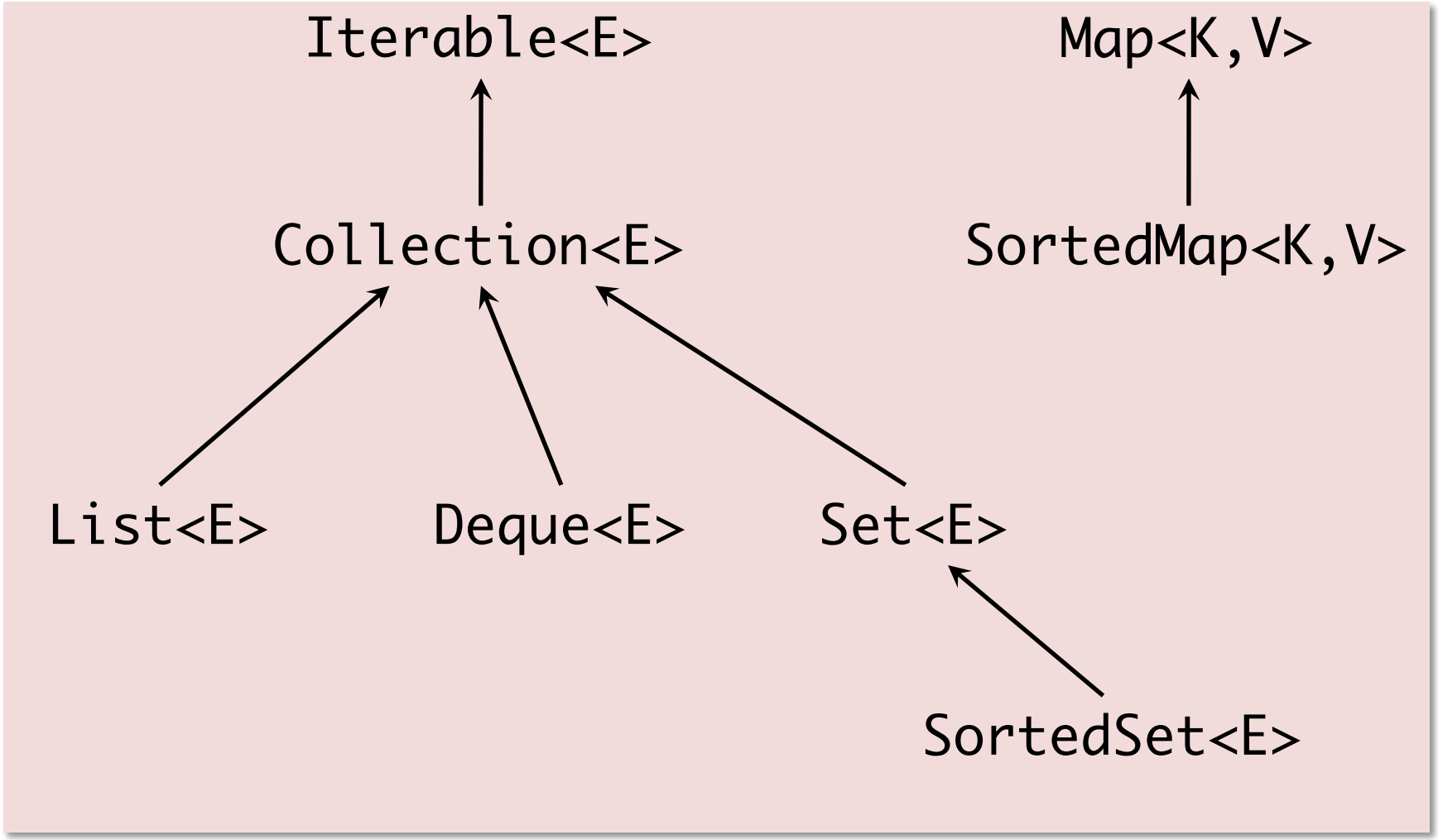
- Important packages
  - java.lang, java.io, **java.util**, java.math, org.junit
- See documentation at http://docs.oracle.com/javase/17/docs/api/
- You will need to refer to this documentation when working on HW 7

Reading Java Docs

java.util

https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/util/package-summary.html

Interfaces* in the Collections Library



*not all of them!

Collection<E> Interface (excerpt)

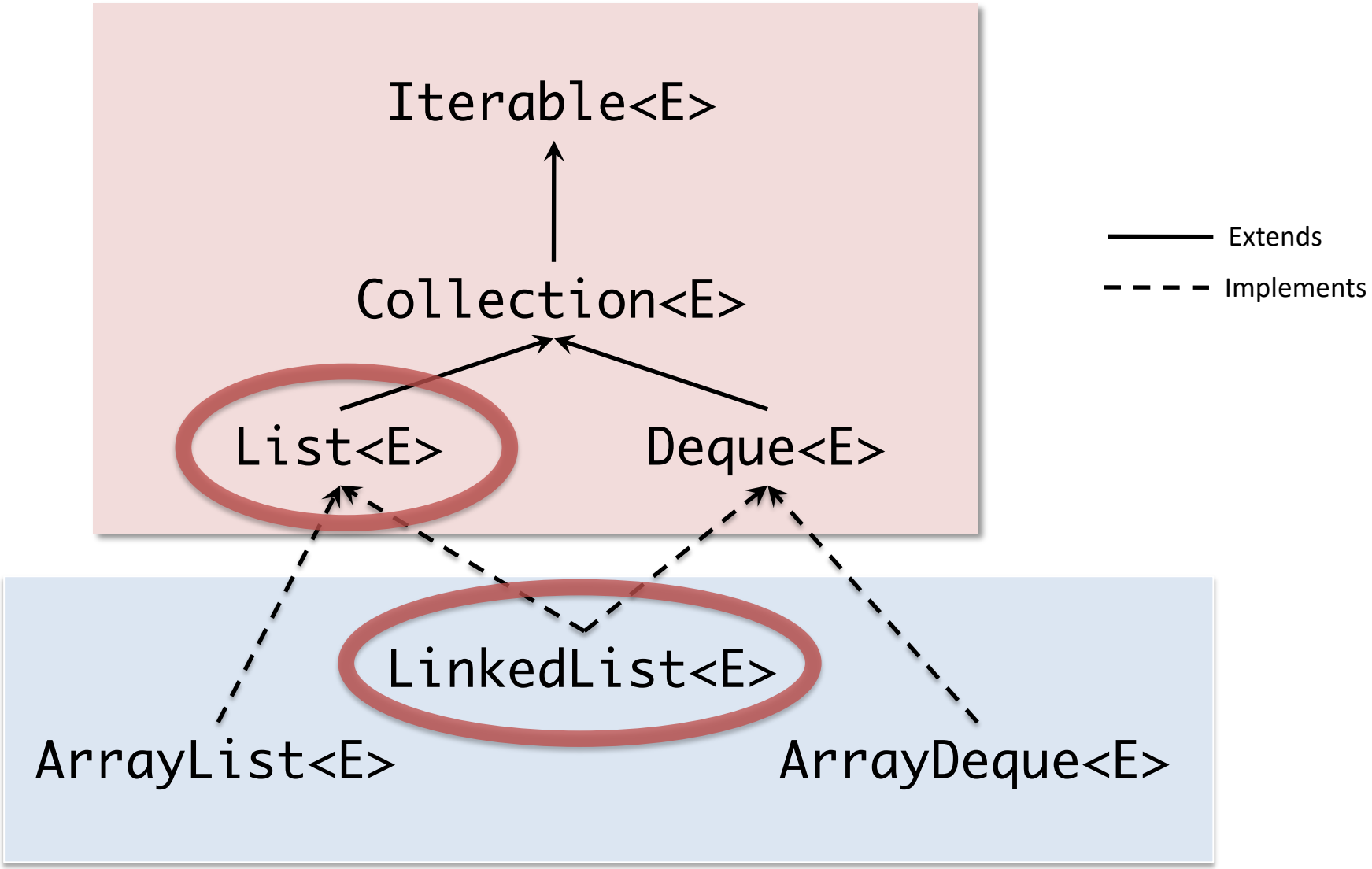
```
interface Collection<E> extends Iterable<E> {
  // basic operations
  int size();
  boolean isEmpty();
  boolean add(E o);
  boolean remove(Object o);     // why not E?*
  boolean contains(Object o);

  // bulk operations
  …
}
```

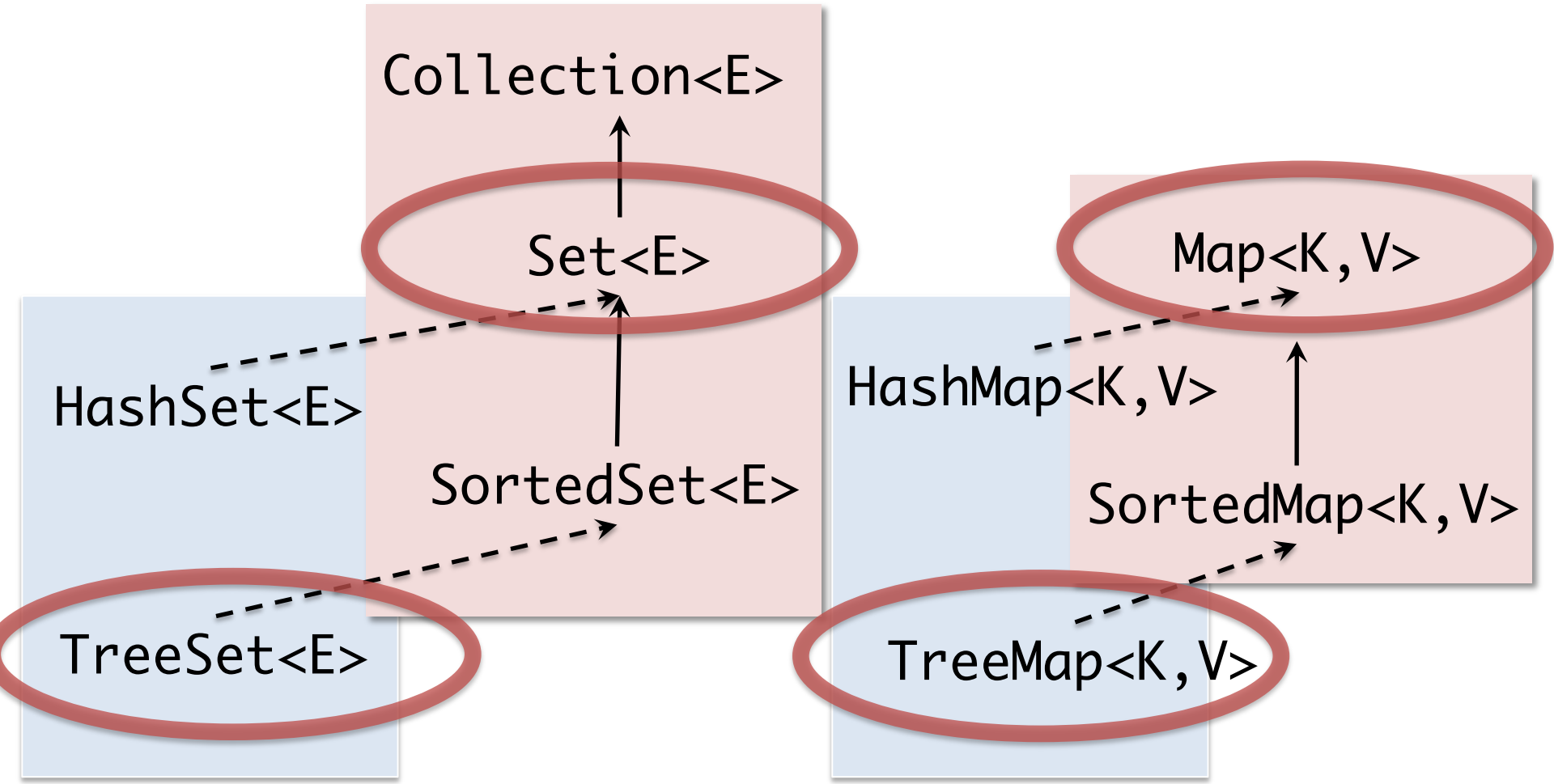
- We've already seen a similar interface in the OCaml part of the course
- Most collections are designed to be *mutable* (like queues and deques)

* Why not E? Internally, collections use the `equals` method to check for equality – membership is determined by o.equals, which does not have to be false for objects of different types. Most applications only store and remove one type of element in a collection, in which case this subtlety never becomes an issue.

Sequences


Iterable<E>
Collection<E>
List<E>
Deque<E>
LinkedList<E>
ArrayList<E>
ArrayDeque<E>
Extends
Implements

Sets and Maps*



*Read javadocs before instantiating these classes! There are some important details to be aware of to use them correctly.

TreeSet Demo

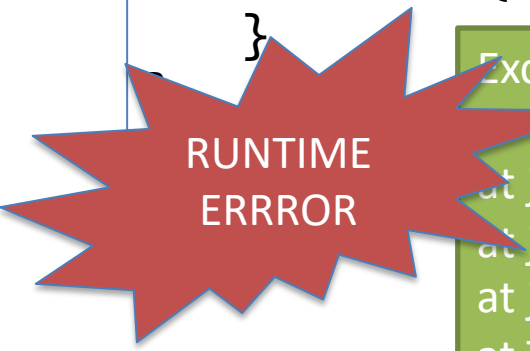
implement Comparable when using SortedSets and Sorted Maps

Buggy Use of TreeSet implementation

```
import java.util.*;

class Point {
    private final int x, y;
    public Point(int x0, int y0) { x = x0; y = y0; }
    public int getX(){ return x; }
    public int getY(){ return y; }
}

public class TreeSetDemo {
    public static void main(String[] args) {
        Set<Point> s = new TreeSet<>();
        s.add(new Point(1,1));
    }
```




```
Exception in thread "main" java.lang.ClassCastException:
                    Point cannot be cast to java.base/java.lang.Comparable
at java.base/java.util.TreeMap.compare(TreeMap.java:1291)
at java.base/java.util.TreeMap.put(TreeMap.java:536)
at java.base/java.util.TreeSet.add(TreeSet.java:255)
at TreeSetDemo.main(TreeSetDemo.java:14)
```

A Crucial Detail of TreeSet

Constructor Detail

TreeSet

public TreeSet()

Constructs a new, empty tree set, sorted according to the natural ordering of its elements. All elements inserted into the set must implement the `Comparable` interface. Furthermore, all such elements must be mutually comparable: `e1.compareTo(e2)` must not throw a `ClassCastException` for any elements `e1` and `e2` in the set. ...

The Interface Comparable

public interface Comparable<T>

This interface imposes a total ordering on the objects of each class that implements it. This ordering is referred to as the class's *natural ordering*, and the class's compareTo method is referred to as its *natural comparison method*. ...

Methods of Comparable

Method Summary

All Methods | **Instance Methods** | **Abstract Methods**

Modifier and Type	Method and Description
`int`	`compareTo(T o)` Compares this object with the specified object for order.

Method Detail

compareTo

```
int compareTo(T o)
```

Compares this object with the specified object for order. Returns a negative integer, zero, or a positive integer as this object is less than, equal to, or greater than the specified object.

The implementor must ensure `sgn(x.compareTo(y)) == -sgn(y.compareTo(x))` for all `x` and `y`. (This implies that `x.compareTo(y)` must throw an exception iff `y.compareTo(x)` throws an exception.)

The implementor must also ensure that the relation is transitive: (x.compareTo(y)>0 &&

Adding Comparable to Point

```
import java.util.*;

class Point implements Comparable<Point> {
    private final int x, y;
    public Point(int x0, int y0) { x = x0; y = y0; }
    public int getX(){ return x; }
    public int getY(){ return y; }

    public int compareTo(Point o) {
        if (this.x < o.x) {
            return -1;
        } else if (this.x > o.x) {
            return 1;
        } else if (this.y < o.y) {
            return -1;
        } else if (this.y > o.y) {
            return 1;
        }
        return 0;
    }
}
```

```
Point p1 = new Point(0,1);
Point p2 = new Point(0,2);
p1.compareTo(p2);  // -1
p2.compareTo(p1);  // 1
p1.compareTo(p1);  // 0
```

Digging Deeper into Comparable

It is strongly recommended (though not required) that natural orderings be consistent with equals. This is so because sorted sets (and sorted maps) without explicit comparators behave "strangely" when they are used with elements (or keys) whose natural ordering is inconsistent with equals. *In particular, such a sorted set (or sorted map) violates the general contract for set (or map), which is defined in terms of the equals method.*

How do we change the definition of equals?

Method Overriding

When a subclass replaces an inherited method with its own re-definition…

28: What gets printed to the console?

0

I'm a C

0%

I'm a D

0%

NullPointerException

0%

NoSuchMethodException

0%

A Subclass can *Override* its Parent

```
class C {
      public void printName() { System.out.println("I'm a C");
}
}

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

Answer: I'm a D

A Subclass can *Override* its Parent

```
class C {
  public void printName() { System.out.println("I'm a C"); }
}

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.
- Overriding can be useful for changing the default behavior of classes.
- But… can also be quite confusing if not used carefully.

Overriding Example

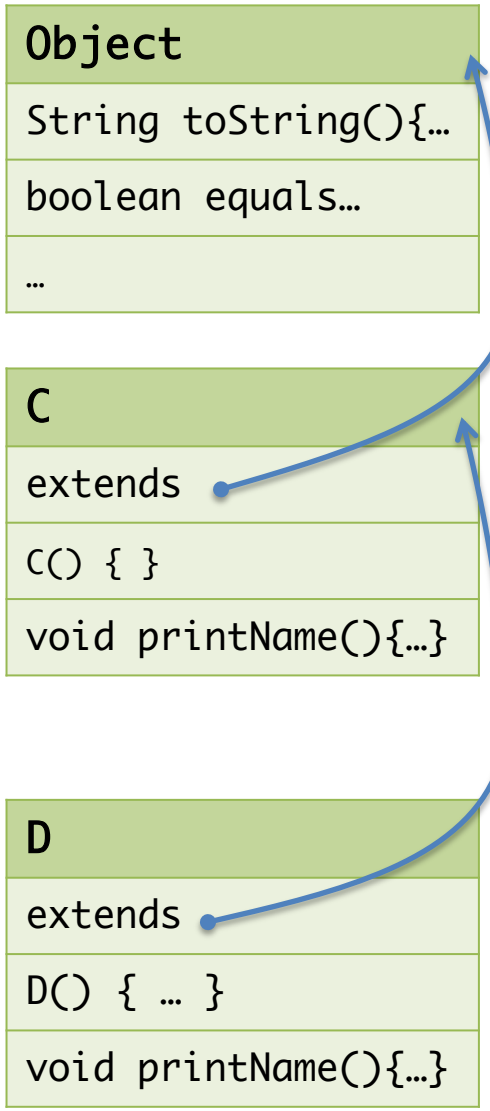
Workspace

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

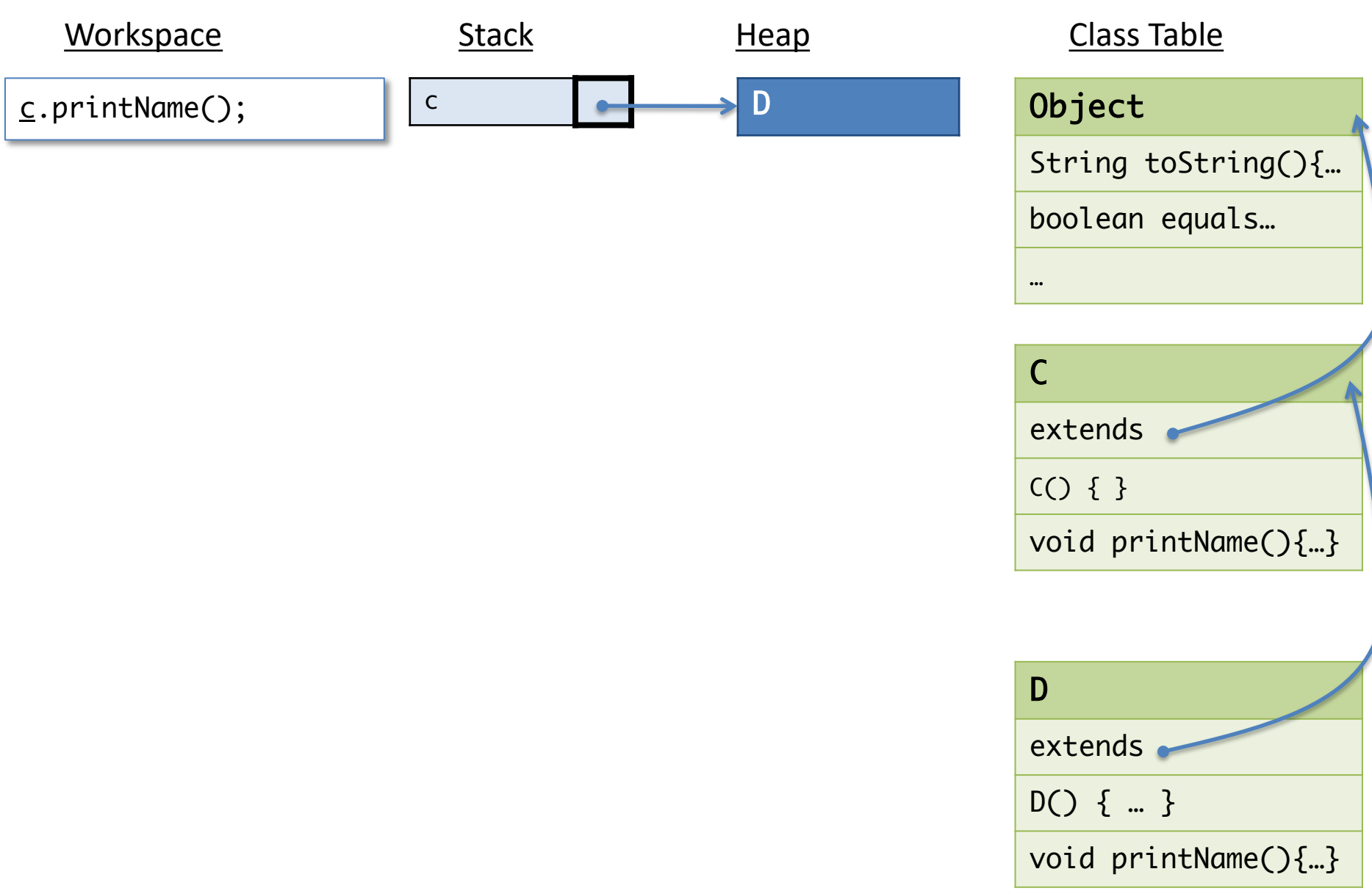
Stack

Heap

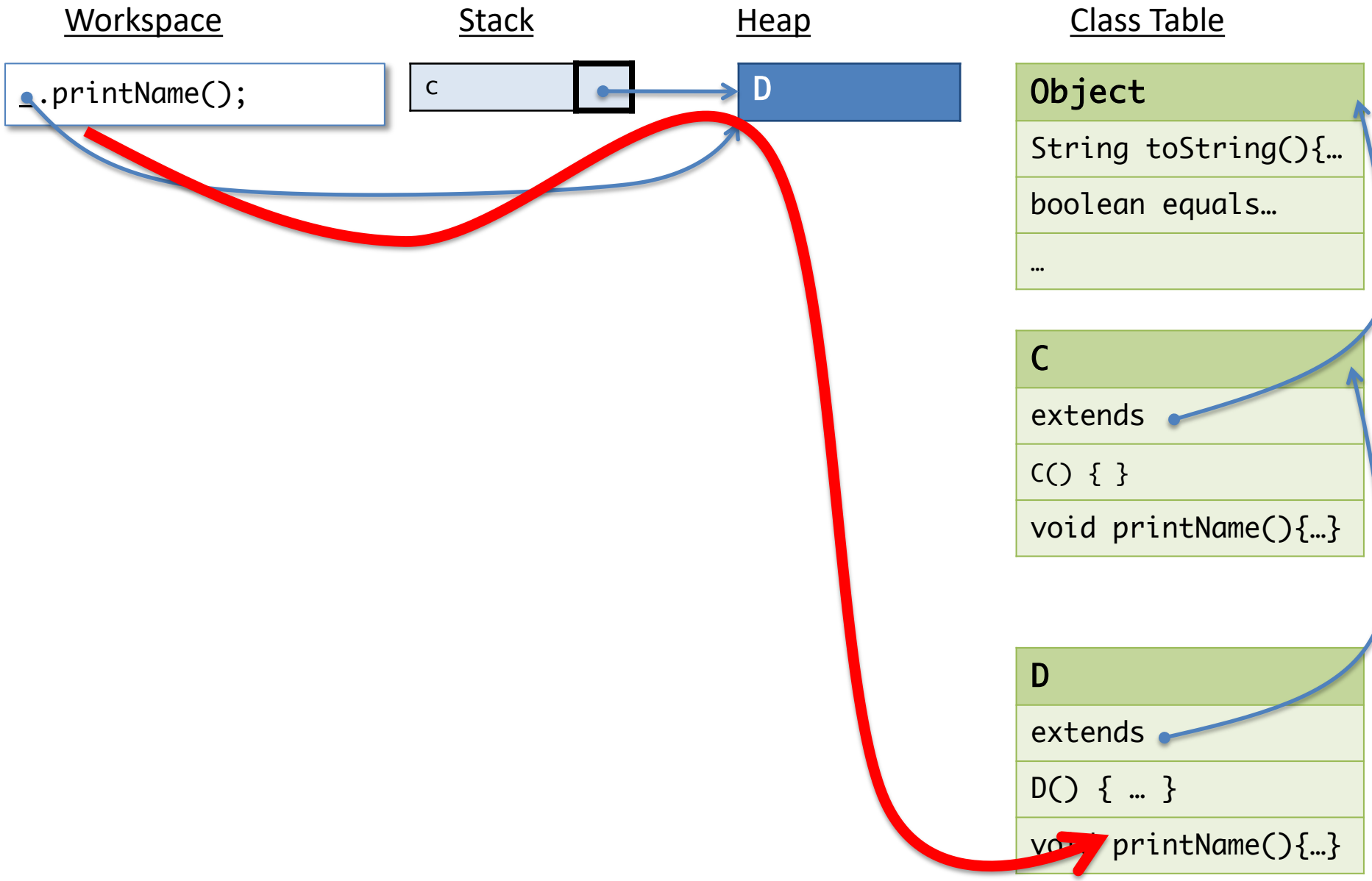
Class Table



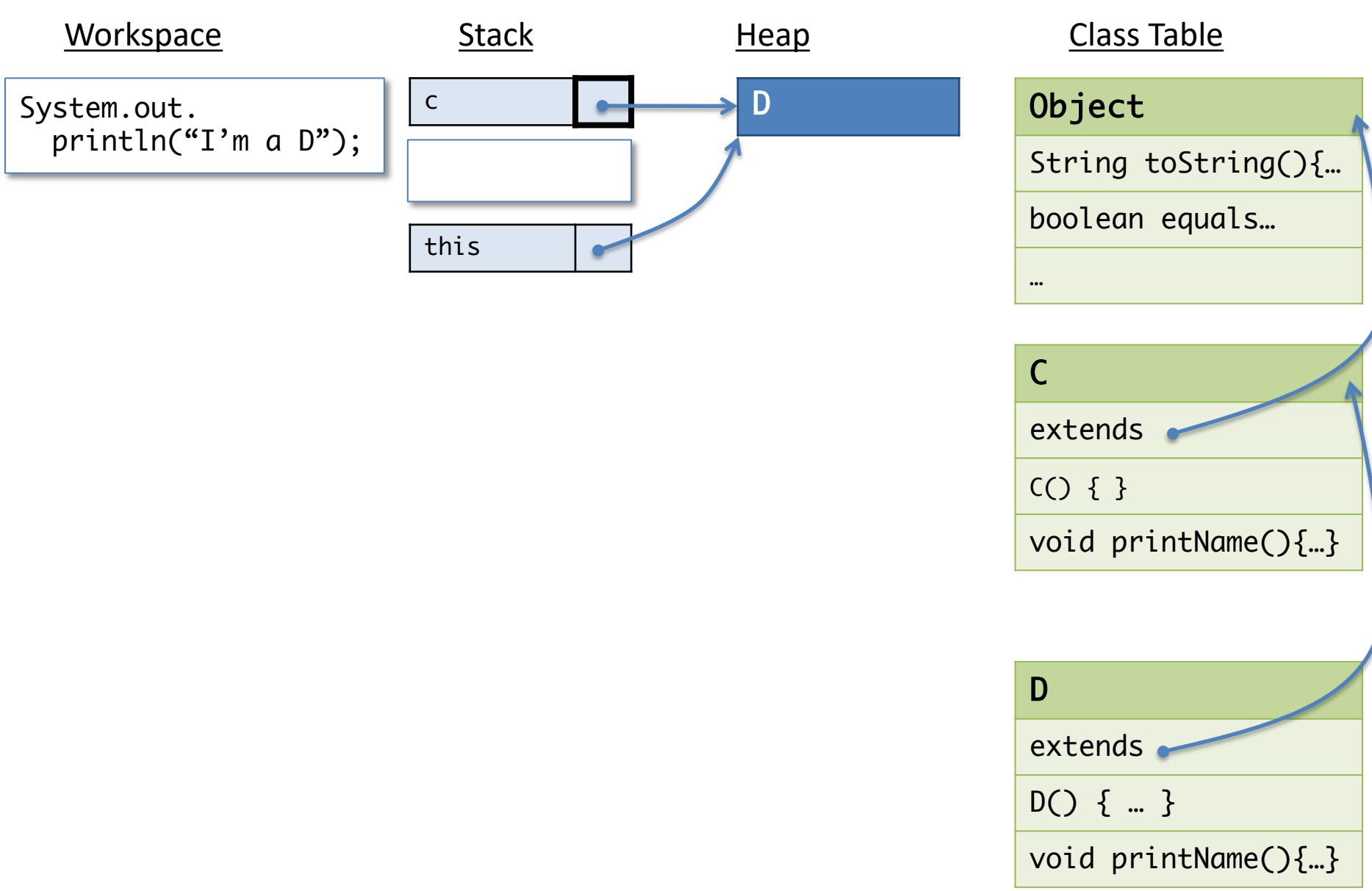
Overriding Example



Overriding Example



Overriding Example



28: What gets printed to the console?

0

I'm a C

0%

I'm a E

0%

NullPointerException

0%

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();
```

What gets printed to the console?

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

Answer: I'm a E

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 writes E might not be aware of the implications of changing `getName`.

Overriding the `getName` method causes the behavior of `printName` to change!

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