Programming Languages and Techniques (CIS120)

Lecture 27

November 4, 2015

Generics, Collections, and Iterators

Announcements

- *Midterm 2 is Friday, November 6th in class*
  - Last names A – L Leidy Labs 10 (here)
  - Last names M – Z Cohen G17
  - Everything starting with mutable state in Ocaml to Subytping in Java

- Review Session:
  TONIGHT
  Levine 100
  7-9PM
  Pizza!

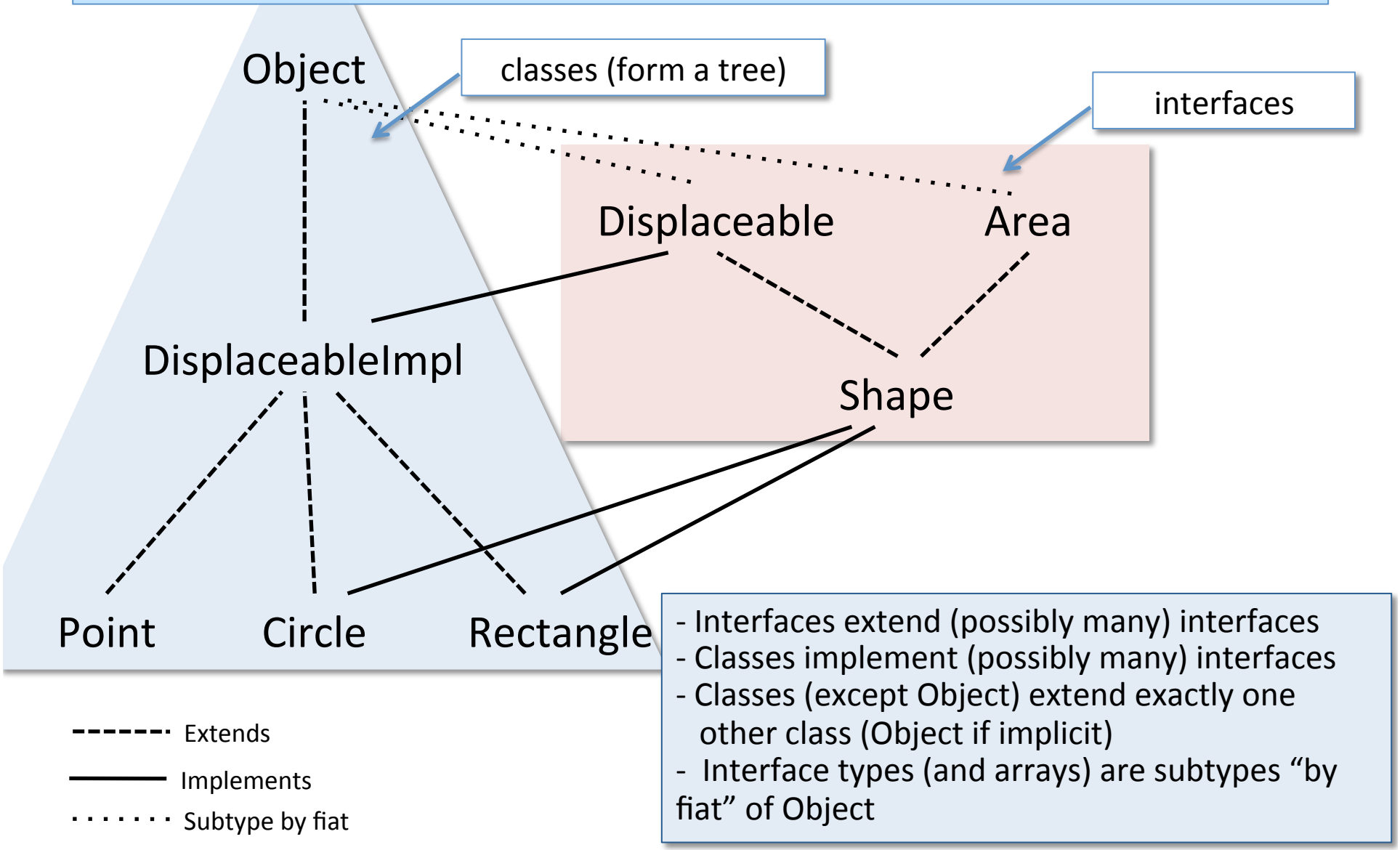
Java Generics

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

Subtype Polymorphism*

- Main idea:

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

```
void method(A obj) {
     // use obj at type A
}

method(new B());
```

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

*polymorphism = many shapes

Is subtyping good enough?

Subtype Polymorphism

vs.

Parametric Polymorphism

Subtype Polymorphism

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

  …
}
```

```
ObjQueue q = …;

q.enq(" CIS 120 ");
Object  x = q.deq();
System.out.println(x.trim());
```

← Does this line type check

1. Yes
2. No
3. It depends

Subtype Polymorphism

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

  …
}
```

```
ObjQueue q = …;

q.enq(" CIS 120 ");
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

Parametric Polymorphism (a.k.a. Generics)

- Big idea:

  Parameterize a type (i.e. interface or class) by another type.

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

}
```

- The implementations of a parametric polymorphic interface can not depend on the implementation details of the parameter.
  - e.g. the implementation of enq should not invoke methods on 'o'.

Generics (Parametric Polymorphism)

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

```
Queue<String> q = …;

q.enq(" CIS 120 ");
String  x = q.deq();                  // What type of 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*

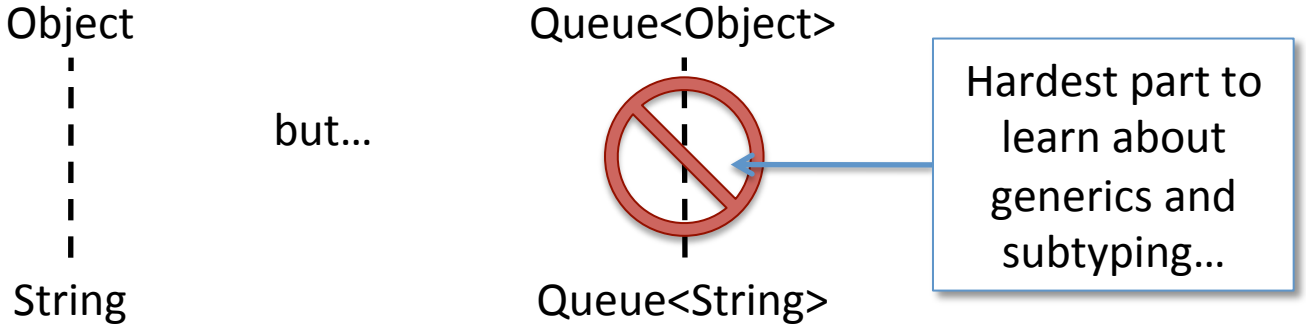
```
Queue<String> qs = new QueueImpl<String>();
Queue<Object> qo = qs;

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 120.

The Java Collections Library

A case study in subtyping and generics

(Also very useful!)

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 file can *import* (parts of) packages that it needs access to:

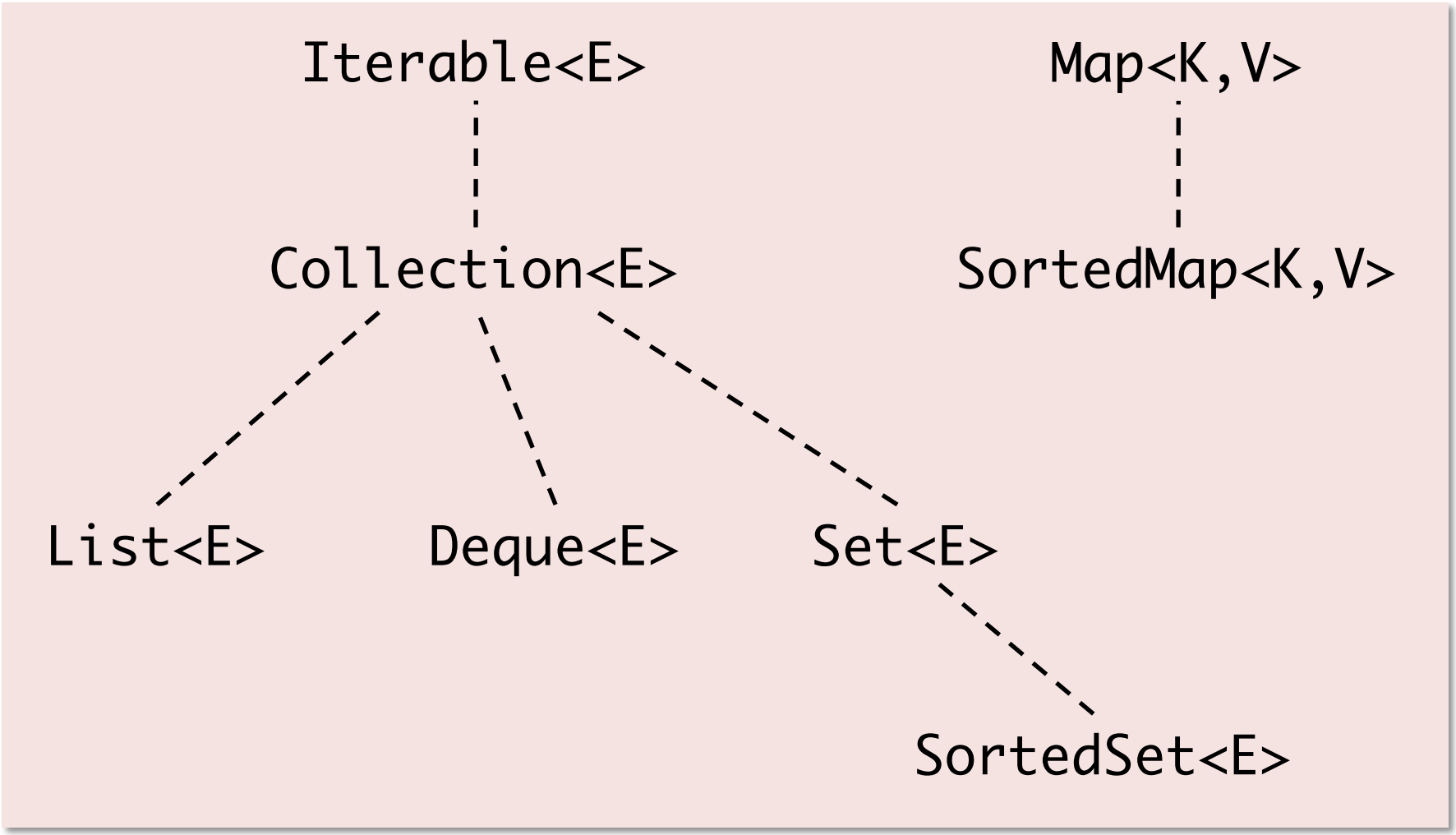
```
import org.junit.Test;     // just the JUnit Test class
import java.util.*;        // everything in java.util
```

- Important packages:
  - java.lang, java.io, java.util, java.math, org.junit
- See documentation at:
  http://download.oracle.com/javase/6/docs/api/index.html

Reading Java Docs

http://docs.oracle.com/javase/6/docs/api/java/util/package-summary.html

Interfaces* of the Collections Library



*not all of them!

Collection<E> Interface (Excerpt)

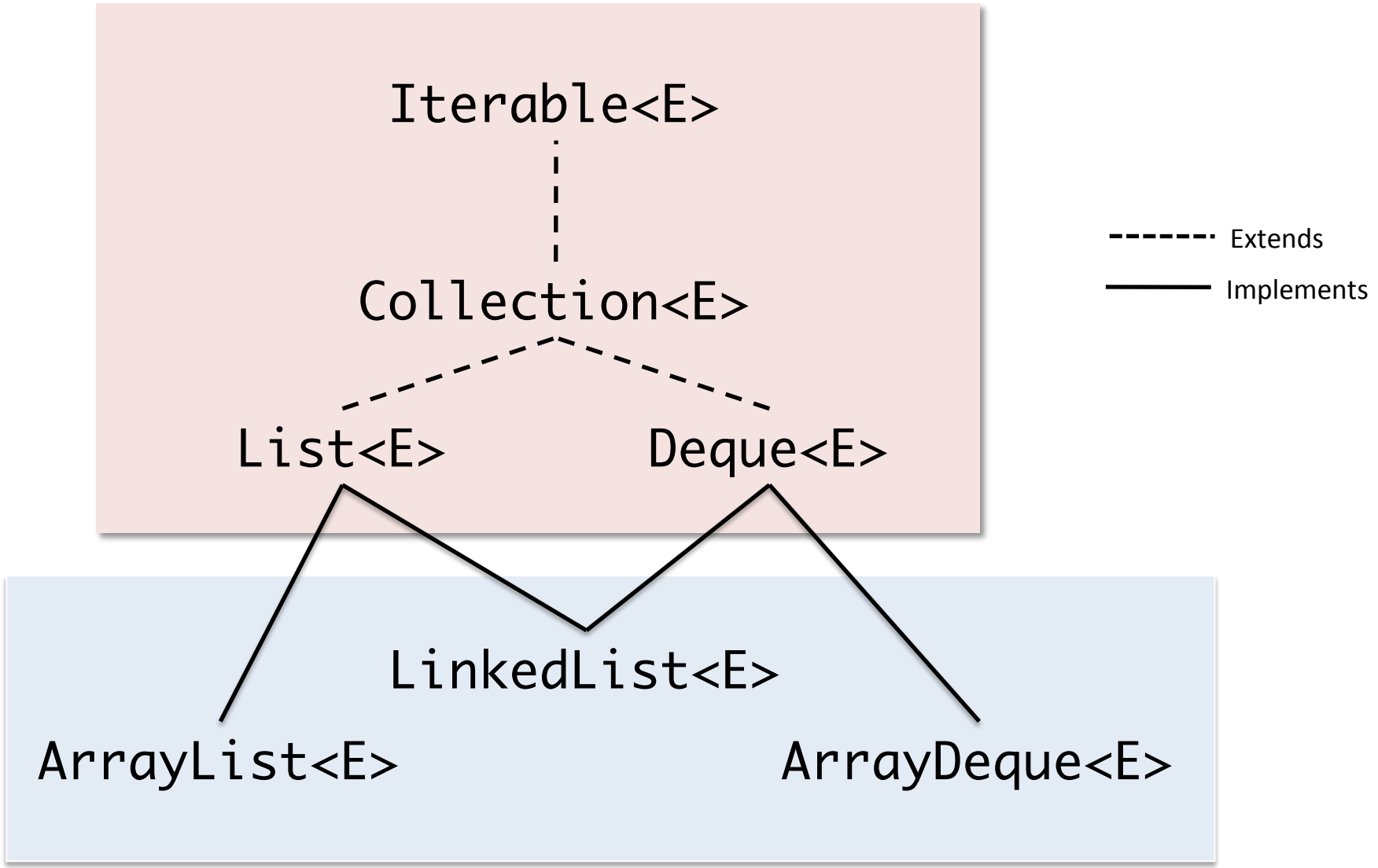
```
public interface Collection<E> extends Iterable<E> {
  // basic operations
  int size();
  boolean isEmpty();
  boolean add(E o);
  boolean remove(Object o);     // why not E?*
  boolean contains(Object o);

  // bulk operations
  …
}
```

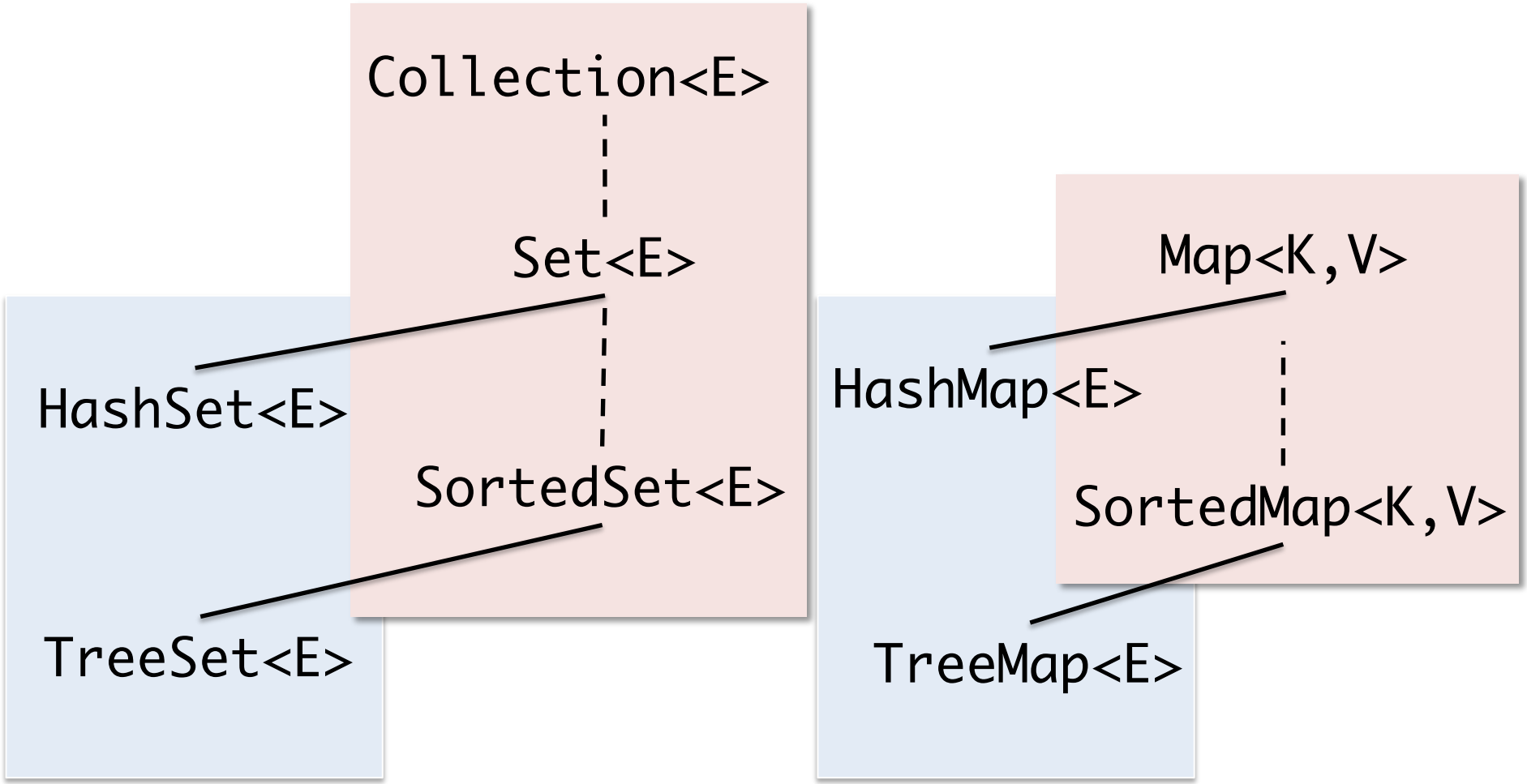
- We've already seen this interface in the OCaml part of the course.
- Most collections are designed to be *mutable* (like queues)

* 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.

Iterating over collections

iterators, while, for, for-each loops

Iterator and Iterable

```
interface Iterator<E> {
    public boolean hasNext();
    public E next();
    public void delete();   // optional
}
```

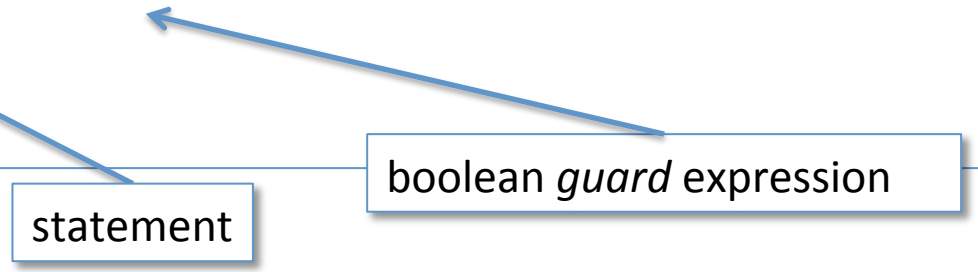
```
interface Iterable<E> {
    public Iterator<E> iterator();
}
```

Challenge: given a List<Book> how would you add each book's data to a catalogue using an iterator?

While Loops

syntax:

```
// repeat body until condition becomes false
while (condition) {
   body
}
```



example:

```
List<Book> shelf = …  // create a list of Books

// iterate through the elements on the shelf
Iterator<Book> iter = shelf.iterator();
while (iter.hasNext()) {
    Book book = iter.next();
    catalogue.addInfo(book);
    numBooks = numbooks+1;
}
```

For Loops

syntax:

```
for (init-stmt; condition; next-stmt) {
  body
}
```

equivalent while loop:

```
init-stmt;
while (condition) {
  body
  next-stmt;
}
```

```
List<Book> shelf = …  // create a list of Books

// iterate through the elements on the shelf
for (Iterator<Book> iter = shelf.iterator();
     iter.hasNext();) {
   Book book = iter.next();
   catalogue.addInfo(book);
   numBooks = numbooks+1;
}
```

For-each Loops

syntax:

```
// repeat body for each element in collection
for (type var : coll) {
   body
}
```

element type

array or instance of Iterable<E>

example:

```
List<Book> shelf = …  // create a list of books

// iterate through the elements on a shelf
for (Book book : shelf) {
    catalogue.addInfo(book);
    numBooks = numbooks+1;
}
```

For-each Loops (Cont'd)

Another example:

```
int[] arr = …  // create an array of ints

// count the non-null elements of an array
for (int elt : arr) {
    if (elt != 0) cnt = cnt+1;
}
```

For-each can be used to iterate over arrays or any class that implements the `Iterable<E>` interface (notably `Collection<E>` and its subinterfaces).

Iterator example

```
public static void iteratorExample() {
    List<Integer> nums = new LinkedList<Integer>();
    nums.add(1);
    nums.add(2);
    nums.add(7);

    int numElts = 0;
    int sumElts = 0;
    Iterator<Integer> iter =
        nums.iterator();
    while (iter.hasNext()) {
      Integer v = iter.next();
      sumElts = sumElts + v;
      numElts = numElts + 1;
    }

    System.out.println("sumElts = " + sumElts);
    System.out.println("numElts = " + numElts);
  }
```

What is printed by iteratorExample()?

1. sumElts = 0 numElts = 0
2. sumElts = 3 numElts = 2
3. sumElts = 10 numElts = 3
4. NullPointerException
5. Something else

Answer: 3

For-each version

```
public static void forEachExample() {
    List<Integer> nums = new LinkedList<Integer>();
    nums.add(1);
    nums.add(2);
    nums.add(7);

    int numElts = 0;
    int sumElts = 0;
    for (Integer v : nums) {
      sumElts = sumElts + v;
      numElts = numElts + 1;
    }

    System.out.println("sumElts = " + sumElts);
    System.out.println("numElts = " + numElts);
  }
```

Iterator example

```
public static void nextNextExample() {
    List<Integer> nums = new LinkedList<Integer>();
    nums.add(1);
    nums.add(2);
    nums.add(7);

    int sumElts = 0;
    int numElts = 0;
    Iterator<Integer> iter =
        nums.iterator();
    while (iter.hasNext()) {
      Integer v = iter.next();
      sumElts = sumElts + v;
      v = iter.next();
      numElts = numElts + v;
    }
    System.out.println("sumElts = " + sumElts);
    System.out.println("numElts = " + numElts);
  }
```

What is printed by nextNextExample()?

1. sumElts = 0 numElts = 0
2. sumElts = 3 numElts = 2
3. sumElts = 8 numElts = 2
4. NullPointerException
5. Something else

Answer: 5 NoSuchElementException

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

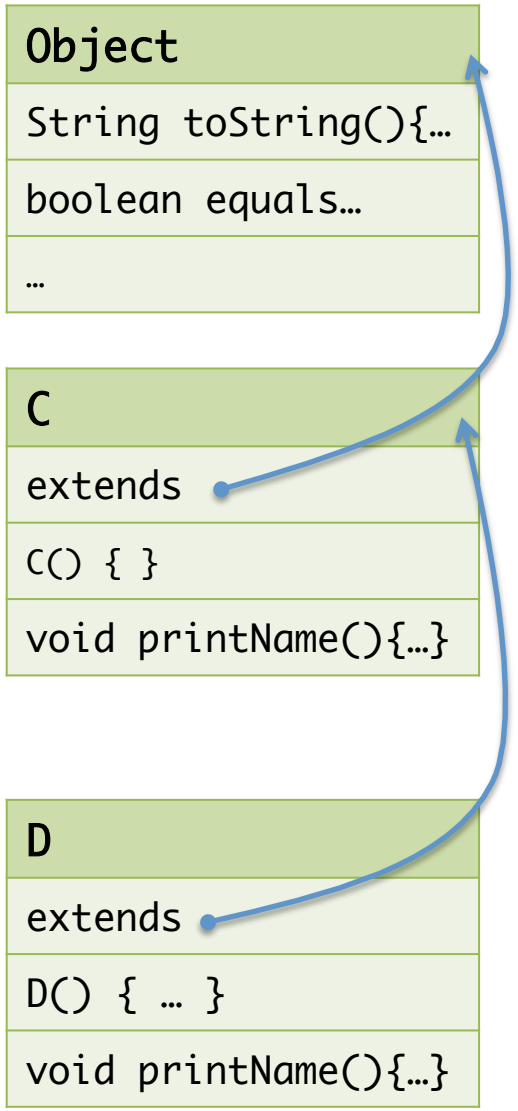
Workspace

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

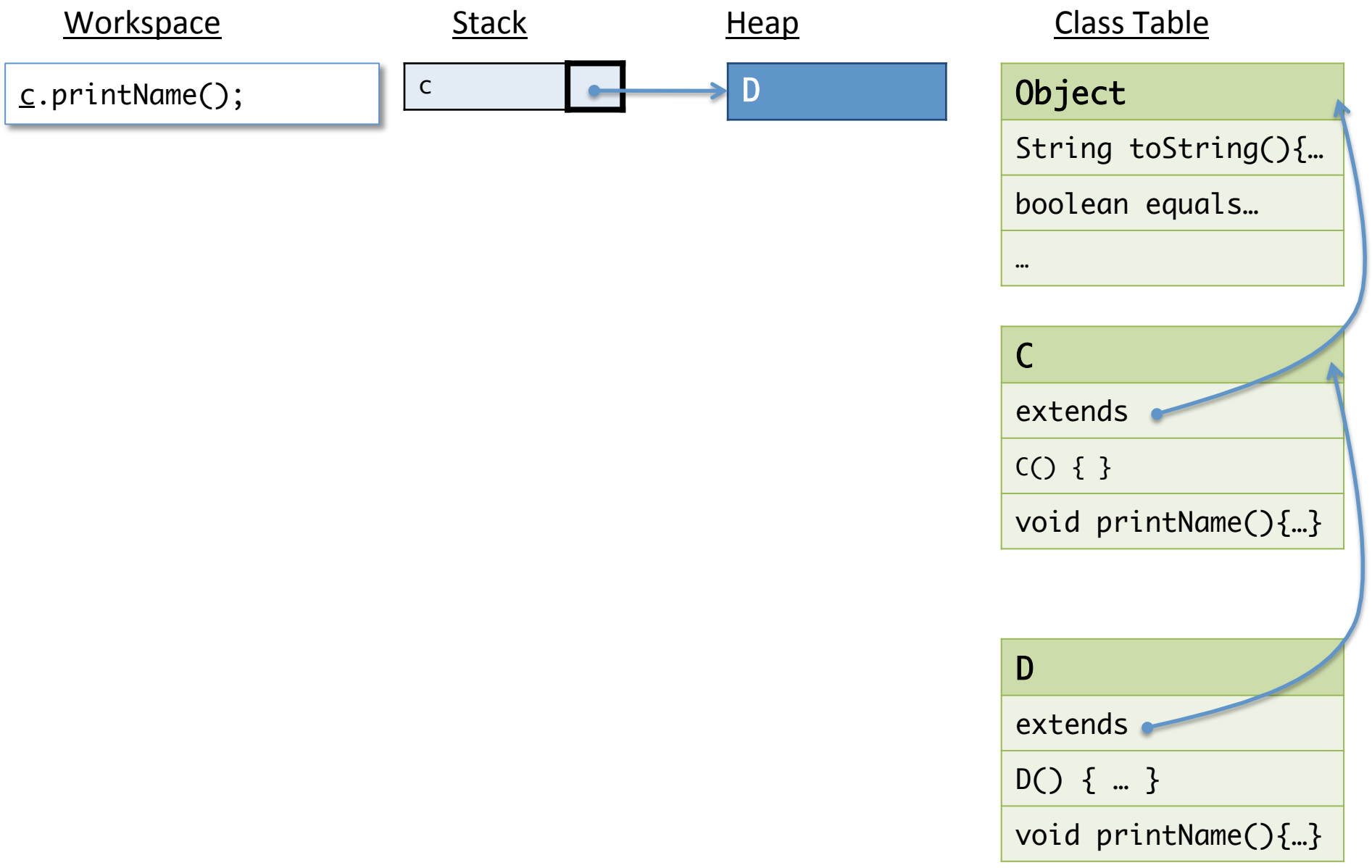
Stack

Heap

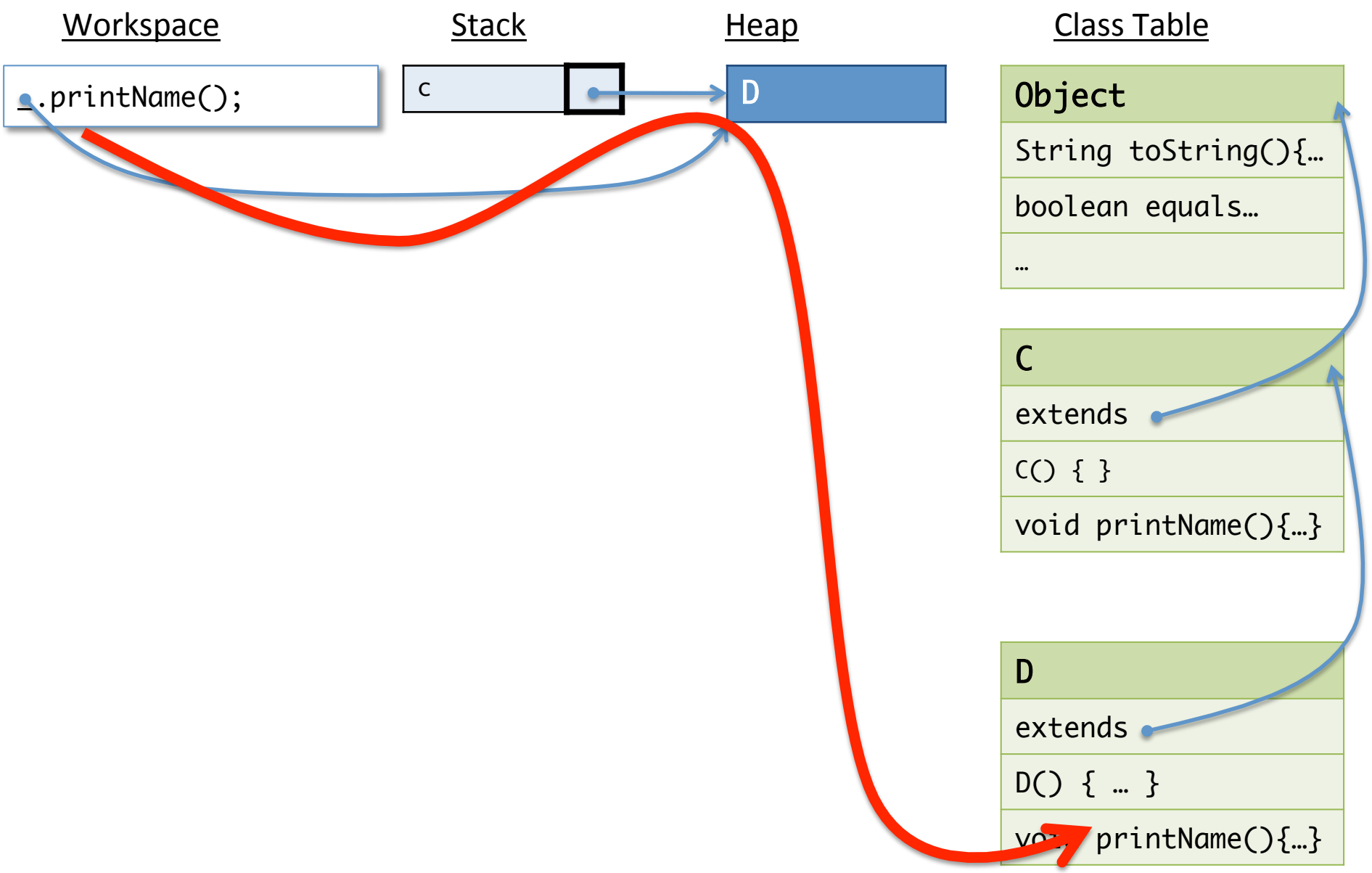
Class Table



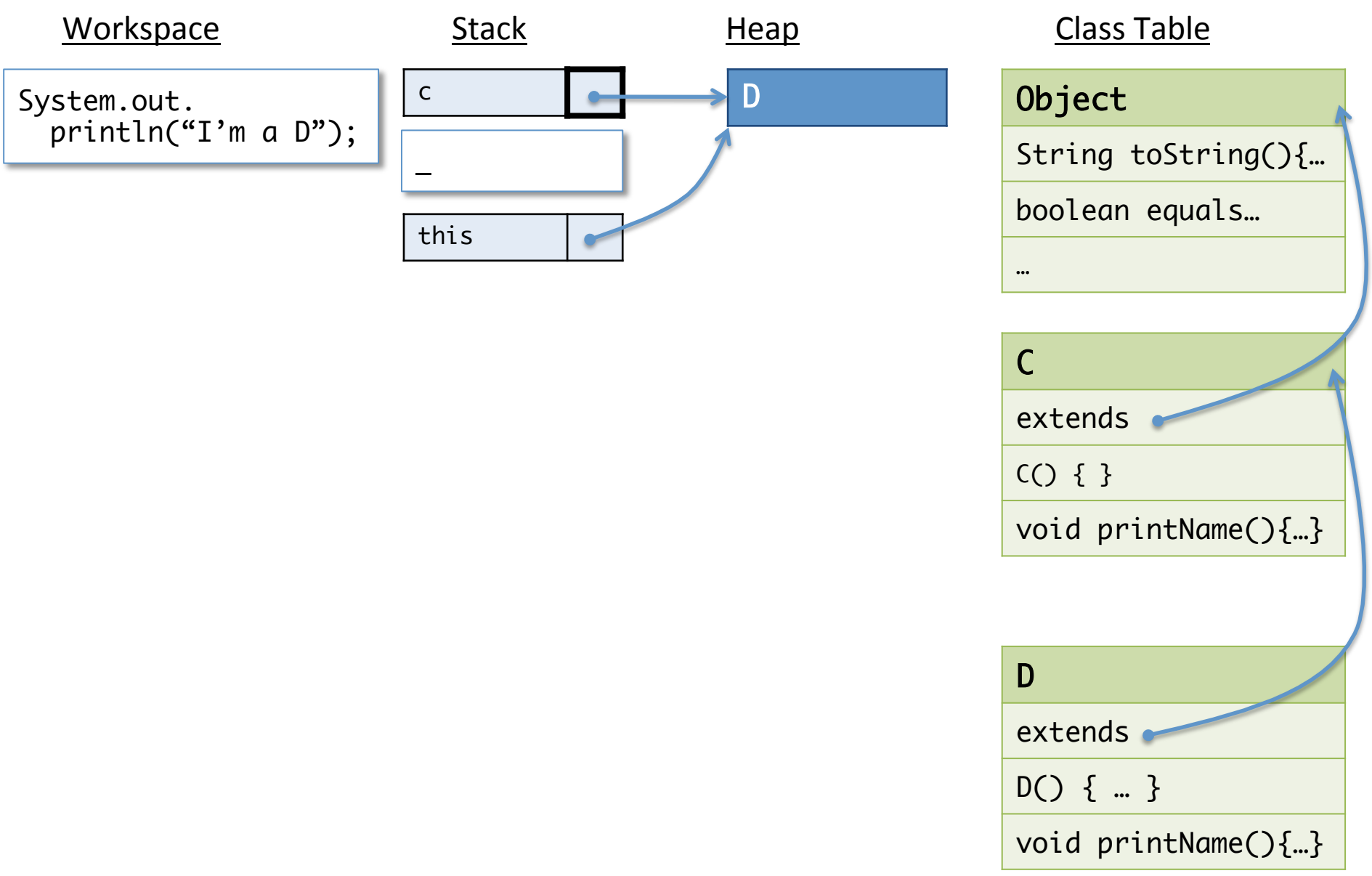
Overriding Example



Overriding Example



Overriding Example



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. I'm an E
4. 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.