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Advanced Java

- *inheritance*
- *interfaces*
- *iterators*

Advanced Java

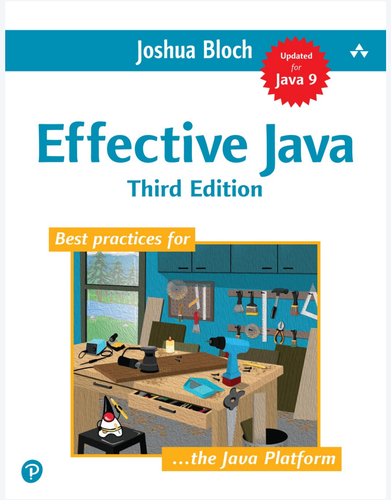
Subtitle. Java features that we (occasionally) use in this course, but don't cover (much) in COS 126.

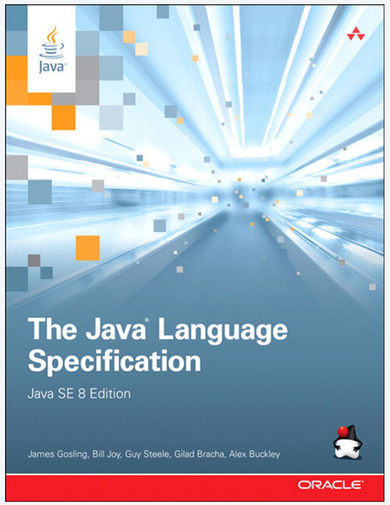
- Inheritance.
- Generics.
- Interfaces.
- Iterators.

← *common theme: promote code reuse*

Q. How to take your Java to the next level?

A.





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Advanced Java

- *inheritance*
- *interfaces*
- *iterators*

Motivation

Q1. How did the Java architects design `System.out.println(x)` so that it works with all reference types?

Q2. How would an Android developer create a custom Java GUI text component, without re-implementing these 400+ required methods?

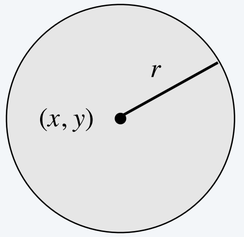
A. Inheritance.

```
action() • add() • addAncestorListener() • addCaretListener() •
addComponentListener() • addContainerListener() • addFocusListener() •
addHierarchyBoundsListener() • addHierarchyListener() • addImpl() •
addInputMethodListener() • addKeyListener() • addKeymap() • addMouseListener() •
addMouseMotionListener() • addMouseWheelListener() • addNotify() •
addPropertyChangeListener() • addVetoableChangeListener() •
applyComponentOrientation() • areFocusTraversalKeysSet() • bounds() • checkImage() •
coalesceEvents() • computeVisibleRect() • contains() • copy() • countComponents() •
createImage() • createToolTip() • createVolatileImage() • cut() • deliverEvent() •
disable() • disableEvents() • dispatchEvent() • doLayout() • enable() •
enableEvents() • enableInputMethods() • findComponentAt() • fireCaretUpdate() •
firePropertyChange() • fireVetoableChange() • getActionForKeyStroke() •
getActionMap() • getAlignmentX() • getAlignmentY() • getAncestorListeners() •
getAutoscrolls() • getBackground() • getBaseline() • getBaselineResizeBehavior() •
```

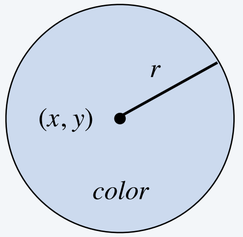
Inheritance overview

Implementation inheritance (subclassing).

- Derive a new class (child class) from an existing class (parent class).
- The child class inherits properties from its parent class:
  - state (instance variables)
  - behavior (instance methods)
- The child class can override instance methods in the parent class.
  (replacing those methods with its own versions)



Disc
(parent class)



ColoredDisc
(child class)

Main benefits.

- Facilitates code reuse.
- Enables the design of extensible libraries.

Inheritance example

```
public class Disc {
   private final int x, y, r;

   public Disc(int x, int y, int r) {
      this.x = x;
      this.y = y;
      this.r = r;
   }

   public double area() {
      return Math.PI * r * r;
   }

   public boolean intersects(Disc that) {
      int dx = this.x - that.x;
      int dy = this.y - that.y;
      int dr = this.r + that.r;
      return dx*dx + dy*dy <= dr*dr;
   }

   public void draw() {
      StdDraw.filledCircle(x, y, r);
   }
}
```

child class acquires state and behavior from parent class

parent class

```
import java.awt.Color;

public class ColoredDisc extends Disc {

   private final Color color;

   public ColoredDisc(int x, int y, int r, Color color) {
      super(x, y, r);
      this.color = color;
   }

   public Color getColor() {
      return color;
   }

   public void draw() {
      StdDraw.setPenColor(color);
      super.draw();
   }

}
```

defines new state

calls constructor in parent class

defines new behavior

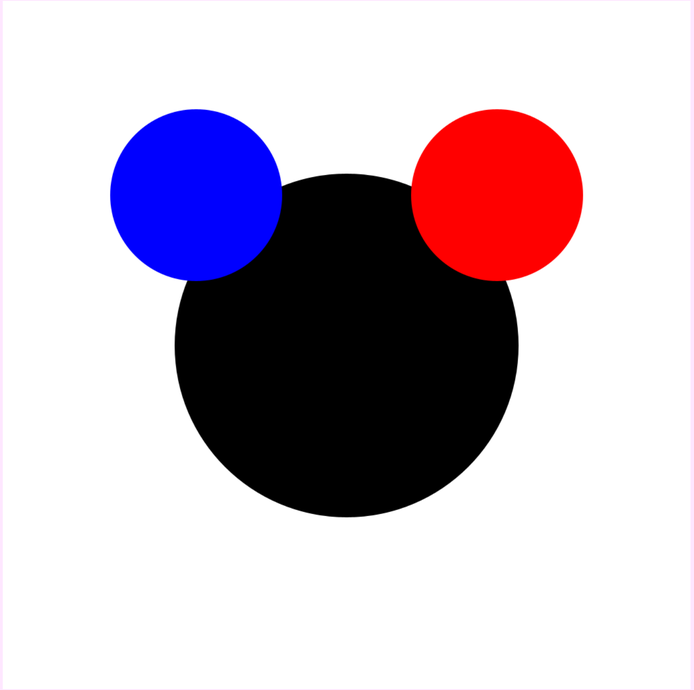
overrides method in parent class

calls method in parent class

child class

Inheritance demo (in JShell)

```
~/cos226/advanced-java> jshell-algs4
/open Disc.java
/open ColoredDisc.java

StdDraw.setScale(0, 800);

Disc disc1 = new Disc(400, 400, 200);
disc1.area();               // 125663.70614359173
disc1.draw();

ColoredDisc disc2 = new ColoredDisc(225, 575, 100, StdDraw.BLUE);
ColoredDisc disc3 = new ColoredDisc(575, 575, 100, StdDraw.RED);
disc2.getColor();           // java.awt.Color[r=0,g=0,b=255]
disc2.draw();
disc3.draw();
disc2.area();               // 31415.926535897932

Disc disc = disc2;          // child also inherits type from parent
disc.area();                // 31415.926535897932

disc1.intersects(disc2);    // true
disc2.intersects(disc3);    // false
```



Advanced Java: quiz 1

Which color will be stored in the variable color?

```
Disc disc = new ColoredDisc(200, 300, 100, StdDraw.BLUE);
Color color = disc.getColor();
```

A. Blue,

B. Black.

C. Compile-time error.

D. 💣

Polymorphism

Ex. A reference variable can refer to any object of its declared type or any of its subclasses.

```
Disc disc = new ColoredDisc(x, y, r, color);
```


```
double area = disc.area();
Color color = disc.getColor();
```

← *can call only* `Disc` *methods (compile-time error)*

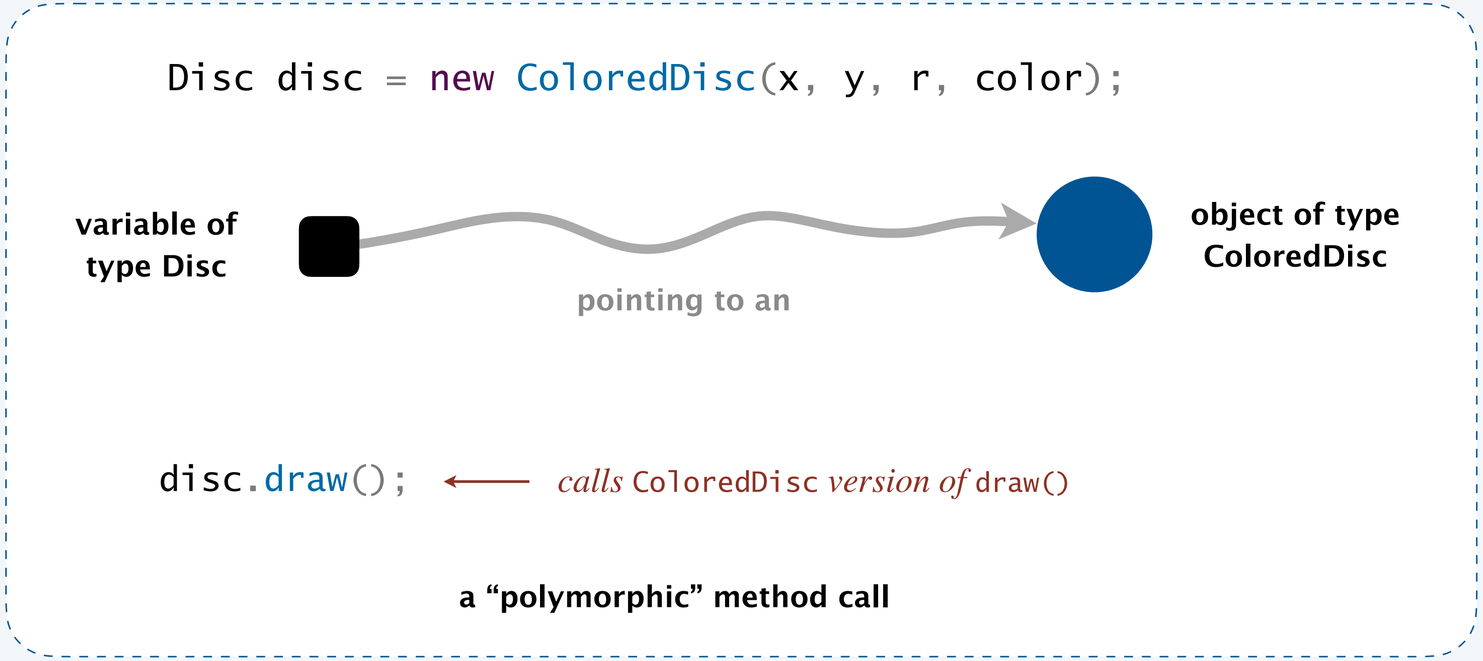
Subtype polymorphism. A subclass is a subtype of its superclass:

objects of the subtype can be used anywhere objects of the superclass are allowed.

RHS of assignment statement, method argument, return value, expression, ...

Polymorphism

Dynamic dispatch. Java determines which version of an overridden method to call using the type of the referenced object at runtime (not necessarily the type of the variable).



Analogy. In math, $\|x\|$ means different things depending on whether x is a real number, complex number, Euclidean vector, matrix, ...

Polymorphism: why useful?

Ex 1. Design a method that can take either `Disc` or `ColoredDisc` objects as arguments.

```
Disc disc1 = new Disc(x1, y1, r1);
ColoredDisc disc2 = new ColoredDisc(x2, y2, r2, color);
boolean result1 = disc1.intersects(disc2);
```

passes an object of type `ColoredDisc`
to a method that takes as an object of type `Disc`

Ex 2. Store a mixed collection of `Disc` and `ColoredDisc` objects.

```
Disc disc1 = new Disc(x1, y1, r1);
Disc disc2 = new Disc(x2, y2, r2);
ColoredDisc disc3 = new ColoredDisc(x3, y3, r3, color);
Disc[] discs = { disc1, disc2, disc3 };

for (int i = 0; i < discs.length; i++)
    discs[i].draw();
```

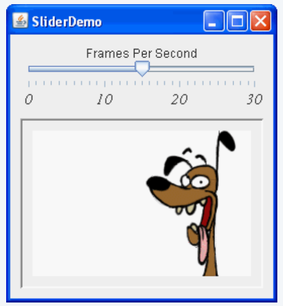
assigns an object of type `ColoredDisc`
to a variable of type `Disc`

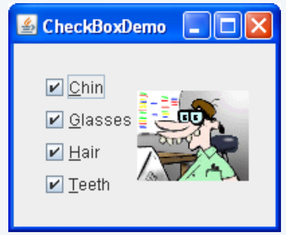
manipulate objects in a uniform manner

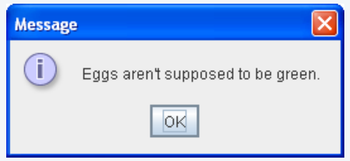
Inheritance hierarchy for Java GUI components

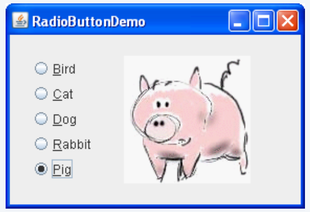
Typical use case. Design an extensible library.

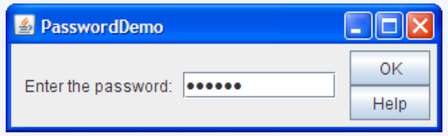
Ex. Android developer design a new GUI widget for their app;
new widget can be used anywhere a `JComponent` is expected.

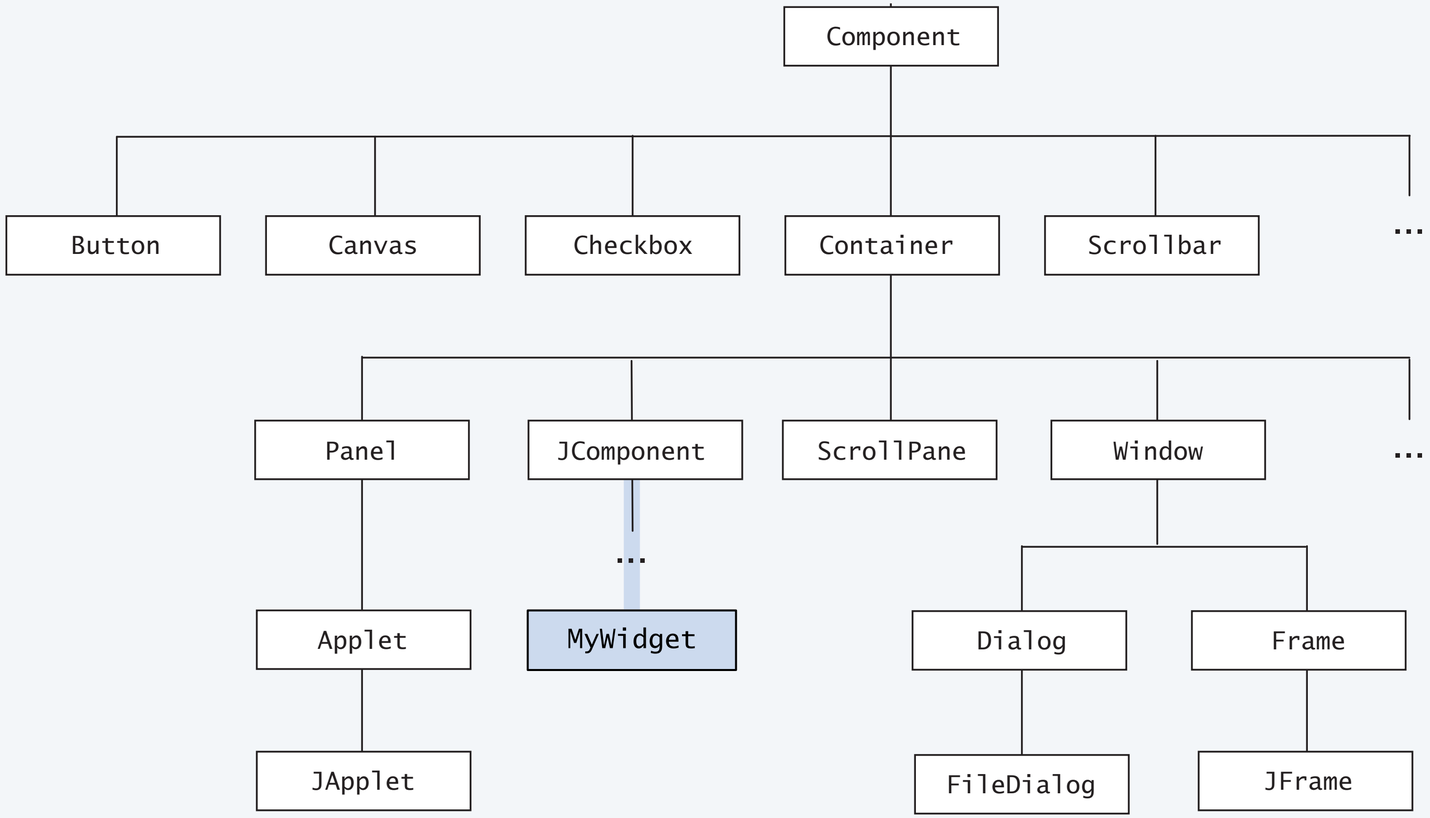












Java GUI class hierarchy

Is-A relationship

Informal rule. Inheritance should represent an Is-A relationship.

child class	parent class
`ColoredDisc`	`Disc`
`ArithmeticException`	`RuntimeException`
`JPasswordField`	`JTextField`
`SamsungGalaxyS24`	`SmartPhone`

> *" Objects of subtypes should behave like those of supertypes if used via supertype methods. "* — Barbara Liskov

Liskov substitution principle

Inheritance oops

`java.util.Stack`. Inherits from `java.util.Vector`.

Java 1.3 bug report (June 27, 2001)

> The iterator method on java.util.Stack iterates through a Stack from the bottom up. One would think that it should iterate as if it were popping off the top of the Stack.

status: closed, won't fix (June 11, 2004)

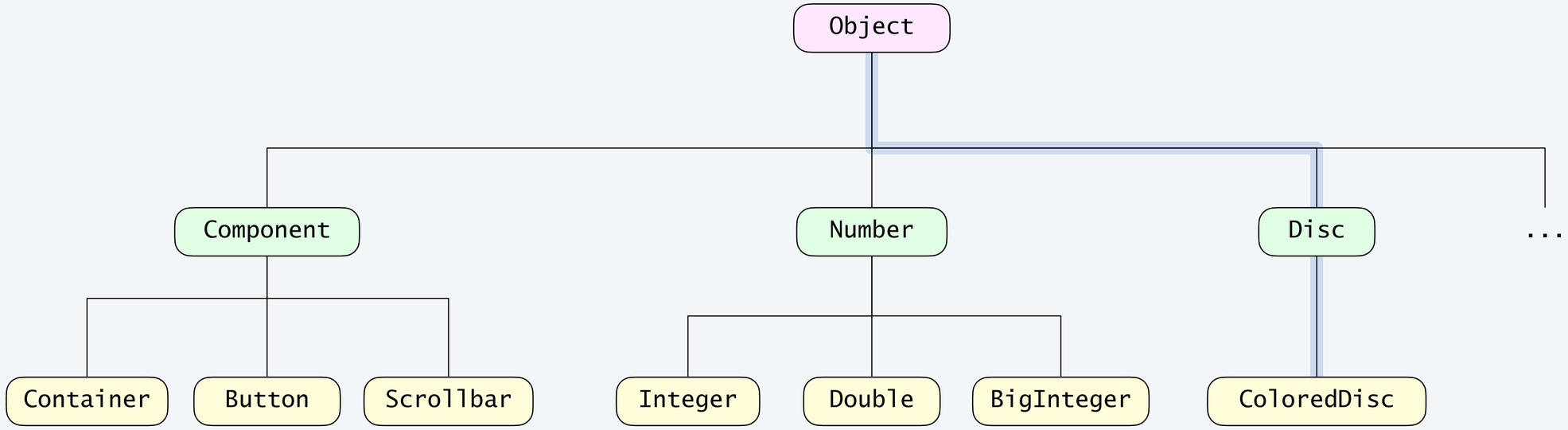
> It was an incorrect design decision to have Stack extend Vector ("is-a" rather than "has-a"). We sympathize with the submitter but cannot fix this because of compatibility.

Java's Object superclass

Object data type. Every other class has `Object` as a (direct or indirect) superclass.

```
public class Disc extends Object {
   ...


}
```

added implicitly
(if no `extends` *clause)*



Java class hierarchy

Java's Object superclass

Object data type. Every other class has `Object` as a (direct or indirect) superclass.

`public class Object`		
`boolean`	`equals(Object x)`	*is this object equal to x ?*
`int`	`hashCode()`	*hash code of this object*
`String`	`toString()`	*string representation*
	⋮	*copy, concurrency, …*

Inherited methods. Behavior inherited from `Object` is rarely what you want ⇒ override them.

- Equals: reference equality (same as ==).
- Hash code: arbitrary integer associated with object. ⟵ *think of as a memory address*
- String representation: name of class, followed by @, followed by hash code.

The toString() method

Best practice. Override the `toString()` method.

```
public class Disc {
   private final int x, y, r;

   ...

   public String toString() {
     return String.format("(%d, %d, %d)", x, y, r);
   }

}
```

works like `printf()` but returns string (instead of printing it)

without overriding toString() method

```
~/cos226/inheritance> jshell-algs4
/open Disc.java
Disc disc = new Disc(100, 100, 20);
StdOut.println("disc = " + disc.toString());
disc = Disc@239963d8
```

after overriding the toString() method

```
disc = (100, 100, 20)
```

String concatenation operator. Java calls an object's `toString()` method implicitly.

```
StdOut.println("disc = " + disc);
```

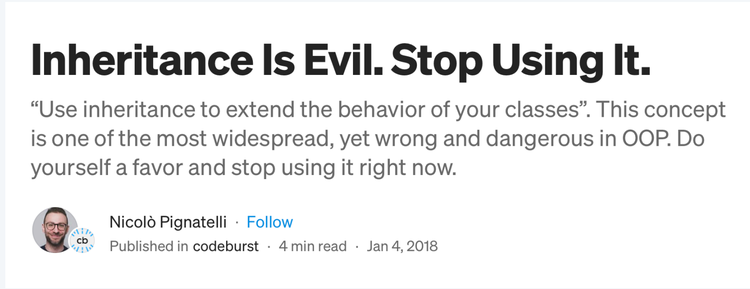
string concatenation operator

Inheritance summary

Subclassing. Powerful OOP mechanism for code reuse.

Caveats.

- Stuck with inherited instance variables/methods forever.
- Subclass may break with seemingly innocuous change to superclass.



Best practices.

- Use with extreme care.
- Favor composition (or interfaces) over subclassing.

This course.

- Yes: override inherited methods: `toString()`, `hashCode()`, and `equals()`.
- No: define inheritance hierarchies.

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Advanced Java

- *inheritance*
- *interfaces*
- *iterators*

Motivation

Q1. How to design a single method that can sort arrays of strings, integers, or dates?

Q2. How to iterate over a collection without knowing the underlying representation?

Q3. How to intercept and process mouse clicks in a Java app?

A. Java interfaces.

```
String[] a = {
   "Apple", "Orange", "Banana"
};
Arrays.sort(a);

Integer[] b = { 3, 1, 2 };
Arrays.sort(b);
```

sort arrays

```
Stack<String> stack = new Stack<>();
stack.push("Yeh");
stack.push("Whitman");
stack.push("Mathey");

for (String s : stack)
   StdOut.println(s);
```

iterate over items in a collection

Java interfaces overview

Interface. A set of related methods that define some behavior (partial API) for a class.

```
public interface Shape2D {
   void draw();
   boolean contains(int x0, int y0);
}
```

the contract: methods with these signatures (and prescribed behaviors)

class promises to honor the contract

```
public class Disc implements Shape2D {
   private final int x, y, r;

   public Disc(double x, double y, double r) {
      this.x = x;
      this.y = y;
      this.r = r;
   }

   public void draw() {
      StdDraw.filledCircle(x, y, r);
   }

   public boolean contains(int x0, int y0) {
      int dx = x - x0;
      int dy = y - y0;
      return dx*dx + dy*dy <= r*r;
   }

   public boolean intersects(Disc that) {
      ...
   }
}
```

class abides by the contract

class can define additional methods

Java interfaces overview

Interface. A set of related methods that define some behavior (partial API) for a class.

```
public interface Shape2D {
   void draw();
   boolean contains(int x0, int y0);
}
```

the contract: methods with these signatures (and prescribed behaviors)

Many classes can implement the same interface.

```
public class Square implements Shape2D {
   ...
}
```

```
public class Triangle implements Shape2D {
   ...
}
```

```
public class Star implements Shape2D {
   ...
}
```

```
public class Heart implements Shape2D {
   ...
}
```

Java interfaces demo (in JShell)

```
~/cos226/inheritance> jshell-algs4
/open Shape2D.java
/open Disc.java
/open Square.java
/open Heart.java

StdDraw.setScale(0, 800);

Square square = new Square(400, 400, 200);
Shape2D disc = new Disc(400, 700, 100);
Shape2D heart = new Heart(400, 400, 100);

Shape2D s = "Hello, World";

square.area();
square.contains(400, 300);
disc.contains(400, 300);
disc.area();

Shape2D[] shapes = { disc, square, heart };

for (int i = 0; i < shapes.length; i++)
    shapes[i].draw();
```

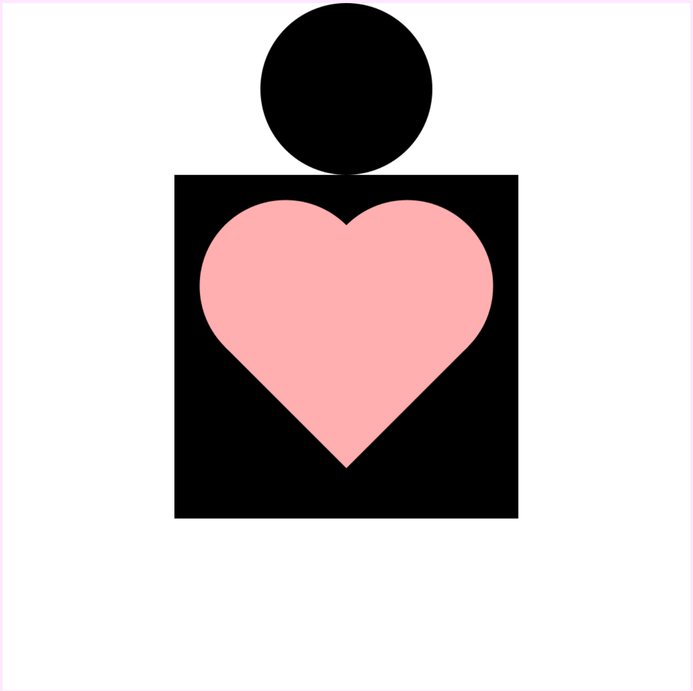
implicit type conversion (upcasting)

compile-time error (incompatible types)

compile-time error (not a Shape2D method)

mixed-type collection

manipulate objects in a uniform manner



Java interface properties

Interfaces are reference types. Can use interface name anywhere you can use a data type name.

variable declarations, argument types, return types

Subtype polymorphism. A class that implements an interface is a subtype of that interface:
objects of the subtype can be used anywhere objects of the interface are allowed.

RHS of assignment statements, method arguments, return types, ...

Key differences with inheritance.

- Uses keyword `implements` instead of `extends`.
- Does not inherit instance variables or instance methods.
- Can implement many interfaces (but extend only one class). ← *"multiple inheritance"*

```
public class MovableDisc extends Disc implements Shape2D, Movable {
   ...
}
```

Advanced Java: quiz 2

Which of the following statements leads to a compile-time error?

A. `Shape2D shape = new Shape2D();`

B. `Shape2D[] shapes = new Shape2D[10];`

C. Both A and B.

D. Neither A nor B.

Java interfaces in the wild

Interfaces are essential for industrial-strength programming in Java.

purpose	built-in interfaces
sorting	`java.lang.Comparable` `java.util.Comparator`
iteration	`java.lang.Iterable` `java.util.Iterator`

collections	`java.util.List`
	`java.util.Map`
	`java.util.Set`

GUI events	`java.awt.event.MouseListener`
	`java.awt.event.KeyListener`
	`java.awt.event.MenuListener`

lambda expressions	`java.util.function.Consumer`
	`java.util.function.Supplier`
	`java.util.function.BinaryOperator`

concurrency	`java.lang.Runnable` `java.lang.Callable`

this course

Java interfaces summary

Java interface. A set of methods that define some behavior (partial API) for a class.

Design benefits.

- Enables callbacks, which promotes code reuse.
- Facilitates lambda expressions for functional programming.

This course.

- Yes: use interfaces built into Java (for sorting and iteration).
- No: define our own interfaces; lambda expressions.

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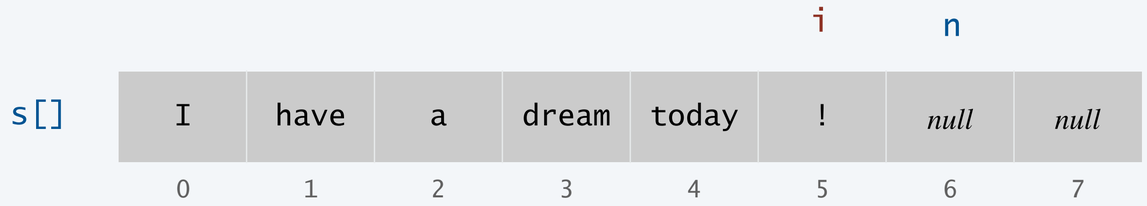
Advanced Java

- *inheritance*
- *interfaces*
- *iterators*

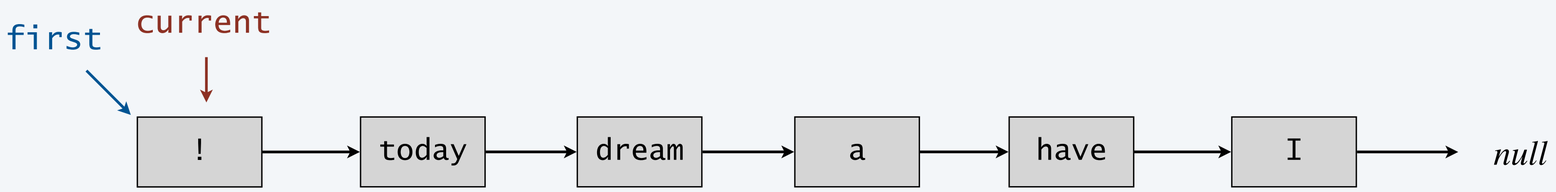
Iteration

Design challenge. Allow client to iterate over the items in a collection, without exposing the collection's internal representation.

stack (resizing-array representation)



stack (linked-list representation)



Java solution. Use a foreach loop.

Foreach loop

Java provides elegant syntax for iterating over the items in a collection.

“foreach” loop (shorthand)

```
Stack<String> stack = new Stack<>();
...

for (String s : stack) {
    ...
}
```

equivalent code (longhand)

```
Stack<String> stack = new Stack<>();
...

Iterator<String> iterator = stack.iterator();
while (iterator.hasNext()) {
   String s = iterator.next();
   ...
}
```

To provide clients the ability to iterate with a foreach loop:

- Collection must have a method `iterator()`, which returns an `Iterator` object.
- An `Iterator` object represents the state of a traversal.
  - the `hasNext()` returns `false` if the traversal is done
  - the `next()` method returns the next item in the traversal

Iterator and Iterable interfaces

Java defines two interfaces that facilitate foreach loops.

- `Iterable` interface: `iterator()` method that returns an `Iterator`.
- `Iterator` interface: `next()` and `hasNext()` methods.
- Each interface is parameterized using generics.

java.lang.Iterable interface

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

" I am a collection that can be traversed with a foreach loop. "

java.util.Iterator interface

```
public interface Iterator<Item> {
   boolean hasNext();
   Item next();
}
```

" I represent the state of one traversal. "

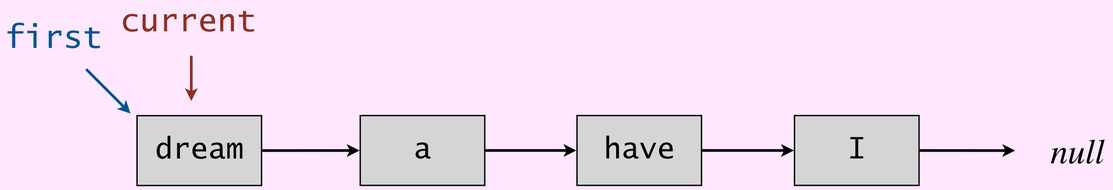
Type safety. Foreach loop won't compile unless collection is `Iterable` (or an array).

Stack iterator: array implementation

```
import java.util.Iterator;
import java.util.NoSuchElementException;

public class ResizingArrayStack<Item> implements Iterable<Item> {
   private int n;     // number of items in the stack
   private Item[] s;  // stack items
   ...

   public Iterator<Item> iterator() {
      return new ReverseArrayIterator();
   }

   private class ReverseArrayIterator implements Iterator<Item> {
      private int i = n-1;   // index of next item to return

      public boolean hasNext() {
         return i >= 0;
      }

      public Item next() {
         if (!hasNext()) throw new NoSuchElementException();
         return s[i--];
      }
   }
}
```

Stack iterator: linked-list implementation (in IntelliJ)

```
import java.util.Iterator;
import java.util.NoSuchElementException;

public class LinkedStack<Item> implements Iterable<Item>  {
   private Node first;
   ...

   public Iterator<Item> iterator() {
      return new LinkedIterator();
   }

   private class LinkedIterator implements Iterator<Item> {
      private Node current = first;

      public boolean hasNext() {
         return current != null;
      }

      public Item next() {
         if (!hasNext()) throw new NoSuchElementException();
         Item item = current.item;
         current   = current.next;
         return item;
      }
   }
}
```



Advanced Java: quiz 3

Suppose that you add A, B, and C to a stack (linked list or resizing array), in that order.

What does the following code fragment do?

```
for (String s : stack)
   for (String t : stack)
      StdOut.println(s + "-" + t);
```

A. Prints `A-A A-B A-C B-A B-B B-C C-A C-B C-C`

B. Prints `C-C B-B A-A`

C. Prints `C-C C-B C-A`

D. Prints `C-C C-B C-A B-C B-B B-A A-C A-B A-A`

E. Depends on the implementation.

Advanced Java: quiz 4

Suppose that you add A, B, and C to a stack (linked list or resizing array), in that order.

What does the following code fragment do?

```
for (String s : stack) {
   StdOut.println(s);
   StdOut.println(stack.pop());
   stack.push(s);
}
```

modifies stack

A. Prints `A A B B C C`

B. Prints `C C B B A A`

C. Prints `C C B C A B`

D. Prints `C C C C C C C C ...`

E. Depends on the implementation

Iteration: concurrent modification

Q. What should happen if a client modifies a collection while traversing it?

A. A fail-fast iterator throws a `java.util.ConcurrentModificationException`.

concurrent modification

```
for (String s : stack)
   stack.push(s);
```

Java iterators summary

Iterator and Iterable. Two Java interfaces that allow a client to iterate over the items in a collection, without exposing the collection's internal representation.

```
Stack<String> stack = new Stack<>();
...

for (String s : stack) {
  ...
}
```

This course.

- Yes: use iterators in client code.
- Yes: implement iterators (Assignment 2 only).

Credits

image	source	license
Effective Java	Addison-Wesley Professional	
Java Language Specification	Addison-Wesley Professional	
Barbara Liskov	Kenneth C. Zirkel	CC BY-SA 3.0
Java GUI Components	Oracle	
Inheritance is Evil	Nicolò Pignatelli	
Barbara Liskov	Donna Coveney / MIT	

A final thought

> *“ I was interested in doing it, there was an opportunity, so I just did it.”* — Barbara Liskov