Inheritance & Polymorphism

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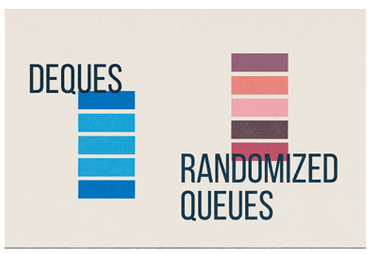
Composition

A `GuitarString` ***has a*** `RingBuffer`.

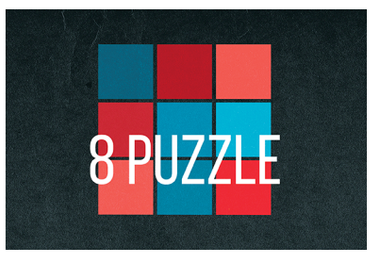
A `MarkovModel` ***has a*** Symbol Table.

A Symbol Table ***has a*** Binary Search Tree.



A `Deque` ***has a*** `Node`.

A `Node` ***has a*** `Node`.



A `Solver` ***has a*** `Node`.

A `Node` ***has a*** `Board` and a `Node`.

A `KdTreeST` ***has a*** `Node`.

A `Node` ***has a*** `Point2D` and a `Node`.

Code reuse through ***Composition***.

Classes are related with a ***has-a*** relationship.

Inheritance *is-a* Basic OOP Feature!

Definition of OBJECT-ORIENTED PROGRAMMING

Inheritance!

: a type of computer programming in which programs are composed of objects (see [1]OBJECT 6a) which communicate with each other, which may be arranged into hierarchies, and which can be combined to form additional objects

Composition

Object-oriented programming

From Wikipedia, the free encyclopedia

Languages that support classes almost always support inheritance. This allows classes to be arranged in a hierarchy that represents "is-a-type-of" relationships.

- Found in (almost) every Java, C++ or Python book.
- Very difficult to find a CS1/CS2 set of courses that does not cover it.

But ...

- Not covered explicitly in COS126/COS226!

Goal Today: — Know what Inheritance and Polymorphism *are*.
— Relate them to what we have seen in 126 and 226 so *far*.

Warm Up Quiz!

http://etc.ch/Vvh7

Which of the following is a valid *Java* Statement?

A. `Iterable<Integer> myStack = new Stack<Integer>();`

B. `Stack<Integer> myStack = new Stack<Integer>();`

C. `Object myStack = new Stack<Integer>();`

D. A and B only.

E. A, B and C.

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D. A and B only.

E. A, B and C.

By the end of this class, you will be able to explain what these statements mean and what implications they have.

Shapes!

A Circle Class

```
 6
 7  public  class Circle {
 8      private double centerX;
 9      private double centerY;
10      private double radius;
11      private Color color;
12
13      public void move(double newX, double newY) {
14          centerX = newX;
15          centerY = newY;
16      }
17
18      public int getX() { return centerX; }
19      public int getY() { return centerY; }
20
21      public void draw() {
22          StdDraw.setPenColor(color);
23          StdDraw.circle(centerX, centerY, radius);
24      }
25
26      public void setColor(int r, int g, int b) {
27          String errorMsg;
28          boolean isValid = true;
29          if (r < 0) {
30              errorMsg = "Red is < 0";
31              isValid = false;
32          }
33          else if (g < 0) {
34              errorMsg = "Green is < 0";
35              isValid = false;
36          }
37          else if (b < 0) {
38              errorMsg = "Blue is < 0";
39              isValid = false;
40          }
41          else if (r > 255) {
```

+ Other Circle methods

A Rectangle Class

```
 6
 7  public  class Rectangle {
 8      private double centerX;
 9      private double centerY;
10      private double width;
11      private double height;
12      private Color color;
13
14      public void move(double newX, double newY) {
15          centerX = newX;
16          centerY = newY;
17      }
18
19      public int getX() { return centerX; }
20      public int getY() { return centerY; }
21
22      public void draw() {
23          StdDraw.setPenColor(color);
24          StdDraw.rectangle(centerX, centerY,
25                            width / 2, height / 2);
26      }
26      public void setColor(int r, int g, int b) {
27          String errorMsg;
28          boolean isValid = true;
29          if (r < 0) {
30              errorMsg = "Red is < 0";
31              isValid = false;
32          }
33          else if (g < 0) {
34              errorMsg = "Green is < 0";
35              isValid = false;
36          }
37          else if (b < 0) {
38              errorMsg = "Blue is < 0";
39              isValid = false;
```

\+ Other Rectangle methods

Classes for Shapes

Circle

- centerX : double
- centerY : double
- color : Color
- radius : double

+ getX(): double
+ getY(): double
+ move(int,int): void
+ setColor(int,int,int): void
+ draw() : String
+ area() : double
+ circumference() : double
+ toString() : String
...

Rectangle

- centerX : double
- centerY : double
- color : Color
- width : double
- height : double

+ getX(): double
+ getY(): double
+ move(int,int): void
+ setColor(int,int,int): void
+ draw(): void
+ area() : double
+ circumference() : double
+ toString() : String
...

...

Triangle

- centerX : double
- centerY : double
- color : Color
- side1 : double
- side2 : double
- side3 : double

+ getX(): double
+ getY(): double
+ move(int,int): void
+ setColor(int,int,int): void
+ draw(): void
+ area() : double
+ circumference() : double
...

Classes for Shapes

Circle

- centerX : double
- centerY : double
- color : Color
- radius : double

+ getX(): double
+ getY(): double
+ move(int,int): void
+ setColor(int,int,int): void
+ draw() : String
+ area() : double
+ circumference() : double
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...

Rectangle

- centerX : double
- centerY : double
- color : Color
- width : double
- height : double

+ getX(): double
+ getY(): double
+ move(int,int): void
+ setColor(int,int,int): void
+ draw(): void
+ area() : double
+ circumference() : double
+ toString() : String
...

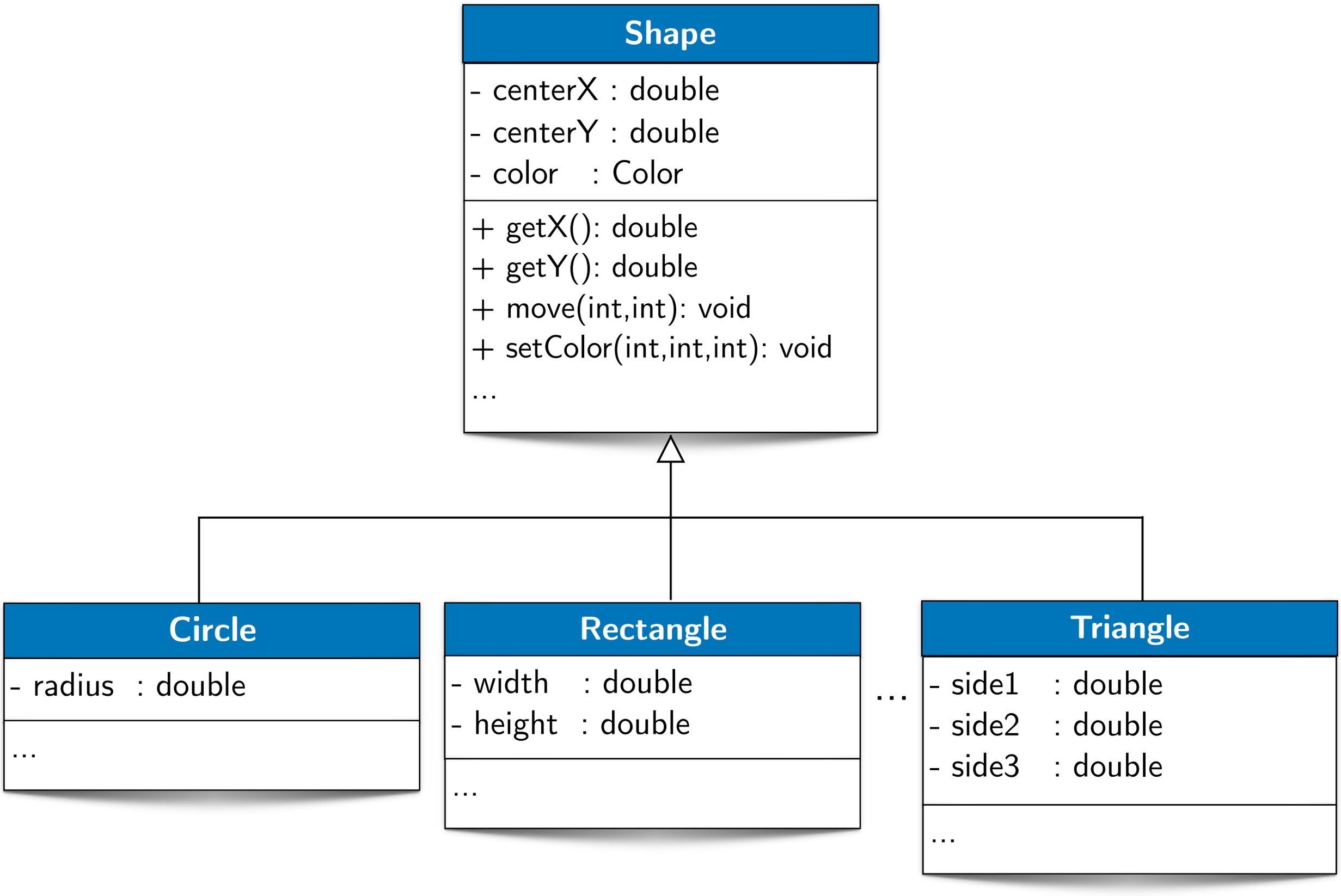
...

Triangle

- centerX : double
- centerY : double
- color : Color
- side1 : double
- side2 : double
- side3 : double

+ getX(): double
+ getY(): double
+ move(int,int): void
+ setColor(int,int,int): void
+ draw(): void
+ area() : double
+ circumference() : double
...

A Shape Base Class



A Shape Base Class

Observations. (1) Lots of **common code** between the classes.

(2) A Circle **is a** Shape, so is a Rectangle and a Triangle.

Solution.

— Create a **Shape class** that has the common code.

— Declare that Circle **is a** Shape. Do the same for Triangle and Rectangle.

— Circle, Triangle and Rectangle **inherit** the code from class Shape.

In Java:

```
public class Circle extends Shape { … }
public class Triangle extends Shape { … }
public class Rectangle extends Shape { … }
```

Demo!

Notes

Terminology. Shape is a ***parent*** class, a ***superclass*** and a ***base*** class.
Circle is a ***child*** class, a ***subclass*** and a ***derived*** class.

Access Modifiers.
`Public`: Accessible to everyone.
`Protected`: Accessible to subclasses and package.
`No Modifier`: Accessible to package.

`Super` and **`this`**.
`this.x` Can be an *x* in the parent or child class.
If both classes have *x*, ***`this.x`*** refers to the x in the child class

`super.x` Always refers to x in the *superclass*.

What did we gain?

- Code Reuse!
- Is-A Relationship!

Can do great things!

Example 1

```
Circle c = new Circle();
Triangle t = new Triangle();
Rectangle r = new Rectangle();

Shape [] shapes = new Shape[3];
shapes[0] = c;
shapes[1] = t;
shapes[2] = r;

for (int i = 0; i < 3; i++)
    shapes[i].setColor(128, 128, 128);
```

Example 2

```
myObj.doSomthing(c);
myObj.doSomthing(t);
myObj.doSomething(r);
```

Method doSomething accepts an argument of type Shape.

Rules of the Game

```
Circle c = new Circle()
```

- Can invoke on *c* any method in class Circle (or Shape).
  `c.setRadius()` <— ***Valid***
  `c.setColor()` <— ***Valid***

```
Shape c = new Circle()
```

- Can invoke on *c* only methods in class Shape.
  `c.setRadius()` <— ***Invalid***
  `c.setColor()` <— ***Valid***

Abstract Classes

Q. Do we want to allow instantiating objects of type Shape?

If not, then declare class Shape as ***abstract***.

```
public abstract class Shape { ... }
```

```
Shape is abstract; cannot be instantiated
        Shape s = new Shape();
                  ^
1 error
```

Q. Do we want method draw() to be defined in class Shape?

Yes! Since all shapes need to be drawn.

However, since each shape is drawn differently, draw() should be ***abstract***.

```
public abstract void draw();
```

An ***abstract method***: Has no body (note the semicolon).

Derived classes MUST either be also abstract or implement all abstract methods in the base class.

Demo!

Quiz

http://etc.ch/Vvh7

```
Circle c = new Circle();
Triangle t = new Triangle();
Rectangle r = new Rectangle();

Shape [] shapes = new Shape[3];
shapes[0] = c;
shapes[1] = t;
shapes[2] = r;

for (int i = 0; i < 3; i++)
    shapes[i].setColor(128, 128, 128);
```

Assume that Circle overrides method setColor. Which method will get called when `shapes[0].setColor` is called?

A. `setColor of Shape.`

B. `setColor` of Circle.

C. The compiler will complain because there are two setColor methods.

D. Armagedon.

Quiz

http://etc.ch/Vvh7

```
Circle c = new Circle();
Triangle t = new Triangle();
Rectangle r = new Rectangle();

Shape [] shapes = new Shape[3];
shapes[0] = c;
shapes[1] = t;
shapes[2] = r;

for (int i = 0; i < 3; i++)
    shapes[i].setColor(128, 128, 128);
```

Assume that Circle overrides method setColor. Which method will get called when `shapes[0].setColor` is called?

A. `setColor of Shape.`

B. `setColor` of Circle.

C. The compiler will complain because there are two setColor methods.

D. Armagedon.

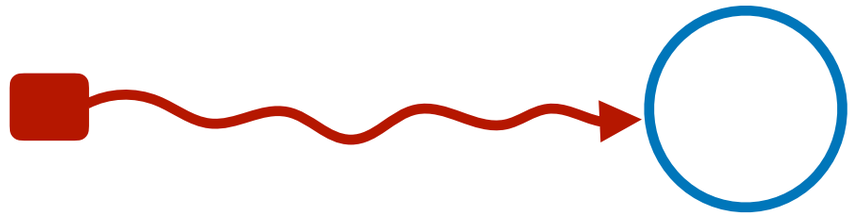
Welcome *Polymorphism*

What? If a subclass defines it's own version of a base class method (***overrides*** it), the subclass version is invoked if the reference points to an object of the subclass type.

Example. Assume class Circle overrides method setColor in Shape.

```
Shape c = new Circle()
```

Reference of type **Shape** pointing to an **Object** of type **Circle**



`c.setRadius()` <— ***Invalid*** Not a Shape method.

`c.getX()` <— ***Valid*** Implemented in Shape.

Polymorphic behavior

`c.draw()` <— ***Valid*** Abstract method of Shape. Implemented in Circle.

`c.setColor()` <— ***Valid*** Implemented in both Shape and Circle. Circle's version gets called.

Déjà vu!

Inheritance & Polymorphism
you have already seen.

The Parent of all Objects

All Java classes implicitly ***extend*** a class named ***Object*** that has the following methods:

— **`equals`**`(Object obj)`	Checks if the object is equal to obj.
— **`toString`**`()`	Returns a string representation of the object.
— **`hashCode`**`()`	Returns a hash code value for the object.
— **`clone`**`()`	Returns a copy of the object.
— **`getClass`**`()`	Returns the type of the object.
— *Others...*	

The Parent of all Objects

When you implement **`equals`** or **`toString`**, you are actually *overriding* the *default implementation* of **`equals`** and **`toString`** in the **`Object`** class.

Default Implementations.

Equals(): Reference comparison of memory locations using the == operator.

ToString(): A String made of the class name + '@' + hashCode(). The default implementation of hashCode returns the memory location of the object.

```
Circle c1 = new Circle()
```

`c1.equals(c2)`	<— ***Valid***	Uses default implementation of Object.
`c1.toString()`	<— ***Valid***	A default implementation in Object and another in Circle. Uses the implementation in Circle.

Quiz

Consider. `Circle c1 = new Circle()`

Explain. How does Java handle the following two lines of code?

```
System.out.print(c1)
System.out.print(c1.toString())
```

Answer. Method print is overloaded:

`print(Object obj)` Prints an object.	**Calls method `toString` on `obj`.**
`print(String s)` Prints a string.	

Polymorphism in action!

Again ... What did we gain?

- Code Reuse! — ***by inheriting state and behavior from parent class.***
- Is-A Relationship! — ***and Polymorphism!***
- A promise for an API — ***through abstract methods***

What if we care only about these? Define an abstract class where ***all methods are abstract.***

Or ...

Define and use an ***interface****!*

Welcome *Interfaces!*

Instead of:

```
public abstract class Shape {
        public abstract double getX();
        public abstract double getY();
        public abstract void draw();
        public abstract void setColor(int, int, int);
        …
}
```

Implement:

```
public interface Shape {
        double getX();
        double getY();
        void draw();
        void setColor(int, int, int);
        …
}
```

All methods are implicitly:

`public abstract.`

All fields are implicitly:

`public static final`

Examples of Interfaces in Java 7

```
public interface Iterable<T> {
        Iterator<T> Iterator();
        …
}
```

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

```
public interface Comparable<T> {
        int compareTo(T other);
}
```

```
public interface Cloneable {}
```

Empty! Useful only for Is-A relationship

Use with interfaces

implements

instead of

extends

Interfaces in Java 8

In Java 8, methods in interfaces are allowed to have a ***default*** implementation.

Question. What is the difference between an abstract class and an interface with default implementations?

Answer.

extending a class	**implementing an interface**
Inherits API, ***state*** and implementation.	Inherits *only* API and implementation.
Multiple Inheritance NOT allowed.	*Multiple Inheritance* allowed.

A class **can extend only one class**, but **can implement several interfaces**. I.e., a class can be only one thing, but can play several roles!

Back to the Warm Up Quiz!

Which of the following is a valid *Java* Statement?

Only iterator() **can be invoked**

A Stack *is Iterable*.

A. `Iterable<Integer> myStack = new Stack<Integer>();`

Same Type

B. `Stack<Integer> myStack = new Stack<Integer>();`

C. `Object myStack = new Stack<Integer>();`

D. A and B only.

E. A, B and C.

A Stack *is an Object*.

Only Object **methods can be invoked**

Discussion

What is the difference between using Generics and using Object?

Example.

```
public class Queue {
    public void enqueue(Object obj) {…}
    public Object dequeue() {…}
}
```

V.S.

```
public class Queue<T> {
    public void enqueue(T element) {…}
    public T dequeue() {…}
}
```

```
Queue<Integer> qT = new Queue<Integer>();
Queue qObj = new Queue();
```

Type Safe.

```
qT.enqueue(myCat); // does not compile!
```

Not Type Safe.

```
qObj.enqueue(myCat); // compiles!
```

No Need to Cast.

```
int element = qT.dequeue();
```

Needs a Cast.

```
int element = (Integer) qObj.dequeue();
```

Abusing Inheritance

1. Extending for implementation. To extend, Is-A should hold

Example 1. Make class Percolation extend class BeadFinder to make use of the DFS method. ***Bad idea!*** A Percolation object is not a BeadFinder.

Example 2. Make class Polygon extend class Circle to make use of getX(), getY(), setColor(), etc. ***Bad idea!*** A Polygon is not a Circle.

2. Methods or variables in base class not relevant in subclasses.

Example. Adding instance variable *radius* and method *getRadius* in class Shape. ***Bad idea!*** Useful for Circle, Oval but not for Triangle and Polygon.

3. Hierarchies that are long and complicated.

Hierarchies should be wide, not deep!

Inheritance Wars!

Anti-Inheritance Clan

- Inheritance violates encapsulation. Child class knows too much about Parent class.
- Widely abused.
- Leads to absurdities, especially with multiple inheritance.
- Code difficult to test and debug.

Anti-Anti-Inheritance Clan

- Inheritance is useful.
- Model's real world entities more naturally.
- Code carefully and avoid abuse.

Widely Used Rules of Thumb:

— *Favor* Composition over Inheritance.

— Use Composition for code re-use and implement interfaces for defining Is-A relationships.

Image on the first slide retrieved on March 25th from: http://www.geneticdisordersuk.org/static/images/up/patterns-of-inheritance_2014_v4.jpg