CSc 133 Lecture Notes

4 - Inheritance

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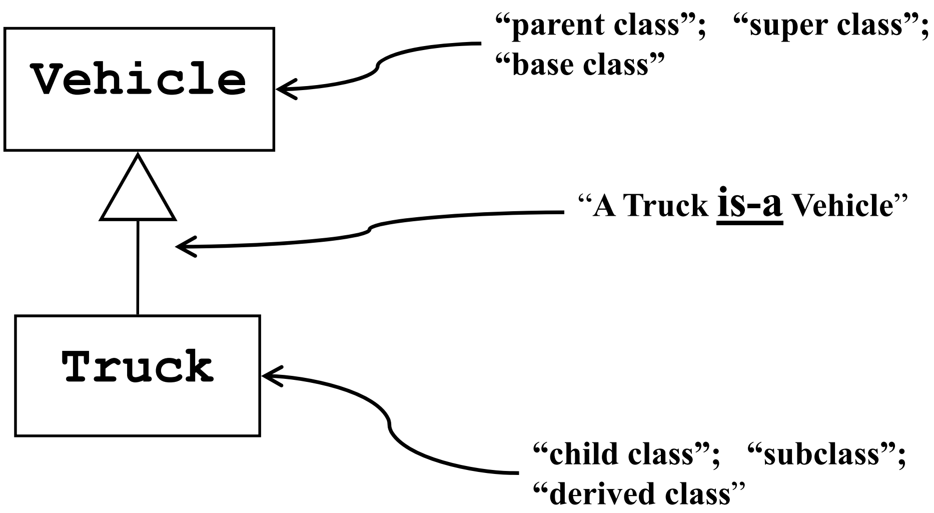
Overview

- **Definition**
- **Representation in UML, Implementation in Java, The "IS-A" concept**
- **Inheritance Hierarchies**
- **Overriding, Overloading**
- **Implications for Public vs. Private data**
- **Forms of Inheritance: Extension, Specialization, Specification**
- **Abstract classes and methods**
- **Single vs. Multiple Inheritance**

What Is Inheritance?

- **A specific kind of *association* between classes**
- **Various definitions:**
  - Creation of a *hierarchy of classes*, where lower-level classes share properties of a common "parent class"
  - A mechanism for indicating that one class is "similar" to another but has specific differences
  - A mechanism for enabling properties (attributes and methods) of a "super class" to be propagated down to "sub classes"
  - Using a "base class" to define what characteristics are *common* to all instances of the class, then defining "derived classes" to define what is special about each subgrouping

Inheritance In UML



"parent class"; "super class"; "base class"

"A Truck is-a Vehicle"

"child class"; "subclass"; "derived class"

Inheritance In Java

- **Specified with the keyword "extends" :**

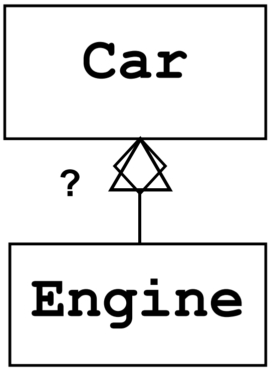
```
public class Vehicle {

  private int weight;
  private double purchasePrice;
  //... other Vehicle data here

  public Vehicle ()
  { ... }

  public void turn (int direction)
  { ... }

  // ... other Vehicle methods here
}
```

```
public class Truck extends Vehicle {
  private int freightCapacity;
  //... other Truck data here

  public Truck ()
  { ... }

  // ... Truck-specific methods here
}
```

- **Note: a Truck "is-a" Vehicle**
- **Only a single "extends" allowed (no "multiple inheritance")**
- **Absence of any "extends" clause implies "extends Object"**

The "IS-A" Relationship

- **Inheritance *always* specifies an "is-a" relationship.**
- **If you can't say "A is a B" (or "A is a kind of B"), *it isn't inheritance***



An Engine "is a" Car ? X

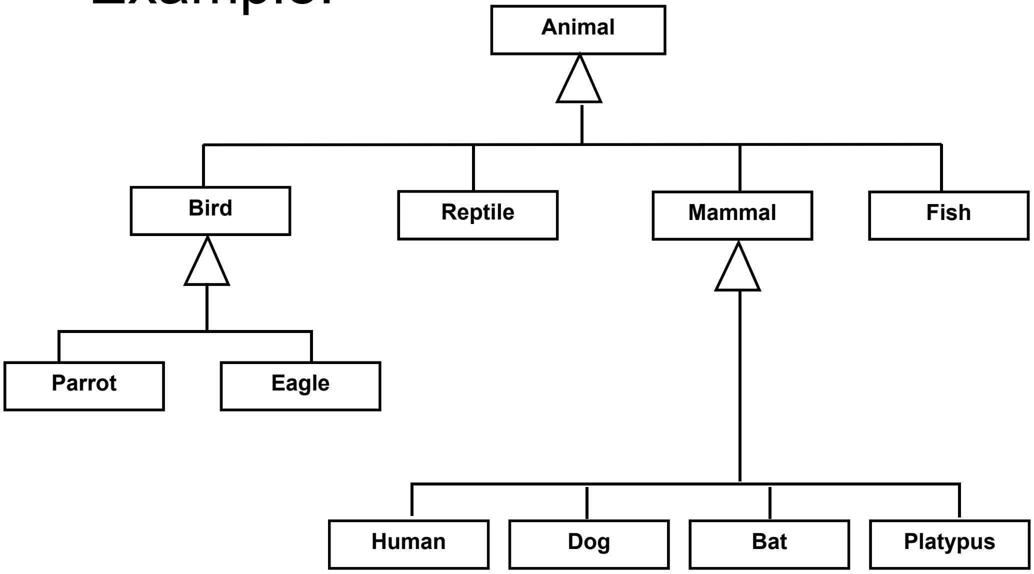
A Car "is an" Engine ? X

A Car "has-an" Engine ✓

An Engine "is a part of" a Car ✓

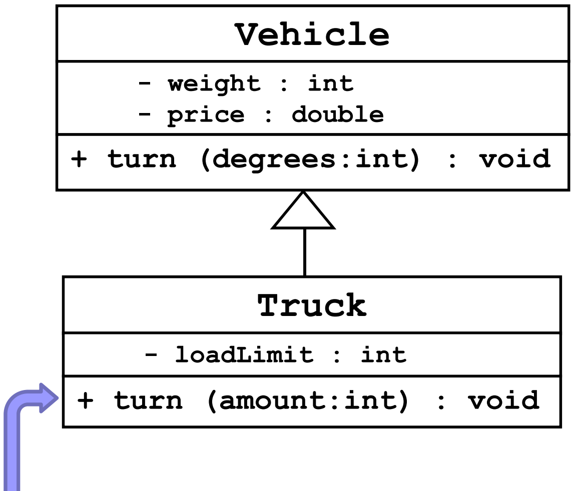
Inheritance Hierarchies

- Example:



Method Overriding

- Inheritance leads to an interesting possibility:
  duplicate method declarations



Truck's turn(int) "***overrides***"
Vehicle's turn(int)

```
public class Vehicle {
  private int weight ;
  private double price ;

  public void turn (int degrees)
  { // some code to accomplish turning... }

  ...
}
```

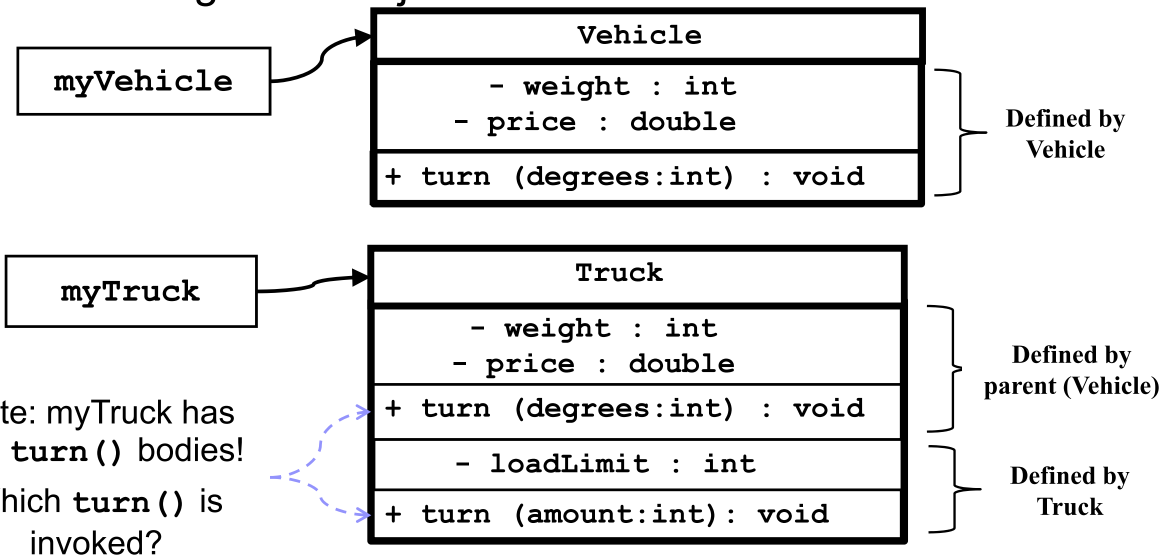
```
public class Truck extends Vehicle {
  private int loadLimit ;

  public void turn (int amount)
  { // different code to accomplish turning... }
  ...
}
```

Effects of Method Overriding

Consider the following code:

```
Vehicle myVehicle = new Vehicle();
Truck myTruck = new Truck();
```

… then we get two objects:



Note: myTruck has *two* **turn()** bodies!

Which **turn()** is invoked?

Method Overriding: Summary

- **Occurs when a child class redefines an inherited method, which:**
  - **has same name**
  - **has same parameters**
  - **returns same type or subtype**
- **Child objects contain the code for both methods**
  - **Parent method code plus the child (overriding) method code**
- **Calling an overridden method (in Java) invokes the child version**
  - **Never invokes the parent version**
  - **The child can invoke the parent method using "super.*xxx (...)*"**
- **It is not legal (in Java) to override and change the *return type which is not a subtype*.**
  - **So for the Vehicle/Truck example, Truck could NOT define**

```
public boolean turn (int amount) { ... }
```

Overloading

- ***Not*** **the same as "overriding"…**
  - **Overloading == same name but different parameter types**
  - **Can occur *in the same class or split between parent/child classes***

- ***Overloading examples:***
  - Methods with different numbers of parameters:

```
distance(p1);    distance(p1,p2);
```

  - Constructors with different parameter sequences:

```
Circle(); Circle(Color c); Circle(int radius);
 Circle(Color c, int radius);
```

  - Changing parameter type:

```
computeStandings(int numTeams);
computeStandings(double average);
computeStandings(Hashtable teams);
```

recall, from the encapsulation section:

`Point` (without "Accessors"):

```
public class Point {

   public double x, y ;

   public Point () {
     x = 0.0 ;
     y = 0.0 ;
   }
}
```

BAD

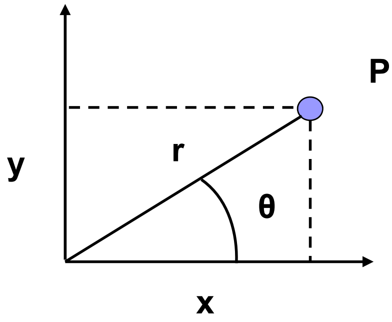
Now we will learn why!

`Point` (with "Accessors"):

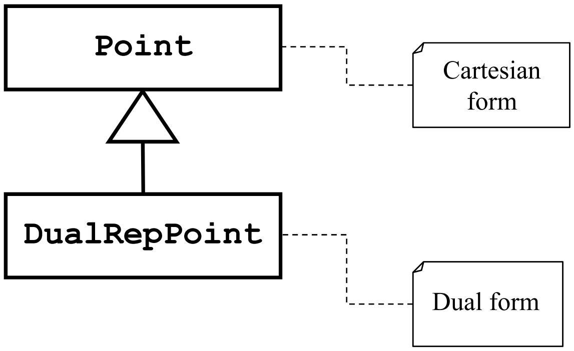
```
public class Point {
   private double x, y ;
   public Point (){
      x = 0.0 ;
      y = 0.0 ;
   }
   public double getX() {
      return x ;
   }
   public double getY() {
      return y ;
   }
   public void setX (double newX) {
      x = newX ;
   }
   public void setY (double newY) {
      y = newY ;
   }
}
```

GOOD

Example: extend "**`Point`**" to create "**`DualRepPoint`**"



P(x,y) = P(r,θ)



DualRepPoint (DRP): Ver. 1

```
public class DualRepPoint extends Point {

  public double radius, angle ;                  ← Note public access

  /** Constructor: creates a default point with radius 2 at 45 degrees */
  public DualRepPoint () {
    radius = 2.0 ;
    angle = 45 ;
    updateRectangularValues();
  }

  /** Constructor: creates a point as specified by the input parameters */
  public DualRepPoint (double theRadius, double angleInDegrees) {
    radius = theRadius ;
    angle = angleInDegrees;
    updateRectangularValues();
  }

  /** Force the Cartesian values (inherited from Point) to be consistent */
  private void updateRectangularValues() {
    x = radius * Math.cos(Math.toRadians(angle));    // legal assignments
    y = radius * Math.sin(Math.toRadians(angle));    // (x & y are public)
  }
}
```

Client Using Public Access

```
/** This shows a "client" class that makes use of the "V. 1 DualRepPoint" class.
 *  It shows how the improper implementation of DualRepPoint (that is, use of
 *  fields with public access) leads to problems...
 */
public class SomeClientClass {

  private DualRepPoint myDRPoint ;   //declare client's local DualRepPoint

  // Constructor: creates a DualRepPoint with default values,
  // then changes the DualRepPoint's radius and angle values

  public SomeClientClass() {
      myDRPoint = new DualRepPoint() ;      //create private DualRepPoint
      myDRPoint.radius = 5.0 ;              //update DualRepPoint's values
      myDRPoint.angle = 90.0 ;
  }
  ...
}
```

Anything wrong?

DualRepPoint: Ver. 2

```
/** This class maintains a point representation in both Polar and Rectangular
 *  form and protects against inconsistent changes in the local fields */
public class DualRepPoint extends Point {

  private double radius, angle ;

  // constructors as before (not shown) ...
  public double getRadius() { return radius ; }
  public double getAngle() { return angle ; }

  public void setRadius(double theRadius) {
    radius = theRadius ;
    updateRectangularValues();
  }

  public void setAngle(double angleInDegrees) {
    angle = angleInDegrees;
    updateRectangularValues();
  }

  // force the Cartesian values (inherited from Point) to be consistent
  private void updateRectangularValues() {
    x = radius * Math.cos(Math.toRadians(angle));
    y = radius * Math.sin(Math.toRadians(angle));
  }
}
```

← **New: private access**

New: public accessors

Client Using DRP Accessors

```
/** This new version of the client code shows how requiring the use of accessors
 *  when manipulating the DualRepPoint radius & angle fields fixes (one) problem ...
 */

public class SomeClientClass {

  private DualRepPoint myDRPoint ;

  public SomeClientClass() {                 // client constructor
       myDRPoint = new DualRepPoint();       // create a private DualRepPoint
       myDRPoint.setRadius(5.0) ;  // alter DualRepPoint's values (safely): client has
       myDRPoint.setAngle(90.0) ;  // no way to access radius/angle directly
  }

  .... etc.
}
```

Problem solved?

Accessing Other DRP Fields

```
/** This newer version of the client code shows how requiring the use of accessors
 *  when manipulating the DualRepPoint radius & angle fields fixes (one) problem
 *  ... but not all problems...
 */
public class SomeClientClass {

  private DualRepPoint myDRPoint ;

  public SomeClientClass() {                 // client constructor as before
       myDRPoint = new DualRepPoint();
       myDRPoint.setRadius(5.0) ;
       myDRPoint.setAngle(90.0) ;
  }

  //a new client method which manipulates the portion inherited from Point
  public void someMethod() {
       myDRPoint.x = 2.2 ;
       myDRPoint.y = 7.7 ;
       ...
  }
  ... etc.
}
```

Anything wrong?

Public Fields *Break Code*

- `Point` (without "Accessors"):

```
public class Point {
      public double x, y ;
      public Point () {
        x = 0.0 ;
        y = 0.0 ;
      }
        . . .
   }
```

BAD BAD BAD

Using Accessors

- `Point` (with "Accessors"):

```
public class Point {
    private double x, y ;
    public Point (){
      x = 0.0 ;
      y = 0.0 ;
    }
    public double getX() { return x ; }
    public double getY() { return y ; }
    public void setX (double newX) {
      x = newX ;
    }
    public void setY (double newY) {
      y = newY ;
    }
    // other methods here...
}
```

Good ! Good ! Good ! Good !

Accessors Don’t Solve All Problems

```
/** This new version of the client code shows how requiring the use of accessors
 *  in ALL classes may have fixed ONE problem ... but another still exists
 */

public class SomeClientClass {

   private DualRepPoint myDRPoint ;

   public SomeClientClass() {                   // client constructor
         myDRPoint = new DualRepPoint();        // create a private DualRepPoint
         myDRPoint.setX(2.2) ;         // alter DualRepPoint’s inherited X,Y values
         myDRPoint.setY(7.7) ;         //   using inherited accessors
   }

   .... etc.
}
```

- **Problem still exists!**
- **Solution ?**

DualRepPoint: Correct Version

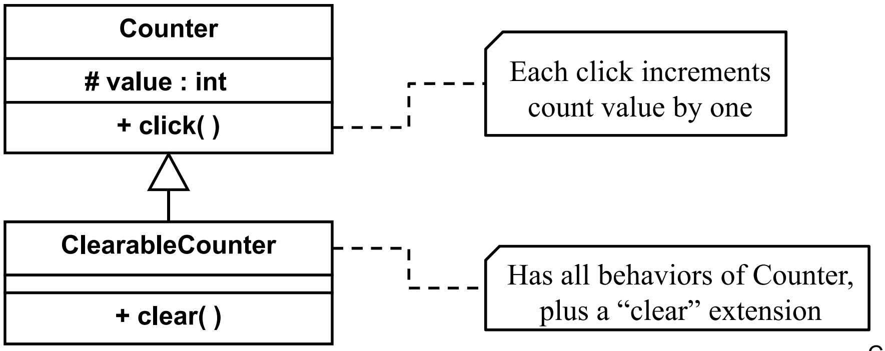
```
public class DualRepPoint extends Point   {   //uses “Good” Point with accessors

   private double radius, angle ;

   //...constructors and accessors for radius and angle here as before ...

   // Override inherited accessors

   public void setX (double xVal) {  //note that overriding the parent accessors
      super.setX(xVal) ;              // makes it impossible for a client to put
      updatePolarValues() ;          // put a DualRepPoint into an inconsistent state
   }

   public void setY (double yVal) {
      super.setY(yVal) ;
      updatePolarValues() ;
   }

   private void updateRectangularValues() {
      super.setX(radius * Math.cos(Math.toRadians(angle))) ;
      super.setY(radius * Math.sin(Math.toRadians(angle))) ;
   }

   //new private method to maintain consistent state
   private void updatePolarValues() {
      double x = super.getX() ;      // note: some people would use protected to
      double y = super.getY() ;      // allow direct subclass access to X & y
      radius = Math.sqrt (x*x + y*y) ;
      angle = MathUtil.atan2 (y,x) ;// in CN1, atan2() is a member of MathUtil class
   }
}
```

Typical Uses for Inheritance

- **Extension**
  - **Define *new behavior,* and**
  - **Retaining existing behaviors**
- **Specialization**
  - **Modify existing behavior(s)**
- **Specification**
  - **Provide ("specify") the implementation details of "abstract" behavior(s)**

Inheritance for Extension

- **Used to *define <u>new</u> behavior***
  - **Retains parent class's behaviors**
- **Example: Counter**
  - **Parent class increments on each "click"**
  - **Extension adds support for "clearing" (resetting)**



Counter

# value : int

+ click( )

Each click increments count value by one

ClearableCounter

+ clear( )

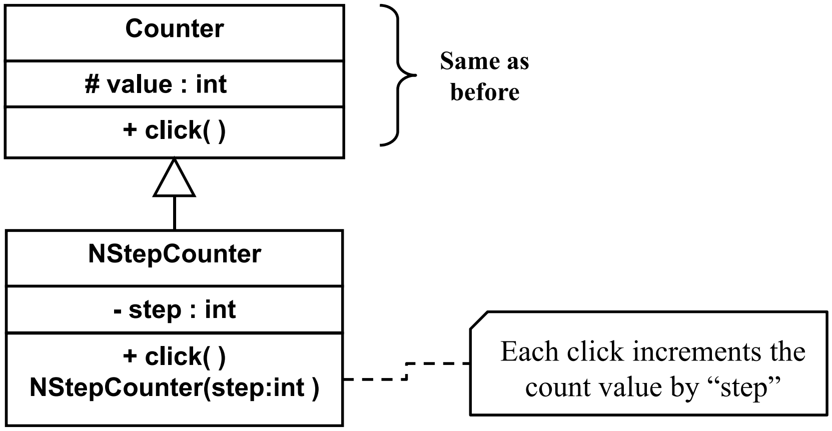
Has all behaviors of Counter, plus a "clear" extension

Inheritance for Extension (cont.)

```
/** This class defines a counter which is incremented on each call to click().
 * The Counter has no ability to be reset.  */
public class Counter {
  protected int value ;

  /** Increment the counter by one. */
  public void click() {
    value = value + 1;
  }
}

/** This class defines a type with all the properties of a Counter, and
 *  which also has a "clear" function to reset the counter to zero. */
public class ClearableCounter extends Counter {

  // Reset the counter value to zero.  Note that this method can
  // access the "value" field in the parent because that field
  //  is defined as "protected".

  public void clear () {
    value = 0 ;
  }
}
```

Inheritance for Specialization

- Used to *modify* ***existing*** *behavior*   (i.e., behavior defined by parent)
- Uses ***overriding*** to change the behavior
- Example: N-Step Counter



Counter

# value : int

+ click( )

Same as before

NStepCounter

- step : int

+ click( )
NStepCounter(step:int)

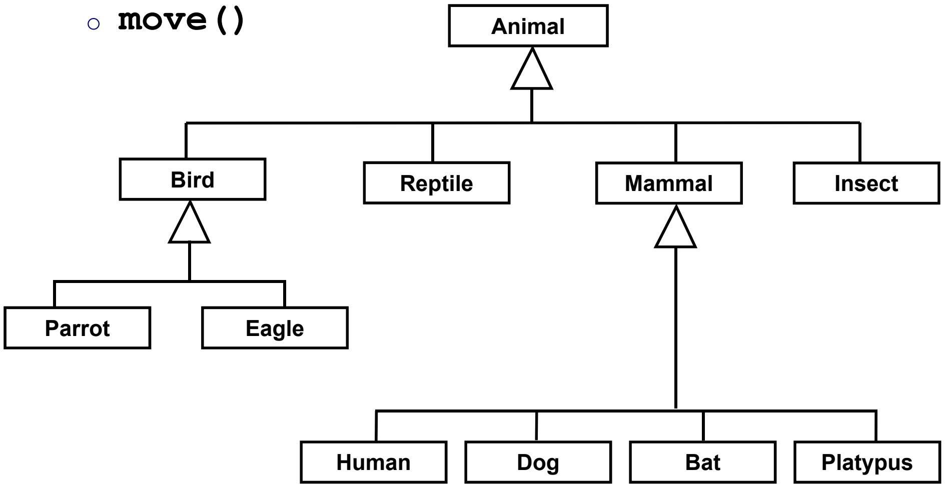
Each click increments the count value by “step”

Inheritance for Specification

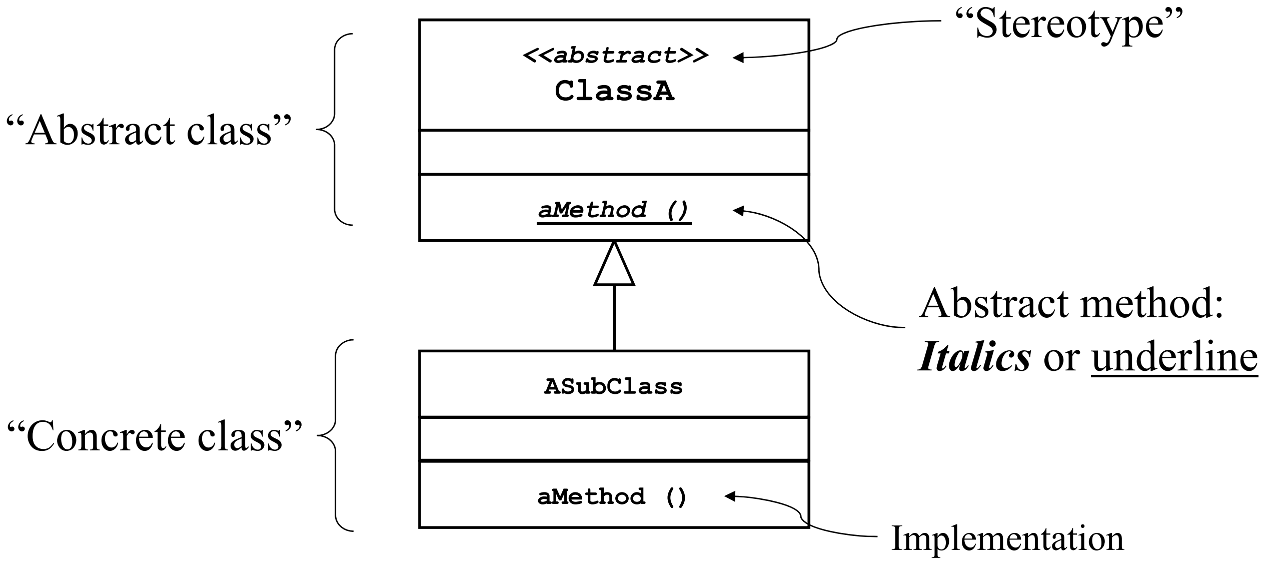
- Used to *specify (define)* behavior *declared* (but not *defined*) by the parent
  - Classes which declare but don't define behavior: Abstract Classes
  - Methods which don't contain implementations: *Abstract methods*

Abstract Classes & Methods

- Some classes will never logically be instantiated
  - `Animal`, `Mammal`, …
- Some methods cannot be "specified" completely at a given class level
  - `move()`

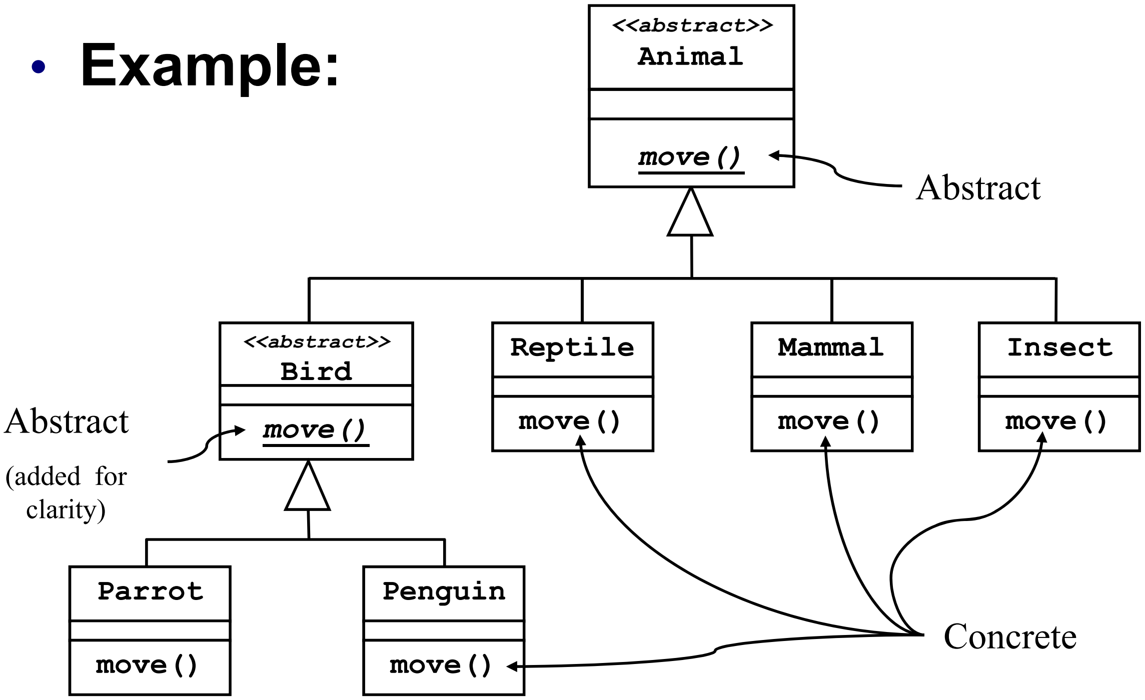


Inheritance for Specification (cont.)



Inheritance for Specification (cont.)

- **Example:**

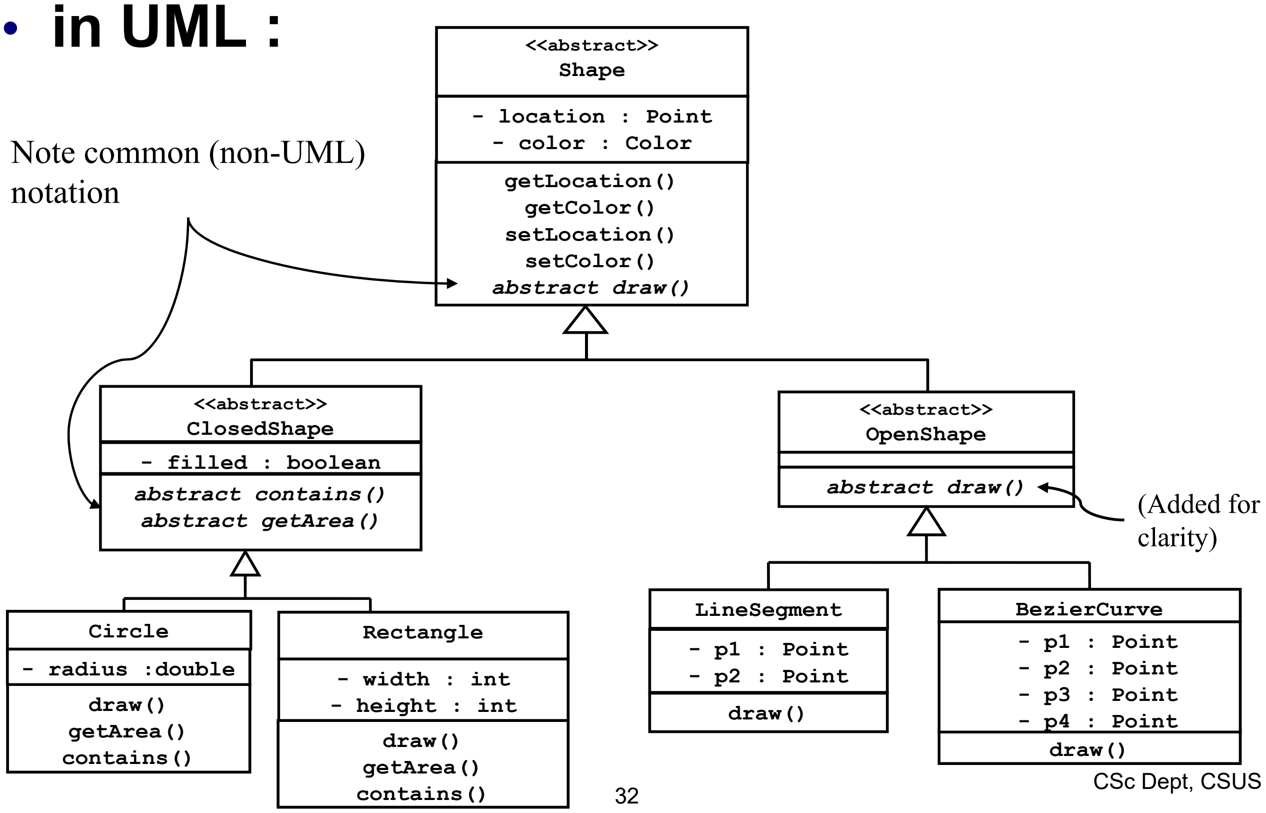


Inheritance for Specification (cont.)

- **Another example: abstract shapes**
  - Different kinds of shapes:
    - `Line    Circle    Rectangle    BezierCurve    ...`
  - Common (shared) characteristics :
    - a “Location”
    - a Color
    - …
  - Common operations (methods) :
    - **`getLocation()`**
    - **`setLocation()`**
    - **`getColor()`**
    - **`setColor()`**
    - **`draw()`** ← Depends on the shape!
    - **`getArea()`** ← Might be undefined!

Inheritance for Specification (cont.)

- **in UML :**



<<abstract>>
Shape
- location : Point
- color : Color
getLocation()
getColor()
setLocation()
setColor()
abstract draw()

<<abstract>>
ClosedShape
- filled : boolean
abstract contains()
abstract getArea()

<<abstract>>
OpenShape
abstract draw()

Circle
- radius :double
draw()
getArea()
contains()

Rectangle
- width : int
- height : int
draw()
getArea()
contains()

LineSegment
- p1 : Point
- p2 : Point
draw()

BezierCurve
- p1 : Point
- p2 : Point
- p3 : Point
- p4 : Point
draw()

Note common (non-UML) notation

(Added for clarity)

Abstract Classes

- Both classes and methods can be declared abstract

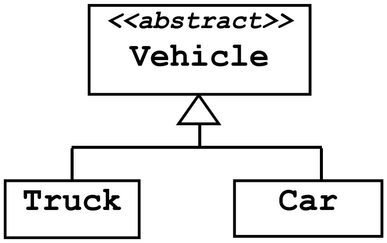
  In Java:

```
public abstract class Animal {
     public abstract void move () ;
}
```

- Abstract classes cannot be instantiated
  - But they can be extended
- If a class contains an abstract method, the class must be declared abstract
  - But abstract classes can also contain concrete methods
- For a subclass to be concrete, it must implement bodies for all inherited abstract methods
  - Otherwise, the subclass is also automatically abstract (and must be declared as such)

Abstract Classes (cont.)

- Can *declare* a variable of abstract type
- Cannot *instantiate* such a variable



```
Vehicle v ;
Truck t = new Truck();
Car c = new Car();
...
v = t ;
...
v = c ;
```

Abstract Classes (cont.)

- **`static`**, **`final`**, and/or **`private`** methods *cannot* be declared abstract
  - No way to override or change them; no way to provide a “specification”
- **`protected`** methods *can* be declared abstract.
- Java “abstract method” = C++ “pure virtual function”:

```
abstract void move () ;          //Java
```

vs.

```
virtual void move() = 0 ;        //C++
```

Example: Abstract Shapes

```
/** This class is the abstract superclass of all "Shapes". Every Shape has a
 * color, a "location" (origin), accessors, and a draw() method.  */
public abstract class Shape {
  private int color;
  private Point location;
  public Shape() {
    color = ColorUtil.rgb(0,0,0);
    location = new Point (0,0);
  }
  public Point getLocation() {
    return location;
  }
  public int getColor() {
    return color;
  }
  public void setLocation (Point newLoc) {
    location = newLoc;
  }
  public void setColor (int newColor) {
    color = newColor;
  }
  public abstract void draw(Graphics g);
}
```

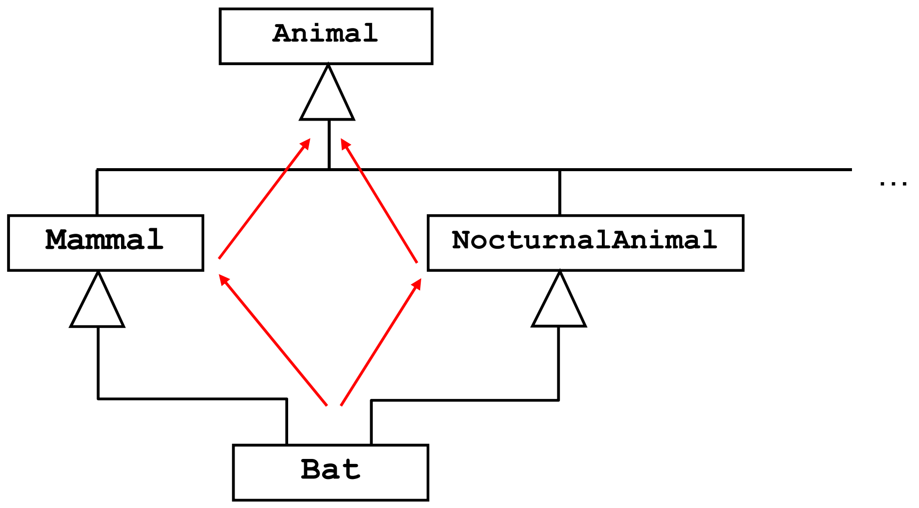
Example: Abstract Shapes (cont.)

```
/** This class defines Shapes which are "closed" - meaning the Shape has a
 *  boundary which delineates "inside" from "outside".  Closed Shapes can either be
 *  "filled" (solid) or "not filled"  (interior is empty). Every ClosedShape must
 *  have a method "contains(Point)", which determines whether a given Point is inside
 *  the shape or not, and a method "getArea()" which returns the area inside the shape.
 */
public abstract class ClosedShape extends Shape {
  private boolean filled;          // attribute common to all closed shapes
  public ClosedShape() {
    //automatically calls super() - no-arg constructor of its parent (Shape)
    filled = false;
  }
  public ClosedShape(boolean filled) {
    //automatically calls super() - no-arg constructor of its parent (Shape)
    this.filled = filled;
  }
  public boolean isFilled() {
    return filled;
  }
  public void setIsFilled(boolean filled) {
    this.filled = filled;
  }
  public abstract boolean contains(Point p);
  public abstract double getArea();
}
```

Example: Abstract Shapes (cont.)

```
/** This class defines closed shapes which are rectangles. */
public class Rectangle extends ClosedShape {
  private int width;
  private int height;
  public Rectangle() {
    super(true);  //no-arg constructor of its parent (ClosedShape) is not called
    width = 2;
    height = 1;
  }
  public boolean contains(Point p) {
    //... code here to return true if p lies inside this rectangle,
    //    or return false if not.
  }
  public double getArea() {
    return (double) (width * height) ;
  }
  public void draw (Graphics g) {
    if (isFilled()) {
      //  code here to draw a filled (solid) rectangle using
      //  Graphics object "g"
    } else {
      //  code here to draw an empty rectangle using
      //  Graphics object "g"
    }
  }
}
```

Multiple Inheritance



A possible alternative Animal Hierarchy

Multiple Inheritance (cont.)

- C++ allows multiple inheritance:

```
class Animal{...};

class Mammal : Animal {
  public : void sleep() {...} ;
   ...
};

class NocturnalAnimal : Animal {
  public : void sleep() {...} ;
   ...
};

class Bat : Mammal, NocturnalAnimal {...};
```

- Programmer must disambiguate references:

```
void main (int argc, char** argv) {
  Bat aBat;
  aBat.NocturnalAnimal::sleep();
}
```