BBM 102 – Introduction to Programming II

Spring 2018

Polymorphism

Today

- Inheritance revisited
- Comparing objects : `equals()` method
- `instanceof` keyword
- Polymorphism

Visibility Revisited

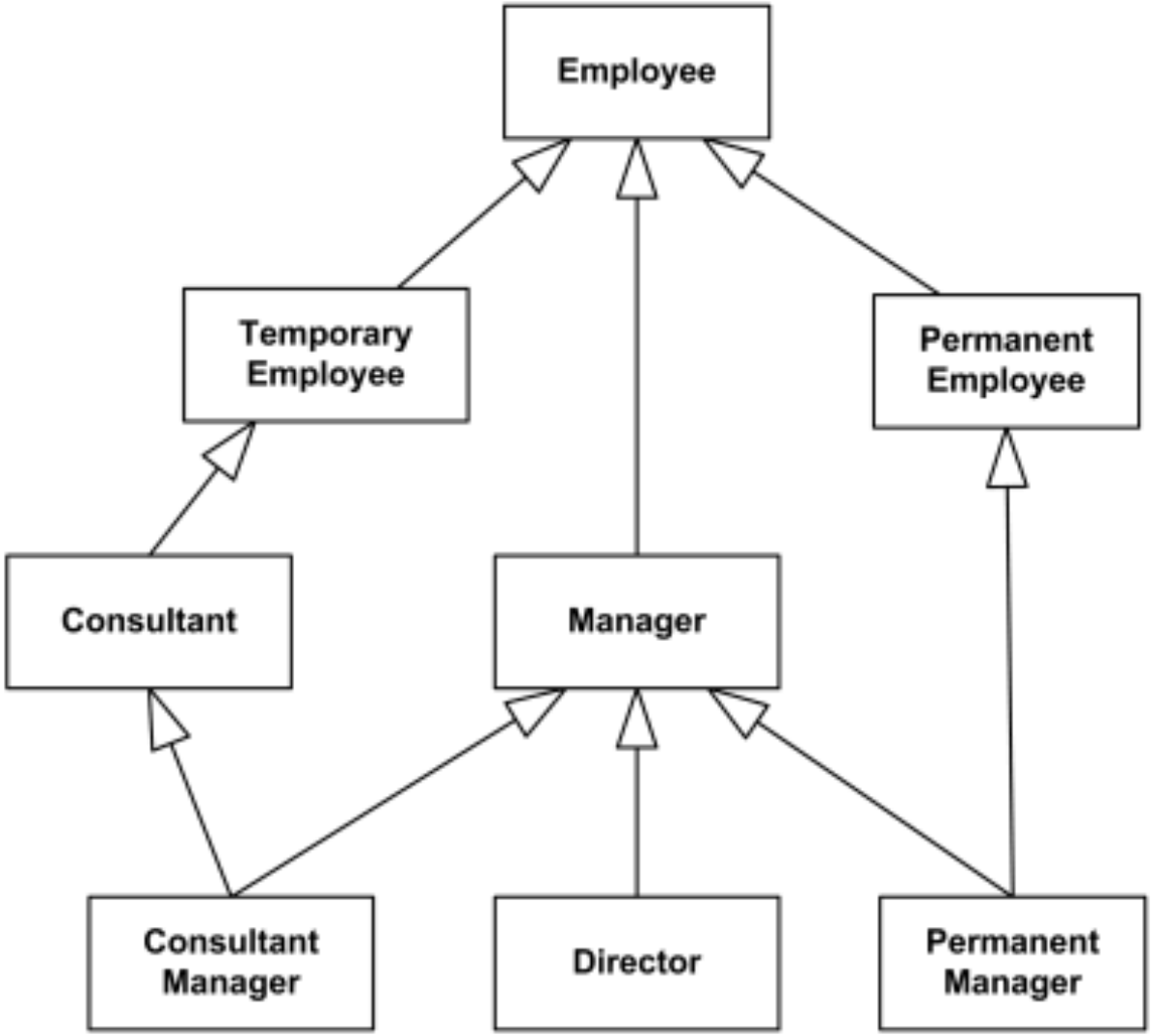
- All variables and methods of a parent class, even private members, are inherited by its children
- As we've mentioned, private members cannot be referenced by name in the child class
- However, private members inherited by child classes exist and can be referenced indirectly
  - Because the parent can refer to the private member, the child can reference it indirectly using its parent's methods
  - The `super` reference can be used to refer to the parent class, even if no object of the parent class exists

Inheritance Design Issues

- Every derivation from the main class should be an is-a relationship
- Think about a potential future class hierarchy
- Design classes to be reusable and flexible
- Find common characteristics of classes and push them as high in the class hierarchy as appropriate, i.e. "generalize" the behavior
- Override methods as appropriate to tailor or change the functionality of a child
- Add new variables to children, but don't redefine (shadow) inherited variables

Inheritance Design Issues

- An example class hierarchy



More generalized

More specialized

Inheritance Design Issues

- Allow each class to manage its own data; use the `super` reference to invoke the parent's constructor to set up its data
- Even if there are no current uses for them, override general methods such as `toString` and `equals` with appropriate definitions
- Use abstract classes to represent general concepts that lower classes have in common
- Use visibility modifiers carefully to provide needed access without violating encapsulation

Restricting Inheritance

- The `final` modifier can be used to cut down inheritance
  - If the `final` modifier is applied to a method, then that method cannot be overridden in any descendent classes
  - If the `final` modifier is applied to an entire class, then that class cannot be used to derive any children at all
- These are key design decisions and establish that a method or class must be used “as is” or not at all

Restricting Inheritance

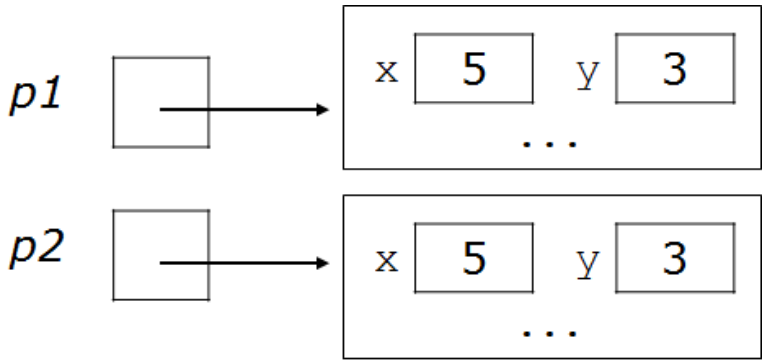
- Example of the `final` modifier

```
public class Base
{
    public       void m1() {...}
    public final void m2() {...}
}
public class Derived extends Base
{
    public void m1() {...}  // OK, overriding Base#m1()
    public void m2() {...}  // forbidden
}
```

Comparing objects

- The == operator does not work well with objects.
  - == compares references to objects, not their contents or state.
  - Example:

```
Point p1 = new Point(5, 3);
Point p2 = new Point(5, 3);
if (p1 == p2) {    // false
    System.out.println("equal");
}
```



The `equals()` method

- The `equals` method compares the contents / state of objects.
  - `equals` should be used when comparing `String`s, `Point`s, …

```
if (str1.equals(str2)) {
    System.out.println("the strings are equal");
}
```

- If you write your own class, its `equals` method will behave just like the `==` operator.

```
Point p1 = new Point(5, 3);
Point p2 = new Point(5, 3);
if (p1.equals(p2)) {   // false
    System.out.println("equal");
}
```

  - This is the behavior we inherit from class `Object`.

Initial flawed `equals()` method

- We can change this behavior by writing an `equals` method.
  - Ours will *override* the default behavior from class Object.
  - The method should compare the state of the two objects and return `true` for cases like the above.

- A flawed implementation of the `equals` method:

```
public boolean equals(Point other) {
    if (x == other.x && y == other.y) {
        return true;
    } else {
        return false;
    }
}
```

Flaws in `equals()` method

- It should be legal to compare a `Point` to any object (not just other `Point` objects):

```
// this should be allowed
Point p = new Point(7, 2);
if (p.equals("hello")) {   // false
    ...
```

  - `equals` should always return false if a non-`Point` is passed.

`equals()` and the Object class

- `equals()` method, general syntax:

```
public boolean equals(Object <name>) {
    <statement(s) that return a boolean value> ;
}
```

  - The parameter to `equals` must be of type `Object`.
  - `Object` is a general type that can match any object.
  - Having an `Object` parameter means *any* object can be passed.

Another flawed version

- Another flawed `equals` implementation:

```
public boolean equals(Object o) {
    return x == o.x && y == o.y;
}
```

- It does not compile:

```
Point.java:36: cannot find symbol
symbol  : variable x
location: class java.lang.Object
return x == o.x && y == o.y;
            ^
```

  - The compiler is saying,
    "`o` could be any object. Not every object has an `x` field."

Type-casting objects

- Solution: *Type-cast* the object parameter to a `Point`.

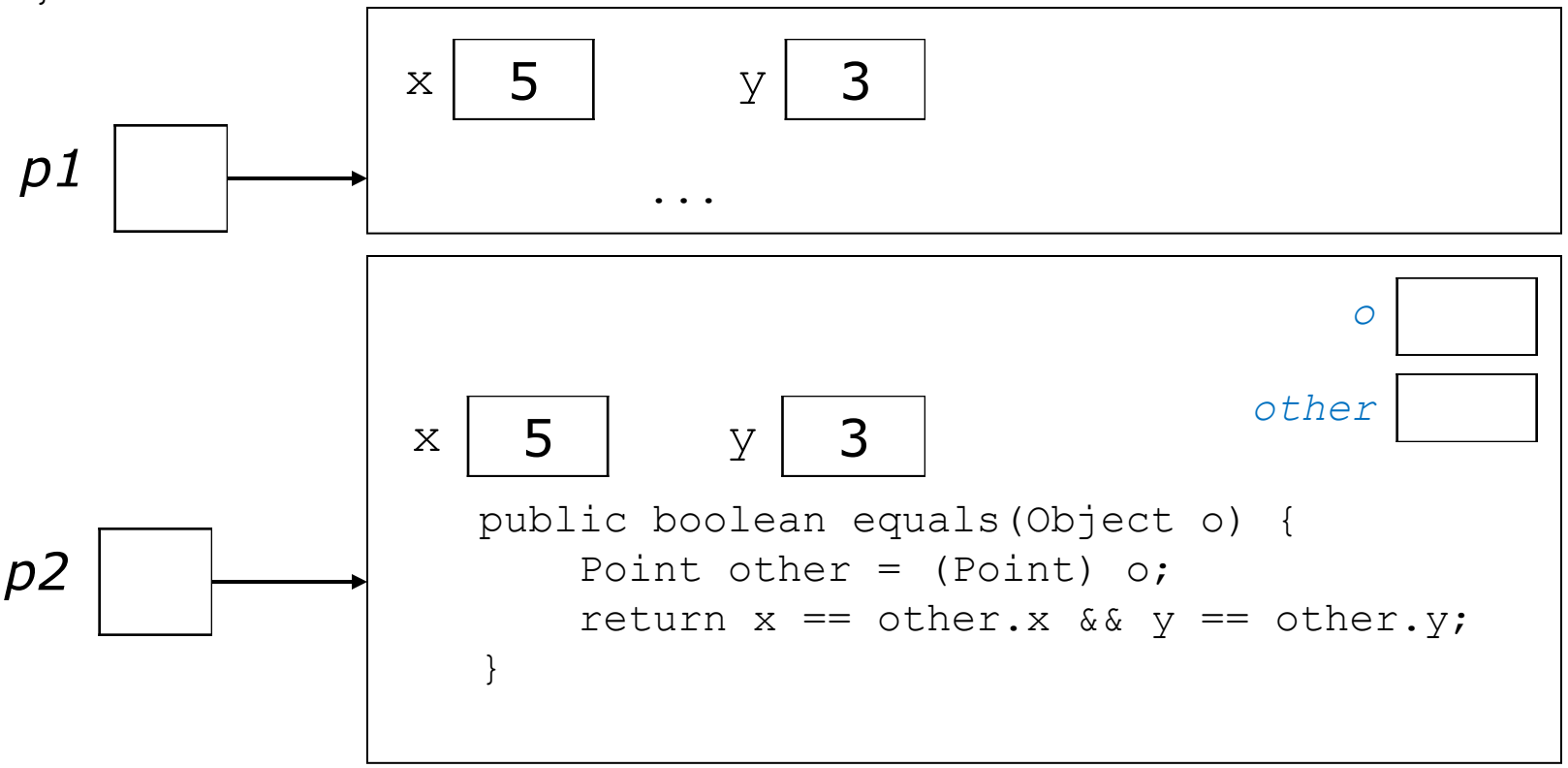
```
public boolean equals(Object o) {
    Point other = (Point) o;
    return x == other.x && y == other.y;
}
```

- Casting objects is different than casting primitives.
  - We're really casting an `Object` reference into a `Point` reference.
  - We're promising the compiler that `o` refers to a `Point` object.

Casting objects diagram

- Client code:

```
Point p1 = new Point(5, 3);
Point p2 = new Point(5, 3);
if (p1.equals(p2)) {
    System.out.println("equal");
}
```



Comparing different types

- When we compare `Point` objects to other types:

```
Point p = new Point(7, 2);
if (p.equals("hello")) {   // should be false
    ...
}
```

  - Currently the code crashes:

```
Exception in thread "main"
java.lang.ClassCastException: java.lang.String
        at Point.equals(Point.java:25)
        at PointMain.main(PointMain.java:25)
```

  - The culprit is the line with the type-cast:

```
public boolean equals(Object o) {
    Point other = (Point) o;
```

The `instanceof` keyword

- We can use a keyword called `instanceof` to ask whether a variable refers to an object of a given type.

- The `instanceof` keyword, general syntax:

  <variable> `instanceof` ***<type>***

  - The above is a `boolean` expression.

  - Example:

```
String s = "hello";
Point p = new Point();
```

expression	result
`s instanceof Point`	`false`
`s instanceof String`	`true`
`p instanceof Point`	`true`
`p instanceof String`	`false`
`null instanceof String`	`false`

Final version of `equals` method

```
// Returns whether o refers to a Point object with
// the same (x, y) coordinates as this Point object.
public boolean equals(Object o) {
    if (o instanceof Point) {
        // o is a Point; cast and compare it
        Point other = (Point) o;
        return x == other.x && y == other.y;
    } else {
        // o is not a Point; cannot be equal
        return false;
    }
}
```

- This version correctly compares `Points` to any type of object.

Polymorphism

Polymorphism

- Polymorphism means *many* (poly) *shapes* (morph) : "having many forms"

- Enables you to “program in the general” rather than “program in the specific.”

- Polymorphism enables you to write programs that process objects that share the same superclass as if they’re all objects of the superclass; this can simplify programming.

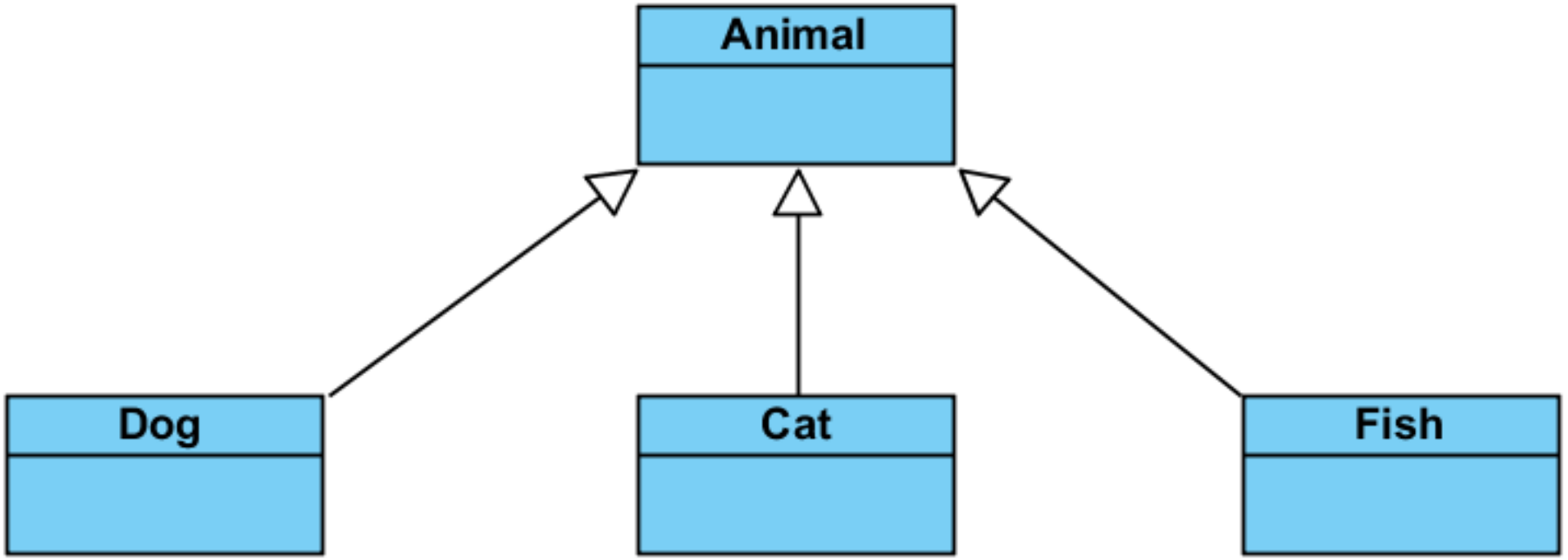
Polymorphism

- A *polymorphic reference* is a variable that can refer to different types of objects at different points in time

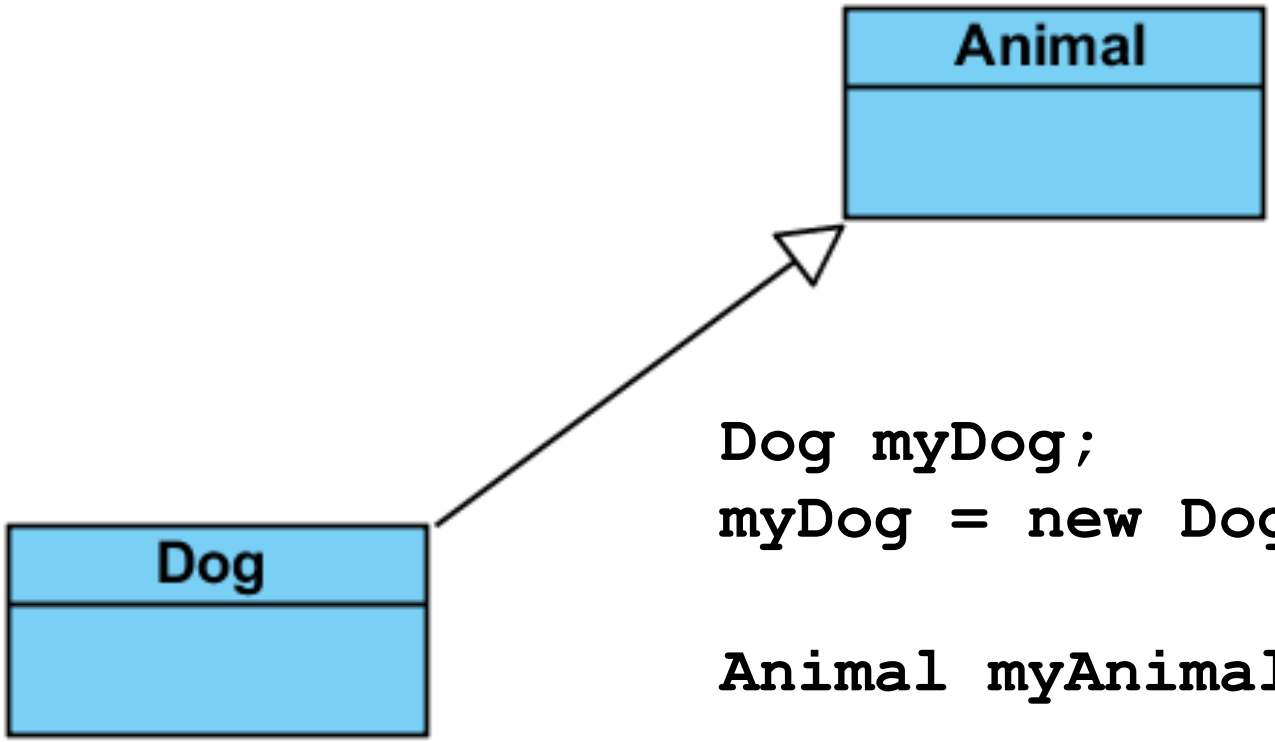
- All object references in Java are potentially polymorphic and can refer to an object of any type compatible with its defined type

- Compatibility of class types can be based on either Inheritance or Interfaces (which we will see later)

An Example Class Hierarchy



A Polymorphic Example



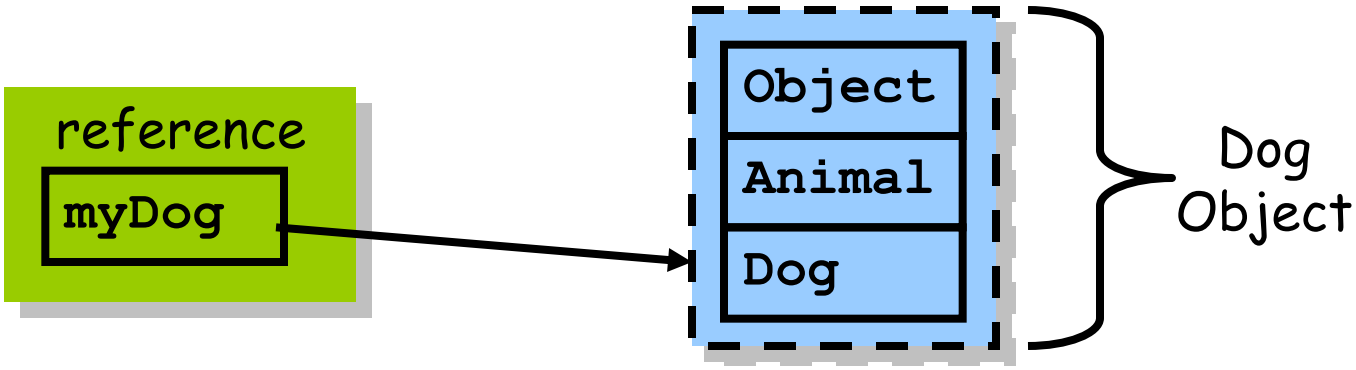

```
Dog myDog;
myDog = new Dog();

Animal myAnimal;

myAnimal = myDog;
```

Everything is an Object!

- When we say:

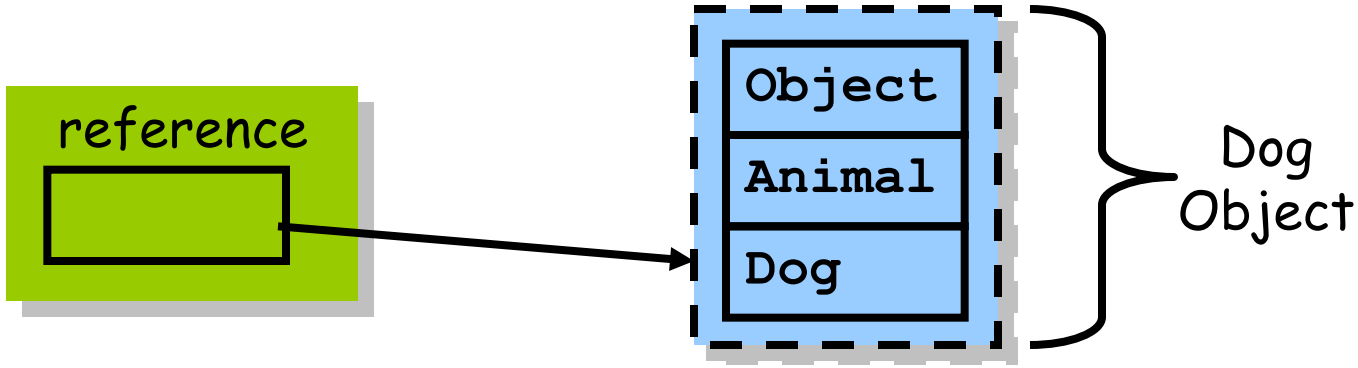
  myDog = new Dog();

- the Dog constructor gets called.
- It, in turn, must call the Animal constructor
- When you don't extend anything, by default you extend Object
- Thus the Animal constructor calls the Object constructor
- Looking at an object in memory it will look like something like this:



Polymorphism Explained

- The rule is very simple
- A reference can refer to an object which is either
  - The same type as the reference
  - Has a superclass of the same type as the reference
- So all of the following are legal
  - Dog d = new Dog();
  - Animal a = new Animal();
  - Object o = new Object();



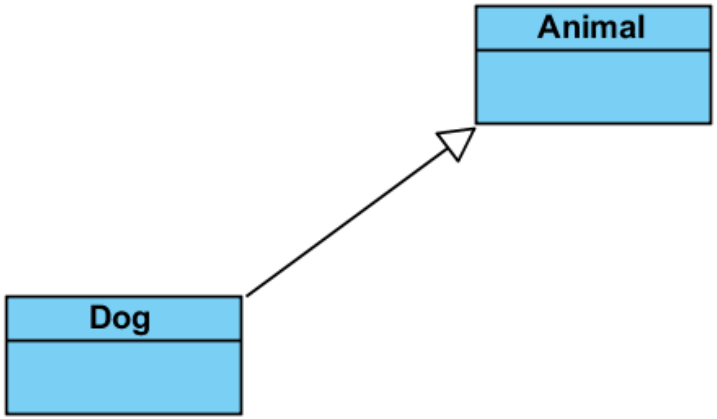
An Illegal Example

- We are able to assign an object of a sub-class into an object of a super-class as in:

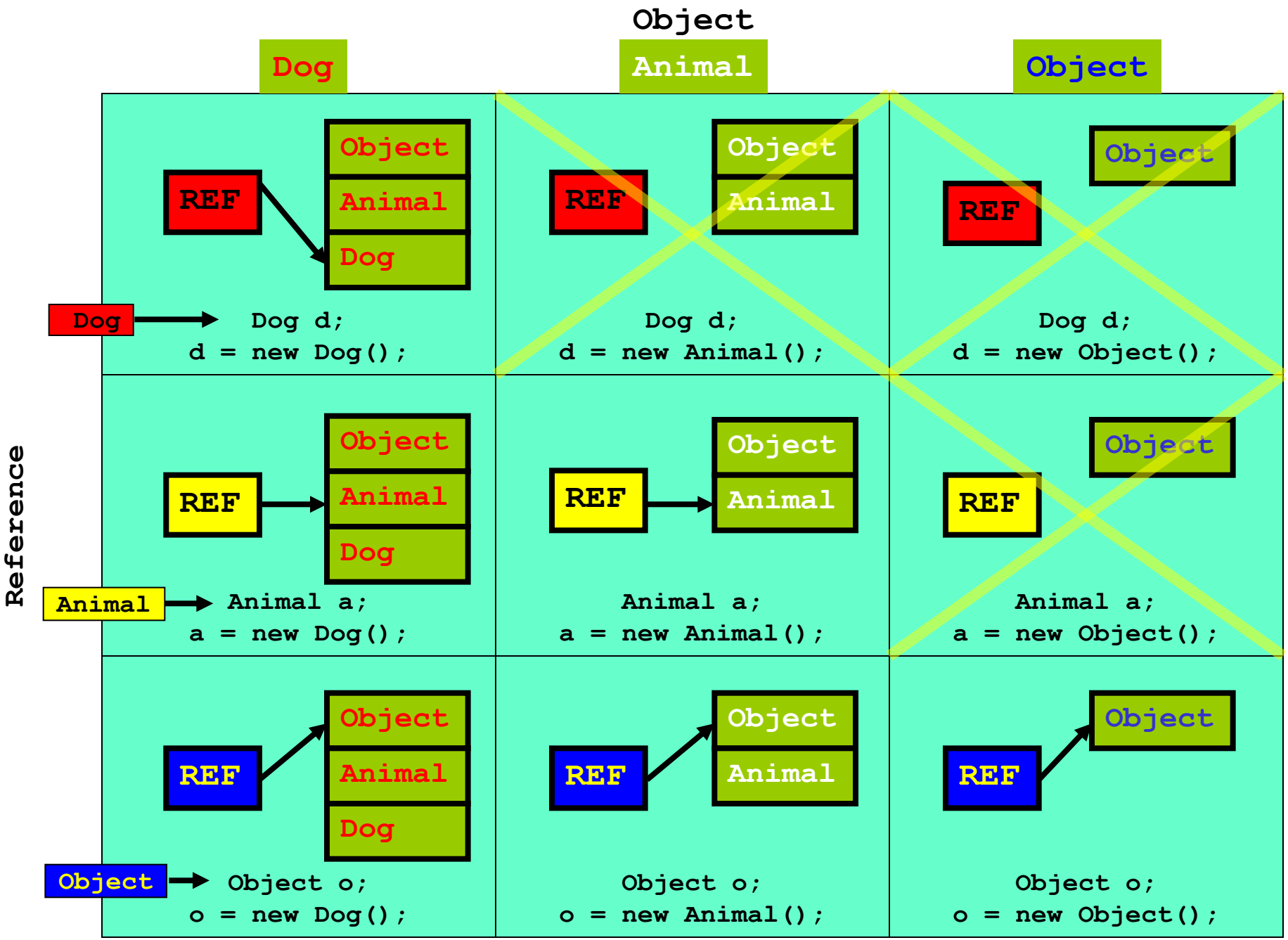
  Animal MyAnimal = new Dog();

- But the reverse is not true. We can't assign a superclass object into a sub-class object.

  Dog MyDog = new Animal(); // illegal



All dogs are animals but not all animals are dogs

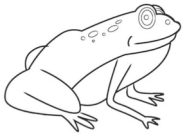

Object
Dog
Animal
Object
Reference
REF
Object
Animal
Dog
Dog
Dog d;
d = new Dog();
Dog d;
d = new Animal();
Dog d;
d = new Object();
Animal
Animal a;
a = new Dog();
Animal a;
a = new Animal();
Animal a;
a = new Object();
Object
Object o;
o = new Dog();
Object o;
o = new Animal();
Object o;
o = new Object();

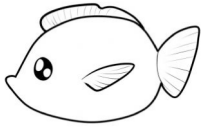
Polymorphism Examples

- **Example:** Suppose we create a program that simulates the movement of several types of animals for a biological study. Classes Fish, Frog and Bird represent the three types of animals under investigation.
  - Each class extends superclass Animal, which contains a method move and maintains an animal's current location as x-y coordinates. Each subclass implements method move.
  - A program maintains an Animal array containing references to objects of the various Animal subclasses. To simulate the animals' movements, the program sends each object the same message once per second—namely, move.

Polymorphism Examples

- Each specific type of Animal responds to a move message in a unique way:
  - a Fish might swim three meters
  - a Frog might jump five meters
  - a Bird might fly ten meters.





- The program issues the same message (i.e., move) to each animal object, but each object knows how to modify its x-y coordinates appropriately for its specific type of movement.
- Relying on each object to know how to "do the right thing" in response to the same method call is the key concept of polymorphism.
- The same message sent to a variety of objects has "many forms" of results—hence the term *polymorphism*.

Polymorphism Examples (Cont.)

- **Example**: Space Objects in a Video Game
  - A video game manipulates objects of classes Martian, Venusian, Plutonian, SpaceShip and LaserBeam. Each inherits from SpaceObject and overrides its draw method.
  - A screen manager maintains a collection of references to objects of the various classes and periodically sends each object the same message—namely, draw.
  - Each object responds in a unique way.
    - A Martian object might draw itself in red with green eyes and the appropriate number of antennae.
    - A SpaceShip object might draw itself as a bright silver flying saucer.
    - A LaserBeam object might draw itself as a bright red beam across the screen.

The same message (in this case, draw) sent to a variety of objects has "many forms" of results.

Polymorphism Examples (Cont.)

- A screen manager might use polymorphism to facilitate adding new classes to a system with minimal modifications to the system's code.

- To add new objects to our video game:

  - Build a class that extends SpaceObject and provides its own draw method implementation.
  - When objects of that class appear in the SpaceObject collection, the screen manager code invokes method draw, exactly as it does for every other object in the collection, regardless of its type.
  - So the new objects simply "plug right in" without any modification of the screen manager code by the programmer.

Demonstrating Polymorphic Behavior

- A superclass object cannot be treated as a subclass object, because a superclass object is *not* an object of any of its subclasses.
- The *is-a* relationship applies only up the hierarchy from a subclass to its direct (and indirect) superclasses, and not down the hierarchy.
- The Java compiler *does* allow the assignment of a superclass reference to a subclass variable if you explicitly cast the superclass reference to the subclass type
  - A technique known as downcasting that enables a program to invoke subclass methods that are not in the superclass.

Demonstrating Polymorphic Behavior (Cont.)

- When a superclass variable contains a reference to a subclass object, and that reference is used to call a method, the subclass version of the method is called.
  - The Java compiler allows this "crossover" because an object of a subclass *is an object of its superclass (but not vice versa).*
- When the compiler encounters a method call made through a variable, the compiler determines if the method can be called by checking the variable's class type.
  - If that class contains the proper method declaration (or inherits one), the call is compiled.
- At execution time, the type of the object to which the variable refers determines the actual method to use.
  - This process is called *dynamic binding*.

Method Calls and Polymorphism

Assume the Dog class extends the Animal class, redefining the "makeNoise" method.

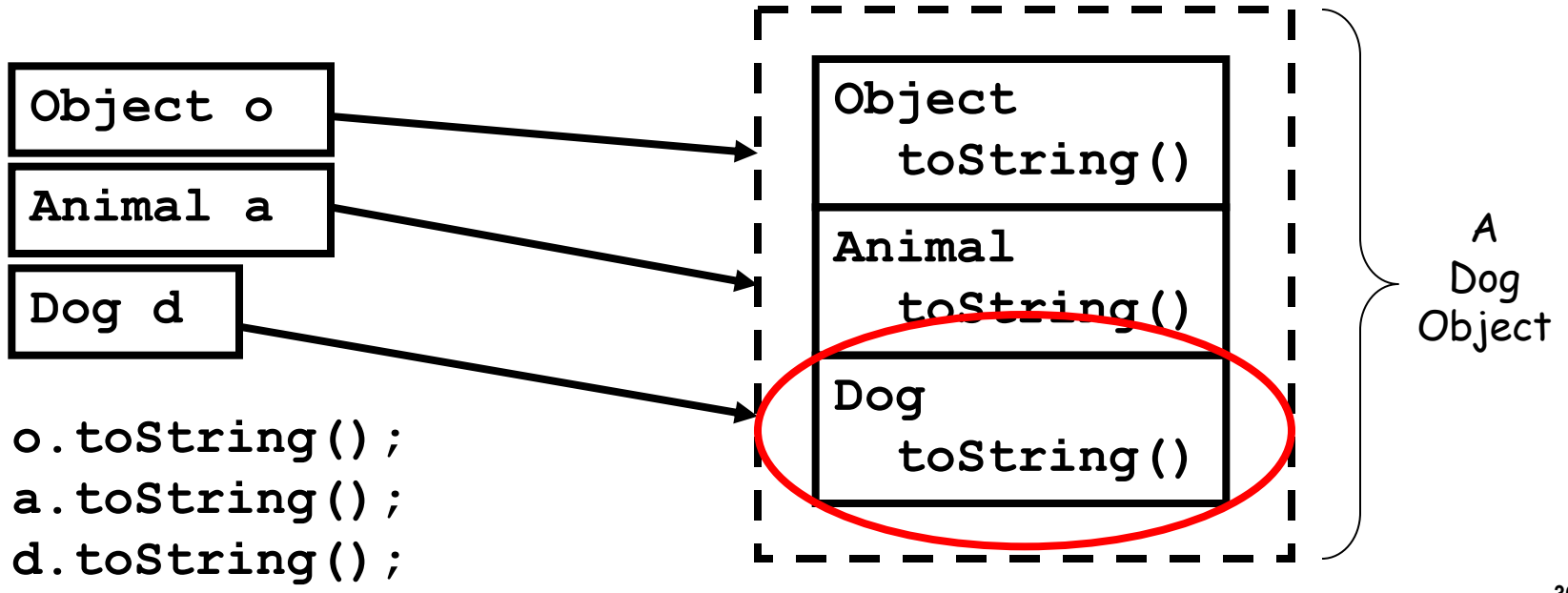
Consider the following:

```
Animal myAnimal = new Dog();
myAnimal.makeNoise();
```

Note: The Animal reference is referring to a Dog object. And it is the Dog's makeNoise method that gets invoked!

Dynamic Binding

- Very simple rule.
  - No matter what the reference type is, Java will search the object and execute the lowest occurrence of a method it finds.
- class Object has a toString method
- Assume that both Animal and Dog have overridden the toString method



Polymorphism

- With polymorphism, we can design and implement systems that are easily extensible

- New classes can be added with little or no modification to the general portions of the program, as long as the new classes are part of the inheritance hierarchy.

- The only parts of a program that must be altered for new classes are those that require direct knowledge of the new classes.

Polymorphism

- A variable of a type T can legally refer to an object of any subclass of T.

```
Employee person = new Lawyer();
System.out.println(person.getSalary());         // 50000.0
System.out.println(person.getVacationForm());   // pink
```

- You can call any methods from `Employee` on the variable `person`, but not any methods specific to `Lawyer` (such as `Sue`).

- Once a method is called on the object, it behaves in its normal way (as a `Lawyer`, not as a normal `Employee`).

Polymorphism + parameters

- You can declare methods to accept superclass types as parameters, then pass a parameter of any subtype.

```
public class EmployeeMain {
        public static void main(String[] args) {
            Lawyer lisa = new Lawyer();
            Secretary steve = new Secretary();
            printInfo(lisa);
            printInfo(steve);
        }

        public static void printInfo(Employee empl) {
            System.out.println("salary = " + empl.getSalary());
            System.out.println("days = " + empl.getVacationDays());
            System.out.println("form = " + empl.getVacationForm());
            System.out.println();
        }
    }
```

OUTPUT:

```
salary = 50000.0
vacation days = 21
vacation form = pink

salary = 50000.0
vacation days = 10
vacation form = yellow
```

- You can declare arrays of superclass types, and store objects of any subtype as elements.

```
public class EmployeeMain2 {
        public static void main(String[] args) {
            Employee[] employees = {new Lawyer(), new Secretary(),
                    new Marketer(), new LegalSecretary()};

            for (int i = 0; i < employees.length; i++) {
                System.out.println("salary = " +
                                   employees[i].getSalary());
                System.out.println("vacation days = " +
                                   employees[i].getVacationDays());
                System.out.println();
            }
        }
    }
```

OUTPUT:

```
salary = 50000.0
vacation days = 15

salary = 50000.0
vacation days = 10

salary = 60000.0
vacation days = 10

salary = 55000.0
vacation days = 10
```

Polymorphism vs. Inheritance

- Inheritance is required in order to achieve polymorphism (we must have class hierarchies).
  - Re-using class definitions via extension and redefinition
- Polymorphism is not required in order to achieve inheritance.
  - An object of class A acts as an object of class B (an ancestor to A).

References and Inheritance

- Assigning a child object to a parent reference is considered to be a *widening conversion*, and can be performed by simple assignment
  - The widening conversion is the most useful

- Assigning a parent object to a child reference can be done, but it is considered a *narrowing conversion* and two rules/guidelines apply:
  - A narrowing conversion must be done with a cast
  - A narrowing conversion should only be used to restore an object back to its original class (back to what it was "born as" with the new operator)

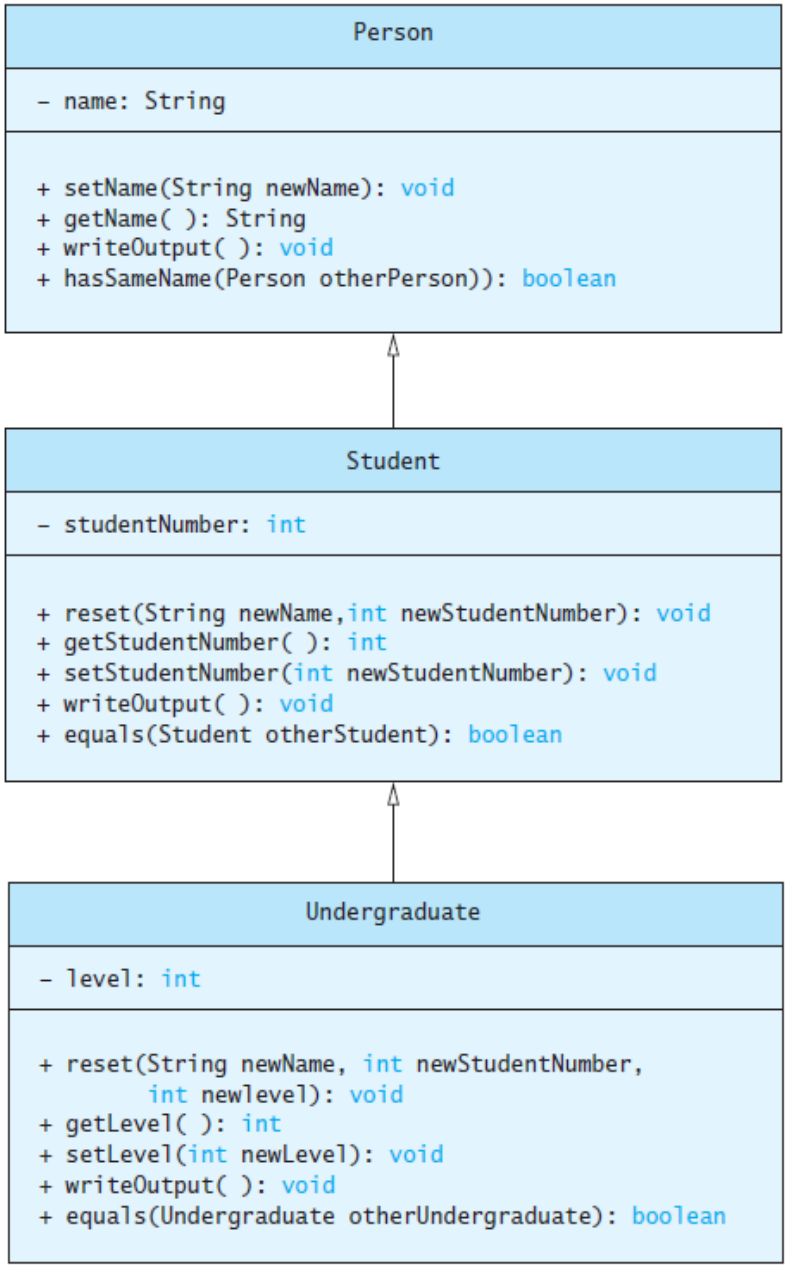
Polymorphism Example

- Consider an array of **Person**

```
Person[] people = new Person[4];
```

- Since **Student** and **Undergraduate** are types of **Person**, we can assign them to **Person** variables

```
people[0] = new Student("DeBanque,
Robin", 8812);

people[1] = new
Undergraduate("Cotty, Manny",
8812, 1);
```



Example

- Given:

```
Person[] people = new Person[4];
people[0] = new Student("DeBanque, Robin", 8812);
```

- When invoking:

```
people[0].writeOutput();
```

- Which **`writeOutput()`** is invoked, the one defined for **`Student`** or the one defined for **`Person`**?

- Answer: The one defined for **`Student`**

Example

```
public class PolymorphismDemo
{
    public static void main(String[] args) {
       Person[] people = new Person[4];
       people[0] = new Undergraduate("Cotty, Manny", 4910, 1);
       people[1] = new Undergraduate("Kick, Anita", 9931, 2);
       people[2] = new Student("DeBanque, Robin", 8812);
       people[3] = new Undergraduate("Bugg, June", 9901, 4);

       for (Person p : people)
       {
          p.writeOutput();
          System.out.println();
       }
    }
}
```

```
Name: Cotty, Manny
Student Number: 4910
Student Level: 1

Name: Kick, Anita
Student Number: 9931
Student Level: 2

Name: DeBanque, Robin
Student Number: 8812

Name: Bugg, June
Student Number: 9901
Student Level: 4
```

A polymorphism problem

- Assume that the following four classes have been declared:

```
public class Foo {
    public void method1() {
        System.out.println("foo 1");
    }

    public void method2() {
        System.out.println("foo 2");
    }

    public String toString() {
        return "foo";
    }
}
```

(continued on next slide)

A polymorphism problem (cont'd)

```
public class Bar extends Foo {
    public void method2() {
        System.out.println("bar 2");
    }
}

public class Baz extends Foo {
    public void method1() {
        System.out.println("baz 1");
    }

    public String toString() {
        return "baz";
    }
}

public class Mumble extends Baz {
    public void method2() {
        System.out.println("mumble 2");
    }
}
```

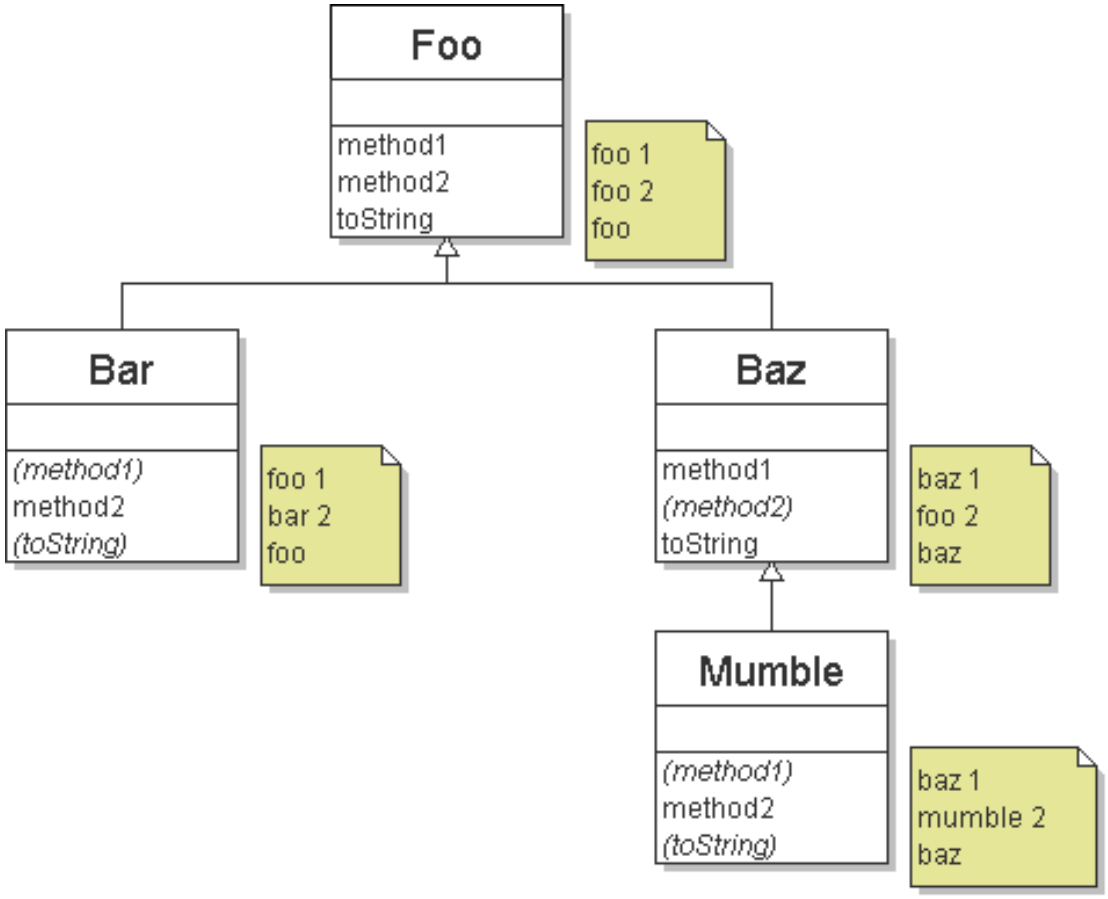
A polymorphism problem (cont'd)

- What would be the output of the following client code?

```
Foo[] pity = {new Baz(), new Bar(), new Mumble(), new Foo()};
for (int i = 0; i < pity.length; i++) {
    System.out.println(pity[i]);
    pity[i].method1();
    pity[i].method2();
    System.out.println();
}
```

Finding output with diagrams

- One way to determine the output is to diagram each class and its methods, including their output:
  - Add the classes from top (superclass) to bottom (subclass).
  - Include any inherited methods and their output.



Finding output with tables

- Another possible technique for solving these problems is to make a table of the classes and methods, writing the output in each square.

method	Foo	Bar	Baz	Mumble
`method1`	`foo 1`	*`foo 1`*	`baz 1`	*`baz 1`*
`method2`	`foo 2`	`bar 2`	*`foo 2`*	`mumble 2`
`toString`	`foo`	*`foo`*	`baz`	*`baz`*

Polymorphism answer

```
Foo[] pity = {new Baz(), new Bar(), new Mumble(), new Foo()};
for (int i = 0; i < pity.length; i++) {
    System.out.println(pity[i]);
    pity[i].method1();
    pity[i].method2();
    System.out.println();
}
```

Output:

```
baz
baz 1
foo 2

foo
foo 1
bar 2

baz
baz 1
mumble 2

foo
foo 1
foo 2
```

Another problem

- Assume that the following classes have been declared:
  - The order of classes is changed, as well as the client.
  - The methods now sometimes call other methods.

```
public class Lamb extends Ham {
    public void b() {
        System.out.print("Lamb b   ");
    }
}
public class Ham {
    public void a() {
        System.out.print("Ham a   ");
        b();
    }
    public void b() {
        System.out.print("Ham b   ");
    }
    public String toString() {
        return "Ham";
    }
}
```

(continued on next slide)

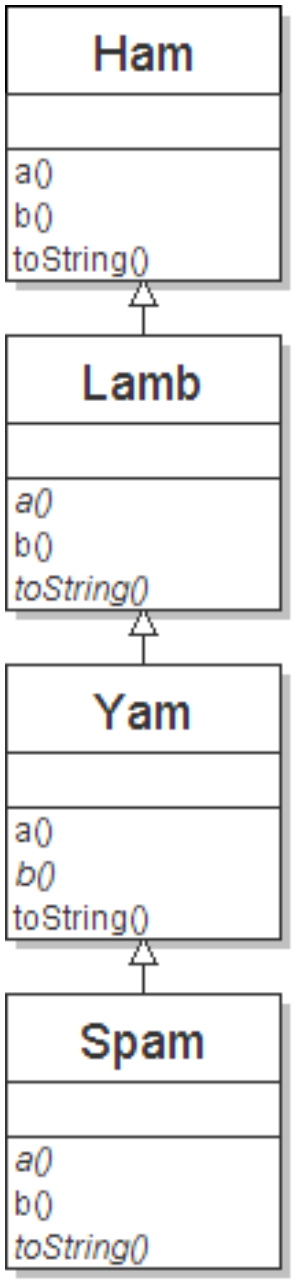
```
public class Spam extends Yam {
    public void b() {
        System.out.print("Spam b   ");
    }
}

public class Yam extends Lamb {
    public void a() {
        System.out.print("Yam a   ");
        super.a();
    }

    public String toString() {
        return "Yam";
    }
}
```

- What would be the output of the following client code?

```
Ham[] food = {new Spam(), new Yam(), new Ham(), new Lamb()};
for (int i = 0; i < food.length; i++) {
    System.out.println(food[i]);
    food[i].a();
    System.out.println();     // to end the line of output
    food[i].b();
    System.out.println();     // to end the line of output
    System.out.println();
}
```

The class diagram

- The following diagram depicts the class hierarchy:



- Notice that Ham's a method calls b. Lamb overrides b.
  - This means that calling a on a Lamb will also have a new result.

```
public class Ham {
    public void a() {
        System.out.print("Ham a   ");
        b();
    }
    public void b() {
        System.out.print("Ham b   ");
    }
    public String toString() {
        return "Ham";
    }
}
public class Lamb extends Ham {
    public void b() {
        System.out.print("Lamb b   ");
    }
}
```

Polymorphism at work!

- Lamb 's a output: `Ham a    Lamb b`

The table

- Fill out the following table with each class's behavior:

method	Ham	Lamb	Yam	Spam
`a`				
`b`				
`toString`				

The answer

```
Ham[] food = {new Spam(), new Yam(), new Ham(), new Lamb()};
for (int i = 0; i < food.length; i++) {
    System.out.println(food[i]);
    food[i].a();
    food[i].b();
    System.out.println();
}
```

Output:

```
Yam
Yam a   Ham a   Spam b
Spam b

Yam
Yam a   Ham a   Lamb b
Lamb b

Ham
Ham a   Ham b
Ham b

Ham
Ham a   Lamb b
Lamb b
```

Acknowledgments

- The course material used to prepare this presentation is mostly taken/adopted from the list below:
  - Java - How to Program, Paul Deitel and Harvey Deitel, Prentice Hall, 2012
  - Java - An Introduction to Problem Solving and Programming, Walter Savitch, Pearson, 2012
  - Reges/Stepp. *Building Java Programs: A Back to Basics Approach, 3rd edition*
  - Mike Scott, CS314 Course notes, University of Texas Austin