Lecture Set #19: Inheritance

Inheritance
- Conceptual
- Is-A relationship compared to contains-a
- Terminology
- Overloading compared to Overriding
- super
- isInstanceOf and getClass()

Inheritance

- A crucial feature of object-oriented programming languages
  - One class (derived class, subclass) is constructed …
  - … by including (extending, inheriting) information …
  - … from another (base class, superclass, parent class) …
  - … and adding new information / redefining existing
- Example
  - Base class: Clock
    - setTime
    - getTime
    - tick
  - Derived class: Alarm Clock
    - Same methods as Clock plus a few additional ones: setAlarm, ring

Can We Avoid Code Copying and therefore redundancy?

- `Alarm Clock` "IS-A" `Clock`
- Operations on `Clock` (e.g. `setTime`) should be inherited by `Alarm Clock`
- `Alarm Clock` should only have to add information specific to alarm clocks
  - setAlarm
  - ring
- Inheritance provides just this capability

Inheritance

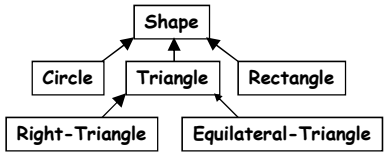
- One class (derived class, subclass, child class) is constructed by including (extending, inheriting) information from another (base class, superclass, parent class) then also adding new information and/or redefining existing information
- To derive a class D from a base class B, use:

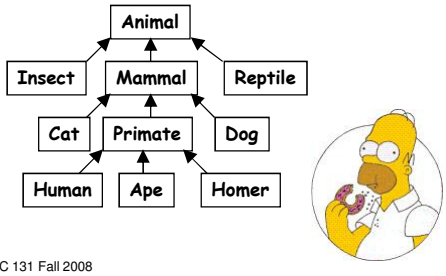
```
public class D extends B { … }
```

- Example (we will look at this in next two slides):
  - Base class: `public class Shape`
  - Derived class: `public class Circle extends Shape`
- Derived class inherits all instance variables, methods from base class. It can also define new instance variables, methods
- Polymorphism: object in derived class can be used anywhere base class is expected (an `alarmClock` "is a" `Clock`!)

Inheritance More Generally

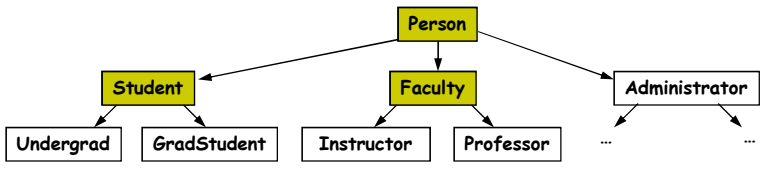
- Classes / objects have a natural “is-a” hierarchy
- Object-oriented programming provides mechanisms for exploiting this for
  - Code re-use
    Common operations implemented in super classes
  - Polymorphism
    Objects in subclasses can be used wherever superclass objects are needed



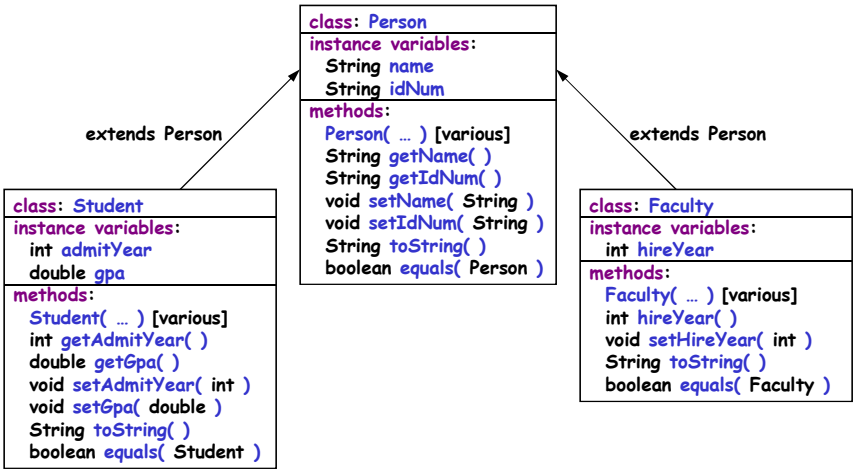


Example: People at University

- Base class: person
- Derived classes: student, faculty, administrator
- Derived from those: undergrad, grad, instructor, professor,…



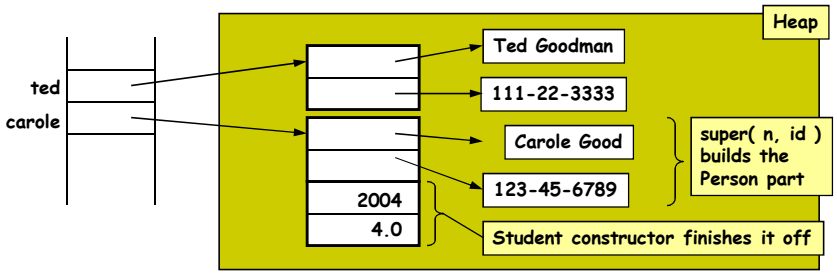
University Person Example



Memory Layout and Initialization Order

- When you create a new derived class object:
  - Java allocates space for base class instance variables and derived class variables
  - Java initializes base class variables first, and then the derived class variables
- Example

```
Person ted = new Person("Ted Goodman", "111-22-3333" );
Student carole = new Student("Carole Goode", "123-45-6789",
                    2004, 4.0 );
```



Method Overriding

- A derived class can define new instance variables and methods (e.g. `hireYear` and `getHireYear( )`)
- A derived class can also redefine (override) existing methods

```
public class Person {
    …
    public String toString( ) { … }
}
public class Student extends Person {
    …
    public String toString( ) { … }
}

Student bob =
   new Student("Bob Goodstudent","123-45-6789",2004,4.0 );
System.out.println( "Bob's info: " + bob.toString( ) );
```

Overrides base-class definition of this method

Since bob is Student, Student toString used

Overriding vs. Overloading

- Overriding: a derived class defines a method with same name, parameters as base class
- Overloading: two or more methods have the same name, but different parameters
- Example

```
public class Person {
    public void setName( String n ) { name = n; }
    …
}
public class Faculty extends Person {
    public void setName( String n ) {
        super.setName( "The Evil Professor " + n );
    }
    public void setName( String first, String last ) {
        super.setName( first + " " + last );
    }
}
```

Base class setName( )

Overriding

Overloading

Calling an overridden function

- Possible but use sparingly.
  - Overriding hides methods of the base class (can still access them using `super.methodName()` in subclass, but not in "outside world")

```
public class Person {
   public String toString(){ /*one def here*/}
   …
}
public class Administrator extends Person {
   public String toString(){/*different def here*/}
   public String regPrint(){
      return super.toString(); /* will use Person's def of toString*/
      /*return toString();  will use Administrator's def of toString*/
   }
}
```

  - Often better to pick a different name rather than overload if you want both.

Derived class: Student

```
package university;
public class Student extends Person {
   private int admitYear;
   private double gpa;

   public Student( ) {
       super( );
       admitYear = -1;
       gpa = 0.0;
   }

   public Student( String n, String id, int yr, double g ) {
       super( n, id );
       admitYear = yr;
       gpa = g;
   }

   public Student( Student s ) {
       super( s );
       admitYear = s.admitYear;
       gpa = s.gpa;
   }
   // …other methods in part 2
}
```

Tells Java that Student is derived from Person

Additional instance variables

Default constructor

This calls the default constructor for base class (superclass), Person, to set name and idNum.

Standard constructor

Calls Person constructor.

Copy constructor

Calls Person copy constructor.

Understanding the Student

- `extends` specifies that `Student` is subclass of `Person`:
  `public class Student` **`extends Person`**
- `super()`
  - When creating a new Student object, we need to initialize its base-class instance variables (from Person)
  - This is done by calling `super( … )`. E.g.
    `super(name, id)` invokes constructor `Person(name, id)`
- `super( … )` must be the first statement of your constructor
  - If you do not call `super()`, Java will automatically invoke the base class's default constructor
  - If the base class's default constructor is undefined? Error
  - You must use `super( … )`, not `Person( … )`

Shadowing

- Can we override instance variables just like methods?
- Yes, but be careful!
  - Overriding instance variable is called shadowing
  - Shadowing hides instance variables of base class (can still access them using `super.varName` in subclass, but not in "outside world")

```
public class Person {
   String name;
   …
}
public class Administrator extends Person {
   String name;  // name refers to Administrator's name
}
```

  - Confusing! Better to pick a new variable name

`super` vs. `this`

- `super`: refers to the base class
  - Can invoke any base class constructor using `super( … )`
  - Can access data and methods in base class (`Person`) via `super`
    E.g., `toString( )`, `equals( )` invoke the corresponding methods from `Person` base class using `super.toString( )` and `super.equals( )`
- `this`: refers to current class / object
  - Can refer to own data and methods using `this` (usually unnecessary)
  - Can invoke any of its own constructors using `this( … )`. Like `super`:
    - Can only be done within a constructor
    - Must be the first statement of the constructor
    - Example

```
public Faculty( Faculty f ) {
      this( f.getName( ), f.getIdNum( ), f.hireYear );
}
```


Inheritance and `private`

- `Student` inherits all private data (`name` and `idNum`) from `Person`
- However, private members of base class cannot be accessed directly

```
public class Student extends Person {
   …
   public void someMethod( ) {
     name = "Mr. Foobar";          // Illegal!
   }

   public void someMethod2( ) {
      setName( "Mr. Foobar" );     // OK
   }
```

- Why?
  - Although `Student` inherits from `Person` …
  - … they are different classes

Early vs. Late Binding

- Consider:

```
Faculty carol =
  new Faculty("Carol Tuffteacher","999-99-9999", 1995);
Person p = carol;
System.out.println( p.toString() );
```

- Which version of `toString` – `Person` or `Faculty` – is called?
  - Early (static) binding
    - `p` is declared to be of type `Person`
    - Therefore, the `Person` version of `toString` is used
  - Late (dynamic) binding
    - The object to which `p` refers was created as `Faculty` object
    - Therefore, the `Faculty` version of `toString` is used
- Java uses late binding (C++ by default uses early binding)
  - Early binding is more runtime efficient (decisions about method versions can be made at compile time)
  - Late binding respects encapsulation (object defines its operations when it is created)

Polymorphism

- Java's **late binding** makes it possible for a single reference variable to refer to objects of many different types. Such a variable is said to be **polymorphic** (meaning having many forms).
- **Example**: Create an array of various university people and print.

```
Person[ ] list = new Person[3];
list[0] = new Person( "Col. Mustard", "000-00-0000" );
list[1] = new Student ( "Ms. Scarlet", "111-11-1111", 1998, 3.2 );
list[2] = new Faculty ( "Prof. Plum", "222-22-2222", 1981 );
for ( int i = 0; i < list.length; i++ )
        System.out.println( list[i].toString( ) )
```

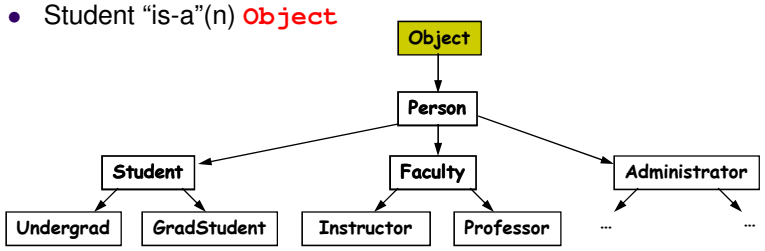
Output:

```
[Col. Mustard] 000-00-0000
[Ms. Scarlet] 111-11-1111 1998 3.2
[Prof. Plum] 222-22-2222 1981
```

- **What type is list[i]?** It can be a reference to any object that is derived from Person. The appropriate toString will be called.

Object

- Recall: inheritance induces "is-a" hierarchy on classes
  - Undergrad "is-a" Student
  - Student "is-a" Person
  - etc.
- Person "is-a" ….?
- Person "is-a"(n) `Object`
- Student "is-a"(n) `Object`



More on `Object`

- Special class at top of class inheritance hierarchy
- Defined in `java.lang` (so available in every program)
- Every class is derived (either directly or indirectly) from `Object`
  - If a class is not derived from anything, it is automatically derived from `Object`
  - e.g.
    `public class Foo { …}`
    is equivalent to
    `public class Foo extends Object {…}`
- Structure of Object
  - No instance variables
  - A number of methods, including:
    - `toString()`
    - `equals (Object o)`

    Note: parameter to `equals` has type `Object`, so any object can be an argument
    - These methods can (and usually should) be overridden

Class vs. Type Information

- In Java
  - Every object is in one class (the one it was created from using `new`)
  - Objects may have many types
    - Interfaces
    - Superclasses
- E.g. consider

```
Student bob = new Student();
Person p = bob;
```

  - Class of object pointed to by `bob`, `p` is `Student`
  - Type of object can be `Student`, `Person`, `Object`, etc.

Accessing Class and Type Information

- Objects can access their class info at run-time
- **`getClass()`**
  - Method defined in `Object`
  - Returns representation of object's class
  - E.g.

```
Person bob = new Person( … );
Person ted = new Student( … );

if ( bob.getClass() == ted.getClass() )
// false (ted is really a Student)
```

- **`instanceof`**
  - Java boolean operator (not a method)
  - Returns true if given object "is-a"(n) object of given (class) type
  - E.g.

```
Student carol = new Student ( … );
if (carol instanceof Person) // true, because carol "is-a" Person
```

Object Casting

- Recall casting in primitive types
  - Casting: conversion of elements from one type to another
  - Widening Conversion
    - Every element in source type is a element in destination type
    - Can be done automatically

```
double x = 3;  // 3 (int) widening conversion to double
```

  - Narrowing Conversion
    - Elements in source type are not necessarily elements in the destination type
    - Must use explicit type conversions to perform this casting

```
int x = (int)3.0; // 3.0 explicitly cast to int
```

- Similar notions can be found with object types also
  - Upcasting
    - Casting a reference to a superclass (casting up the inheritance tree)
    - Always done automatically and is always safe
    - Just ignore the parts that were added by the subclass
  - Downcasting
    - Casting a reference to a derived class
    - Requires explicit casting operator, which checks type info at run-time
    - Can cause runtime error

Example

```
public class Base {
    public void m (int x) { … }
}

public class Derived extends Base {
    public void m (int x) { … }
    public int m (int x) { … }
    public void m (double d) { … }
}

// The following appears in the same package as above

    Base b = new Base( );
    Base d = new Derived( );
    Derived e = new Derived( );
    b.m (5);
    d.m (6);
    d.m (7.0);
    e.m (8.0);
```

Overriding: with increased visibility

Error! duplicate method declaration

Overloading

calls Base:m(int)

calls Derived:m(int)

Error! Since d is declared Base, the compiler looks for Base:m(double) Doesn't exist! So this does not make it past the compiler, even though Derived:m(double) is defined!

calls Derived:m(double)

Safe Downcasting

- Illegal downcasting results in a thrown `ClassCastException` at run-time
- Q: Can we check for the legality of a cast before trying it?
- A: Yes, using `instanceof`
- Example
  - Given: `ArrayList` of university people
  - Want: Print the GPAs of the students
  - Solution approach
    - Iterate through list
    - Print GPAs only of Students

`equals()` Reconsidered

- Recall definition of `equals()`
  - ... in Person

```
public boolean equals (Person p) {
     if (p == null){
            return false;
     }
     return name.equals(p.getName()) &&
            idNum.equals(p.getIdNum());
   }
```

  - ... in Student

```
public boolean equals( Student s ) {
     if (s == null){
        return false;
      }
     return super.equals(s) &&
            admitYear == s.admitYear &&
            gpa == s.gpa;
    }
```

- What does following do?

```
public static void main (String[] args) {
   Student bob = new Student ("R. Goode", "234-56-7890", 1998, 3.89);
   Faculty bob2 = new Faculty ("R. Goode", "234-56-7890", 2005);
   System.out.println (bob.equals (bob2));
}
```

- `true` is printed!

A Better `equals()`

- Take `Object` as input
- Check for non-null-ness of input
- Check that class is correct
- Then do other checks
- For example in `Person`:

```
public boolean equals (Object o) {
   if (o == null)
       return false;
   else if (o.getClass() != getClass())
       return false;
   else {
       Person p = (Person)o;
       return name.equals(p.getName()) &&
           idNum.equals(p.getIdNum());
   }
}
```

- Similar improvements can be made to `Student`, `Faculty`
- Now `bob.equals(bob2)` returns `false`

Inheritance vs. Composition

- Inheritance: a way to build new classes out of old ones
  - Objects in subclass inherit data, methods from superclass
  - Object in a subclass "is-a"(n) object in superclass
- Association: another way to build new classes out of old
  - Class definitions may include instance variables which are objects of other class types
  - Object in a new class "has-a"(n) object in the original class
  - Composition: the strongest form of association – when the lifetime of the enclosed object is completely dependant on the lifetime of the object that contains it

Recall Interfaces

- Interfaces contain lists of method prototypes
- Example from Lecture #23:

```
public interface UMStudent {
   public void goToClass();
   public void study();
   public void add(int a, int b);
   public String getName();
}
```

- Classes can be indicated as implementing interfaces

```
public class CSMajor implements UMStudent {
  …
}
```

  - To satisfy Java compiler, `CSMajor` must provide implementatons of `goToClass()`, `study()`, etc.
- Interfaces can be used as types, and thus to support polymorphism:

```
public void psychoAnalyze(UMStudent student) { … }
```

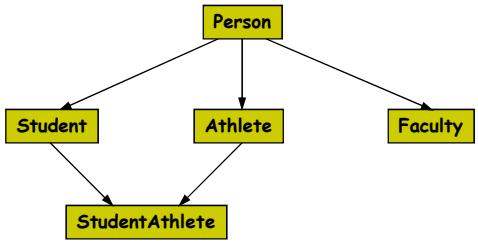
- From last time: interfaces are similar to, but different from, abstract classes
  - Abstract classes can contain abstract, concrete methods
  - Classes can implement multiple interfaces, but inherit (directly) from only one class

Main Uses of Interfaces

- API for classes
- Polymorphism
- "Faking multiple inheritance"
- Specifying sets of symbolic constants

"Multiple Inheritance"?

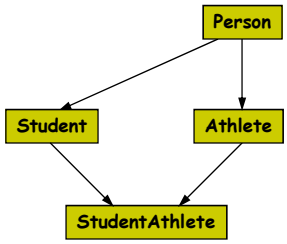
- Intuitively useful to be able to inherit from multiple classes (multiple inheritance)



- But Java does not allow this

Why Does Java Disallow Multiple Inheritance?

- Semantic difficulties!
- Consider `StudentAthlete`
  - Objects would get name field from `Student`
  - Objects would also get name field from `Athlete`
  - Duplicate fields: what to do?
- Some languages (e.g. C++) do allow multiple inheritance



Can We Achieve Some of Benefits of Multiple Inheritance in Java?

- Yes, using interfaces + inheritance
  - Idea: use inheritance for one of inherited classes, interfaces for others
  - Interfaces ensure that relevant methods are implemented
- Example

```
public class Person { … }

public class Student extends  Person { … }

public interface Athlete {
   public String getSport ();
   public void setSport (String sport);
}

public class StudentAthlete extends Student implements Athlete {
   …
}
```

- Objects of type `StudentAthlete` "are" `Student`s
- They also can be wherever objects matching `Athlete` are required

Interfaces and Constants

- Interfaces can also contain `public final static` variables
- Sometimes interfaces are used to provide consistent definitions for constants throughout an application
- Example

```
public interface Months {
    public final static int       JANUARY = 1;
    public final static int       FEBRUARY = 2;
    public final static int       MARCH = 3;
    …
    public final static int       DECEMBER = 12;
}

public class MonthDemo implements Months {

    public static void main( String[ ] args ) {
      System.out.println( "March is month number " + MARCH );
    }
}
```

Because `MonthDemo` implements `Months`, it has access to the constants

Interface Hierarchies

- Inheritance may also be used to build new interfaces from previous ones
- A subinterface inherits all method / constant declarations from its base interface
- A subinterface may also introduce new methods / constants
- E.g.
```
public interface Level1<T> {
    boolean x( );
    T y( );
    void z( );
}
```
We can define a new, bidirectional iterator interface using inheritance
```
public interface Level2<T> extends Level1<T> {
    boolean a();
    T b();
}
```