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:
  ```java
  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

\[
\text{Shape} \quad \text{Animal} \\
\quad \text{Circle} \quad \text{Insect} \quad \text{Cat} \\
\quad \text{Triangle} \quad \text{Mammal} \quad \text{Primate} \\
\quad \text{Rectangle} \quad \text{Reptile} \quad \text{Dog} \\
\quad \text{Right-Triangle} \quad \text{Human} \\
\quad \text{Equilateral-Triangle} \quad \text{Ape} \\
\]

Example: People at University

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

class: Person
instance variables:
String name
String idNum

methods:
Person( ... ) [various]
String getName( )
String getIdNum( )
void setName( String )
void setIdNum( String )
String toString( )
boolean equals( Person )

extends Person

class: Student
instance variables:
int admitYear
double gpa

methods:
Student( ... ) [various]int getAdmitYear( )
double getGpa( )
void setAdmitYear( int )
void setGpa( double )
String toString( )
boolean equals( Student )

extends Person

class: Faculty
instance variables:
int hireYear

methods:
Faculty( ... ) [various]int hireYear( )
void setHireYear( int )
String toString( )
boolean equals( Faculty )

extends Person

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
  ```java
  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

```java
public class Person {
    public String toString() { ... }
}

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

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

Overriding vs. Overloading

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

```java
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 );
    }
}
```
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")

```java
public class Person {
    public String toString() {/*one def here*/
        ...
    }
}
```

```java
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

```java
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
}
```
Understanding the Student

- **extends** specifies that `Student` is subclass of `Person`:
  ```java
  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.
    ```java
    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( ... )`
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
      ```java
      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
  ```java
  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:**
  
  ```java
  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.

  ```java
  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.
    ```java
    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
  
  ```java
  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.
    ```java
    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.
    ```java
    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

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

public class Derived extends Base {
    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();
```

- Overloading: with increased visibility
- Error! duplicate method declaration
- Overloading
- 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!
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:
  ```java
  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:
  ```java
  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
  ```
  ```java
  public class CSMajor implements UMStudent {
      ...
  }
  
  Classes can be indicated as implementing interfaces
  ```
  ```java
  public class CSMajor implements UMStudent {
      ...
  }
  
  To satisfy Java compiler, CSMajor must provide implementations of goToClass(), study(), etc.
- Interfaces can be used as types, and thus to support polymorphism:
  ```java
  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)

```
Person
  /  \
Student Athlete Faculty
     /       |
StudentAthlete
```

- 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
  ```java
  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`
  - 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
  ```java
  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;
  }
  ```
  ```java
  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

```java
public interface Level2<T> extends Level1<T> {
    boolean a();
    T b();
}
```