Lectures 12.1 - 12.2

Inheritance

Why inheritance?

- We are asked to write a class that manages and displays an analog clock
- An analog clock has various properties and behaviors. Some of them are features that *every clock has*
- In other words:
  - An analog clock *is a clock*
  - It has all the features of a clock + some analog clock specific features

Inheritance

If we already have a `Clock` class, we can:

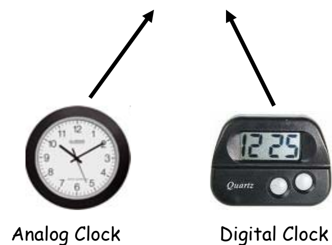
1. Define a new class, say `AnalogClock`, and make it inherit the functionality of the `Clock` class
2. Further, we can endow `AnalogClock` with additional functionality of its own

We can design other clock variants similarly

Implications: less work, less bugs, more consistency.

Clock

```
- Hours : int
- Minutes : int
- Seconds : int
...
+ setTime() : void
+ getSeconds() : int
+ setSeconds(int seconds) : int
+ secondElapsed() : void
+ secondElapsed(int n) : void
...
```



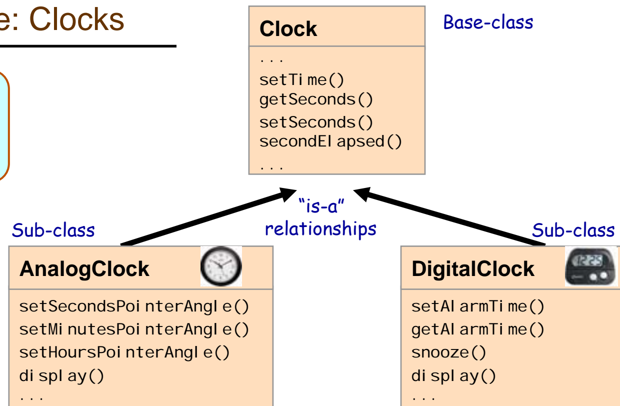
Analog Clock　　Digital Clock

Outline

- Why inheritance?
  - Motivation
  - Examples
- Inheritance anatomy
  - Constructors
  - Methods
  - Example
- The Object class
- Method overriding
- Inheritance implications
  - Narrowing / Widening
  - Run-time types
  - Virtual method calling
- Packages
- Visibility modifiers
- Design issues
  - Multiple inheritance
  - Overloading vs. overriding
  - When to sub-class?
- Benefits of inheritances

Inheritance example: Clocks

Anything that can be done with Clock objects can also be done with AnalogClock and DigitalClock objects



Inheritance = the ability to *derive* one class definition from another

- The derived sub-class *inherits* the members of the base-class
- Usually, the sub-class designer will endow it with additional, sub-class-specific members

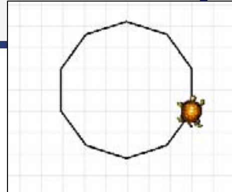
OO terminology:

- Base-class = super-class = parent class
- Sub-class = derived class = child class
- To extend = to derive = to sub-class

Inheritance example: Turtles

```
// A turtle that draws geometric figures like polygons.
public class GeoTurtle extends Turtle {
  // Draws a perfect polygon with n edges of size edgeSize
  public void drawPolygon(int n, double edgeSize) {
    int theta = 360 / n;
    for (int i=0; i<n; i++) {
      moveForward(edgeSize);
      turnLeft(theta);
    }
  }
}
```

The syntax
`C1 extends C2`
implies:
`C1` is a sub-class of `C2`
`C2` is a super-class of `C1`



Turtle
- Turtle()
- moveForward()
- turnLeft()
- turnRight()
- tailUp()
- tailDown()
- ...

GeoTurtle
- drawPolygon()
- drawSquare()
- drawCircle()
- ...

```
public class GeoTurtleDemo {
  public static void main(String[] args) {
    GeoTurtle gTurtle = new GeoTurtle();
    gTurtle.tailDown();
    gTurtle.drawPolygon(10, 50);
  }
}
```

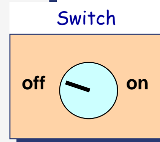
What happens when these methods are invoked?

Inheritance example: Switches

Base-class

```
// A switch that can be on/off.
public class Switch {

  // Records the state of the switch
  private boolean isOn;

  public Switch(boolean isOn) {
    this.isOn = isOn;
  }
  public boolean isOn() {
    return isOn;
  }
  public void setOn(boolean state) {
    isOn = state;
  }
}
```

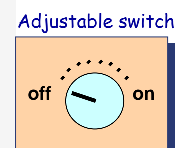
Switch



Sub-class

```
public class AdjustableSwitch extends Switch {

  private float level;

  public AdjustableSwitch(float level) {
     // later ...
  }

  public void setLevel(float level) {
    this.level = level;
    setOn(level > 0);
  }

  public float getLevel() {
    return (isOn() ? level : 0);
  }
}
```

Adjustable switch



- The sub-class is always *more specific* than the base-class.

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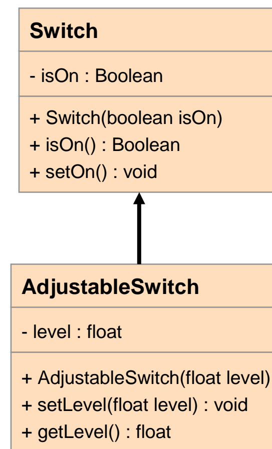
Inheritance anatomy

The sub-class inherits the non-private members of the base-class.

Within the sub-class code:

- Non-private fields and methods of the base-class may be used just like sub-class members
- Private fields of the base-class can be accessed via super-class public methods, as usual (example: see how `isOn` is treated in the `AdjustableSwitch` example)
- How to expose private members of the base-class to the sub-class: later.



Sub-classing constructors

Constructors are not inherited.

A sub-class constructor always has the same logic:

1. Mandatory: First, it invokes a constructor of the base-class. This is done in order to initialize the state of the sub-class object from the base-class perspective
2. Optional: Second, it may do some sub-class construction work.

Base-class

```
public class Switch {
  private boolean isOn;

  public Switch (boolean isOn) {
    this.isOn = isOn;
  }

  // Other Switch methods
```

Example:

Sub-class

```
public class AdjustableSwitch extends Switch {
   private float level;

   public AdjustableSwitch (float level) {
       super(level > 0);
       this.level = level;
   }

   // Other AdjustableSwitch methods
}
```

A sub-class constructor must begin with

Either: `super(...)`

Or: `this.anotherSubClassConstructor(...)`

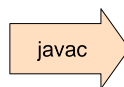
Sub-classing constructors (cont.)

If we don't declare any constructor in the sub-class, the compiler automatically:

1. Adds an empty (default) constructor to the sub-class
2. Puts in it a `super()` call to the constructor of the base-class

A sub-class without any constructor:

```
public class C1 extends C2 {
  // C1 fields
  // C1 methods (no constructor)
}
```



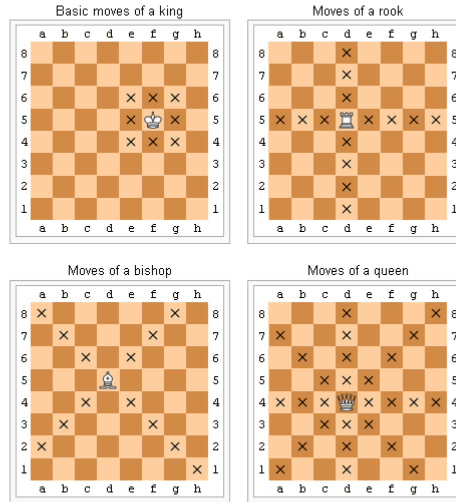
Becomes (implicitly):

```
public class C1 extends C2 {
  // C1 fields
  public C1() {
    super();
  }
  // C1 methods
  ...
```

- If we declare a sub-class constructor, but don't say explicitly `super()` as its first instruction, the compiler will automatically insert `super()` as the first instruction
- If there is no empty constructor in the super-class, the sub-class code will not compile!

Sub-classing methods

Example: a `Rook` is-as `ChessPiece`.
It inherits a `move(x,y)` method. But, being a `Rook`, its movements are restricted. We may want to create a new, `Rook`-specific `move()` method

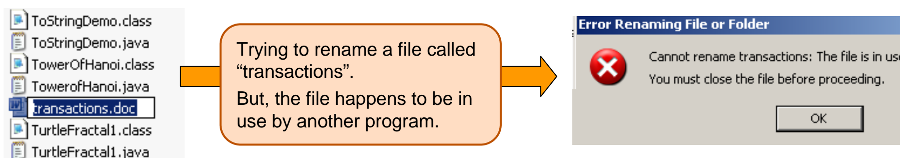


The sub-class inherits all the public methods of the base-class.
For each inherited method, the sub-class code can either:

- Use the inherited method as-is
- Overload the method
- Override the method:
  1. Keep the method signature
  2. Re-write its implementation.

Example: file management (the story)

Typically, a file system lets users access a file only if it in a stable state. Example:



"Stable state" depend on the application. Examples:

- Operating system: As long as some program is doing something to a file, we don't want to let any other program touch this file.
- Transaction processing: As long as some user reserves a seat in a flight, we don't want other users to access the reservations file

Typical solution: the file system designer defines a Boolean attribute that stores the file state (open / not open). Clients can access the file only if it's not open.

Example: file management

Server

```
// File implementation
public class File {

  private String name;
  private boolean isOpen;

  public File(String name) {
    this.name = name;
    this.isOpen = true;
  }

  public void open() {
    if (isOpen)
      // code for denying access
    else
      isOpen = true;
  }

  public void close() {
    isOpen = false;
  }

  // Other File methods

}
```

Client

```
public class FileDemo {

  public static void main (String args[]) {
    File f = new File("reservations");
    // Add some data to the file
    // File processing operations ...
    f.close();

    // Do something else, unrelated to the file
    ...

    // More file processing:
    f.open();
    // File processing operations
    f.close();

    // Etc.
  }
}
```

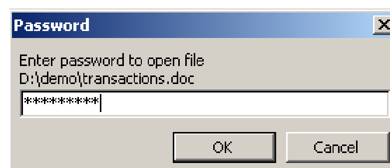
Access control:

- When a client wants to access a file, it calls `f.open()`
- When file processing ends, the client calls `f.close()`
- This allows safe file sharing among clients.

Example: file management (the story, take 2)

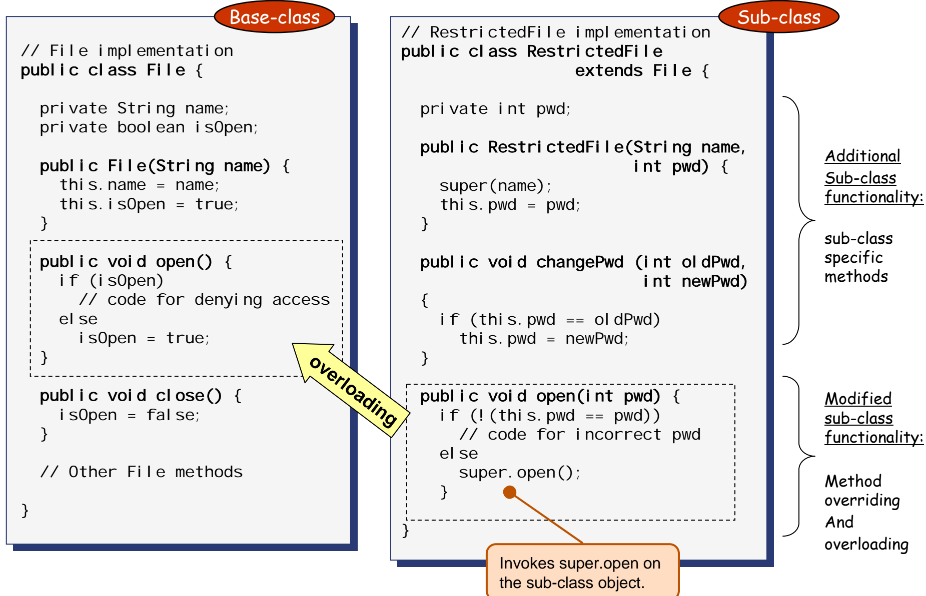
Password control:

In addition to access control, which is mandatory for all files, we may want to allow creation and access of password-protected files:

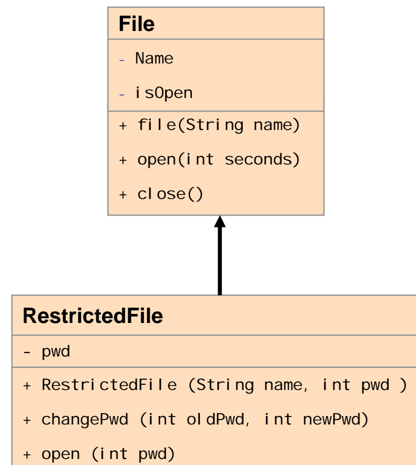


- A protected file should have all the features of a regular file, plus password protection
- This extension can be handled by sub-classing the `File` class.

Example: file management



Example: file management – inheritance hierarchy



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`Object`: the parent class of all Java classes

java.lang
Class Object

From the `Object` class API

`java.lang.Object`

public class **Object**

Class `Object` is the root of the class hierarchy. Every class has `Object` as a superclass. All objects, including arrays, implement the methods of this class.

Method Summary	
protected `Object`	**`clone`**`()` Creates and returns a copy of this object.
`boolean`	**`equals`**`(Object obj)` Indicates whether some other object is "equal to" this one.
protected `void`	**`finalize`**`()` Called by the garbage collector on an object when garbage collection determines that there are no more references to the object.
`Class`	**`getClass`**`()` Returns the runtime class of an object.
`int`	**`hashCode`**`()` Returns a hash code value for the object.
`void`	**`notify`**`()` Wakes up a single thread that is waiting on this object's monitor.
`void`	**`notifyAll`**`()` Wakes up all threads that are waiting on this object's monitor.
`String`	**`toString`**`()` Returns a string representation of the object.

- All classes implicitly extend the class `Object`
- Thus, the `Object` methods are inherited by all Java classes
- Designers of sub-classes often override these base methods.

The `toString` method

java.lang
Class Object

From the `Object` class API

java.lang.Object

toString

`public String toString()`

Returns a string representation of the object. In general, the `toString` method returns a string that "textually represents" this object. The result should be a concise but informative representation that is easy for a person to read. It is recommended that all subclasses override this method.

The `toString` method for class `Object` returns a string consisting of the name of the class of which the object is an instance, the at-sign character `@', and the unsigned hexadecimal representation of the hash code of the object. In other words, this method returns a string equal to the value of:

- When you write a class, you often override the `toString()` method in order to create a suitable textual representation of objects of that class.
- What is expected from overriding methods? See the base class API.

Overriding `toString`

Base class

```
// Represents a point on a grid.
public class Point {

  // The coordinates of the point
  private int x, y;

  // Constructs a point
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public String toString() {
    return "(" + x + "," + y + ")";
  }
}
```

```
public enum Color
    {red, blue, green, yellow};
```

Sub class

```
// Represents a colored point on a grid.
public class ColoredPoint extends Point {

  private Color color;

  // Constructs a new colored point
  public ColoredPoint(int x, int y, Color color) {
    super(x,y);
    this.color = color;
  }

  public String toString() {
    return super.toString() + " "
           + color.toString();
  }

  . . .
}
```

overriding

The `equals` method

java.lang
Class Object

From the `Object` class API

`java.lang.Object`

equals

```
public boolean equals(Object obj)
```

The `equals` method for class `Object` implements the most discriminating possible equivalence relation on objects; that is, for any non-null reference values `x` and `y`, this method returns `true` if and only if `x` and `y` refer to the same object (`x == y` has the value `true`).

- Like `toString()`, class designers normally override `equals()` to suit their needs.

Overriding `equals`

```
public class Point {
  // The coordinates of the point
  private int x, y;
  ...
  public boolean equals(Object other) {
    if (other instanceof Point) {
      Point otherPoint = (Point)other;
      return (x == otherPoint.x && y == otherPoint.y);
    }
    return false;
  }
  ...
}
```

`x instanceof C`
Means
"x refers to an object of type C"

```
public class EqualsDemo {
  public static void main(String[] args) {
    Object obj1 = new Object();
    Object obj2 = new Object();
    Point p1 = new Point(10, 20);
    Point p2 = new Point(10, 20);
    System.out.println(obj1.equals(obj2));
    System.out.println(p1 == p2);
    System.out.println(p1.equals(p2));
  }
}
```

This example illustrates how to design a domain-specific definition of equivalence, overriding the base definition of `equals`

C:\WINDOWS\system32\cmd.exe

```
D:\demo>java EqualsDemo
false
false
true
```

Further sub-classing and overriding

base-class

```
public class Point {
  // The coordinates of the point
  private int x,y;
  ...
  public boolean equals(Object other) {
    if (other instanceof Point) {
      Point otherPoint = (Point)other;
      return (x == otherPoint.x && y == otherPoint.y);
    }
    return false;
  }
  ...
}
```

overriding

sub-class

```
public class ColoredPoint extends Point {

  private Color color;
  ...
  public boolean equals(Object other) {
    if (other instanceof ColoredPoint) {
      ColoredPoint otherPoint = (ColoredPoint)other;
      return (super.equals(other) && color == otherPoint.color);
    }
    return false;
  }
  ...
}
```

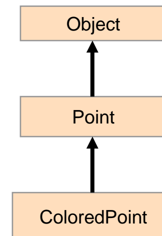

Overriding rules

- The overridden methods of the base-class can still be accessible from the sub-class code using the syntax `super.method(...)`
- The *contract* of a method states, among other things, what is expected of overriding implementations of the method
- The method signature (name, number and type of the parameters) of the overriding method must be the same as that of the overridden method
- The overriding method can have a different `throws` clause as long as it doesn't declare any types not declared by the `throws` clause in the overridden method
- The access modifier of the overriding method can allow more access than the overridden method, but not less. For example, a `protected` method in the base-class can be made `public` but not `private`.

Inheritance hierarchy

The is-a relationship is transitive:

- `ColoredPoint` is-a `Point`
- `Point` is-a `Object`
- `ColoredPoint` is-a `Object`



When you call a method on some object:

- If the compiler finds a matching method declaration in the object's class, it uses it
- Otherwise it searches in its immediate parent
- If not found, it searches in the parent's immediate parent, and so on,
- All the way up to `java.lang.Object`

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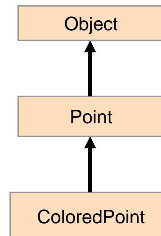
Different views on the same object



Inheritance enable us to treat objects from multiple perspectives

For example, a `ColoredPoint` object can be treated as a …

- `ColoredPoint:` The narrowest, and most specific, point of view
- `Point:` Less specific: we forget about the special characteristics of the object as a `ColoredPoint`
- `Object:` the widest point of view.

Narrowing / widening

Sometimes we want to "widen-up" an object and treat it like its parent object

Sometimes we want to "narrow down" an object and treat it like one of its child objects

```
// Recall that ColoredPoint extends Point.
Point p1;
ColoredPoint p2 = new ColoredPoint(2, 3, Color.red);
p1 = (Point) p2;          // p2 is widened up
p1 = p2;                  // Likewise
p2 = (ColoredPoint) p1 ;  // p1 is narrowed down
```

In Java:

- Narrowing requires explicit casting
- Widening can be done in several different ways.

Widening via parameter passing

case-class

```
// A point on a grid
public class Point {
  private int x,y;
  ...
  // Computes the distance from another point
  public double distanceFrom(Point p) {
    int dx = x - p.x;
    int dy = y - p.y;
    return Math.sqrt(dx * dx + dy * dy);
  }
  ...
}
```

```
public enum Color
      {red, blue, green, yellow};
```

sub-class

```
// A colored point on a grid
public class ColoredPoint extends Point {
  private Color color;
  ...
  // Constructs a new colored point
  public ColoredPoint(int x, int y, Color color) {
    super(x,y);
    this.color = color;
  }
  ...
```

client code

```
...
Point p1;
ColoredPoint p2;
p1 = new Point(2, 3);
p2 = new ColoredPoint(5, 6, Color.red);
double d = p1.distanceFrom(p2);
```

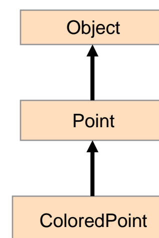
`distanceFrom()` expects to get a `Point` parameter;
Instead, it gets a `ColoredPoint` argument (`p2`).

That's OK – `p2`. has been widened by the type of the formal parameter.

Run-time type

Consider the following code:

```
Point p;
ColoredPoint cp = new ColoredPoint(10, 20, Color.green);
p = cp;
```



Observations:

The compile-time type of `p` is `Point`

But, `p` now contains a reference to a `ColoredPoint` object

Terminology: we say that the run-time type of `p` is `ColoredPoint`

Run-time type

- The run-time type is always some subclass of the compile-time type
- The same object can have different run-time types in different program runs.

Virtual method calling

```
public class Animal {
  public String eats() { return "food"; }
}
```

```
public class Cow extends Animal {
 public String eats() { return "grass"; }
}
```

```
public class NarrowingDemo {
  public static void main(String[] args) {
    Animal a;
    Cow c = new Cow();
    a = c;
    System.out.println(a.eats());
  }
}
```

- In OO, (non-static) methods are always invoked on some object
- If the object has been narrowed or widened, which method implementation should be used?

Virtual method calling:
The method to be invoked is determined by the run-time type of the object and not by its compile-time type

In Java, all methods invocations are virtual.

```
C:\WINDOWS\system32\cmd.exe
D:\demo>java NarrowingDemo
grass
```


InstanceOf

- Problem: If the run-time type of an object is unknown, how can we tell which methods we are allowed to invoke on it?
- Solution: The run-time type can be checked using the operator `instanceOf`.

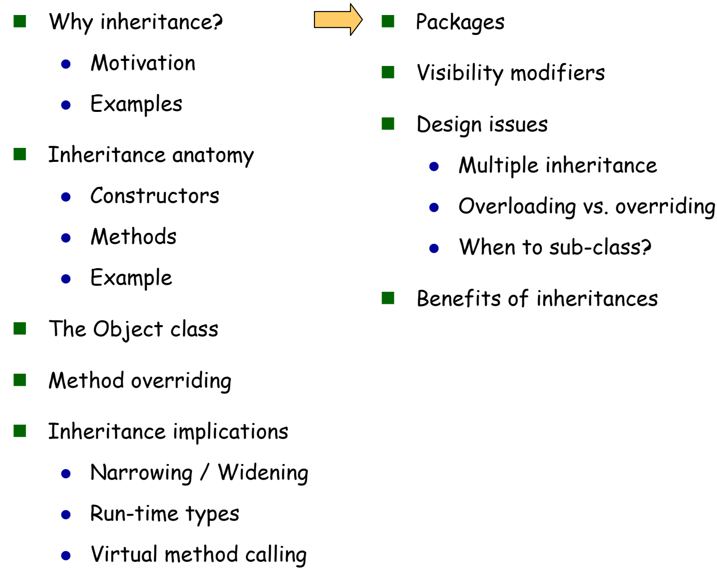
```
public class RunTimeTypeDemo {

  public static void main(String[] args) {
    File f;
    if (Math.random() >= 0.5)
      f = new File("reservations");
    else
      f = new RestrictedFile("reservations", 56789);
    f.close();

    // Many lines of code later, we want to process the f file.
    // How shall we open it? Is it a restricted file, or just a file?

    if (f instanceof RestrictedFile) {
      RestrictedFile rf = (RestrictedFile) f;
      rf.open(56789);
    }
    else
      f.open();
  }
}
```

Outline



Packages

- If you have various classes that do something together, you may want to put them in a package
- Package = a collection of classes and interfaces providing access protection and namespace management
- Classes in a package do not have to be a part of the same inheritance tree

How to group classes into a package:

1. Write `package packageName` at the beginning of each class file
2. Put all class files under a directory whose name is `packageName`.
   The directory that contains this directory should be in our `CLASSPATH`.

Class visibility:

- A class declared as `public` can be used from outside the package
- A class declared without a `public` modifier can be used only inside the package.

Visibility modifiers

The visibility modifier of a member determines which other classes can access the member. There are four possibilities:

`public`: Accessible to any class

`protected`: (1) Accessible to any class in the same package as this class
(2) Accessible to any sub-class of this class

None (default)): Accessible to any class in the same package as this class

`private`: Accessible to this class only

Access Levels

Modifier	Class	Package	Subclass	World
public	Y	Y	Y	Y
protected	Y	Y	Y	N
no modifier	Y	Y	N	N
private	Y	N	N	N

Best practice advice

- Use `protected` if you want to expose a member to sub-classes and hide it from the rest of the world
- Protected methods are useful for customizing the behavior of our class by sub-classing.
- Avoid defining too many protected variables: it hurts encapsulation
- A `protected` member is part of the class interface; Therefore it must be documented in the class API.

Protected fields: usage example

Base class

```
package screen;

// Represents a point on a grid.
public class Point {

  // The coordinates of the point
  protected int x,y;

  // Constructs a point
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  // public getx() and setx() methods
  // public gety() and sety() methods

  ...

}
```

Sub class

```
package screen;

// Represents a colored point on a grid.
public class ColoredPoint extends Point {

  private Color color;

  // Constructs a new colored point
  public ColoredPoint(int x, int y, Color color) {
    super(x,y);
    this.color = color;
  }
  . . .
  public void draw() {
    // This method will need to refer to x,y
    // and it may be cumbersome to do it
    // through accessor methods
  }
  . . .
}
```

The `final` modifier

The `final` modifier can be used for classes, methods and variables; in each case it has a different meaning:

- A `final` class cannot have derived classes
- A `final` method cannot be overridden
- A `final` variable can be initialized only once
  - If the variable is `static` you must specify its value in the declaration and it becomes a constant
  - If the variable is not static, you should either specify a value in the declaration or in the constructor, but only once, and only in either of these two places .

Outline

- Why inheritance?
  - Motivation
  - Examples
- Inheritance anatomy
  - Constructors
  - Methods
  - Example
- The Object class
- Method overriding
- Inheritance implications
  - Narrowing / Widening
  - Run-time types
  - Virtual method calling
- Packages
- Visibility modifiers
- Design issues
  - Multiple inheritance
  - Overloading vs. overriding
  - When to sub-class?
- Benefits of inheritances

When to derive a sub-class?

That's a design issue.

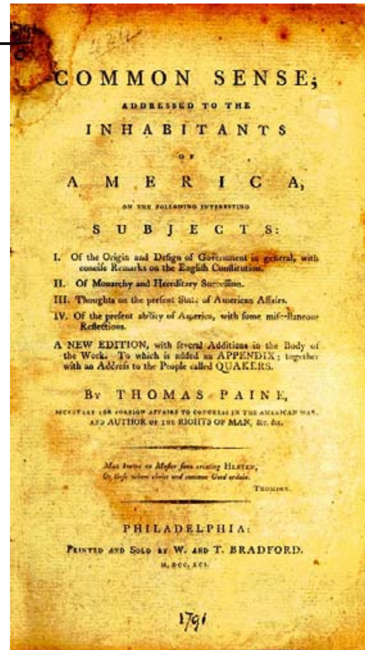
Use inheritance when it makes sense from the abstraction standpoint

Example: we wish to implement dashed lines. Two options:

- Add a `dashed` field to the `Line` class
- Create a `DashedLine` class that extends `Line`

What to do?

- Use judgment and common sense
- Consult the abstraction.



COMMON SENSE;
ADDRESSED TO THE
INHABITANTS
OF
AMERICA,
ON THE FOLLOWING INTERESTING
SUBJECTS:

I. Of the Origin and Design of Government in general, with concise Remarks on the English Constitution.
II. Of Monarchy and Hereditary Succession.
III. Thoughts on the present State of American Affairs.
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To overload, or to override?

Overloading:

- Multiple methods, each with the same name but different signatures
- Enables to define a similar operation in different ways for different data

Overriding:

- Multiple methods, one in a base-class and the other in sub-classes, each having the same signature but different implementations
- Enables to define a similar operation in different ways for different object types.

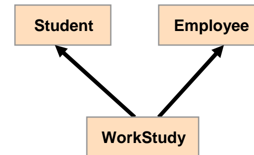
Is this overloading or overriding?

Multiple inheritance

A university typically employs some of its students in all sorts of jobs

Such students / employees are called "work-study"

How to model a WorkStudy abstraction?



<u>Multiple inheritance:</u>

A class is allowed to extend more than one base-class

- Supported by some OO languages, e.g. C++
- Not supported in Java
- But … a workaround is possible, using interfaces.

Advantages of inheritance

- Code re-use: you implement only the *necessary additional functionality*
  - Time
  - Money
  - Ease of use: if users are familiar with the base-class, they need learn only the additional functionality
  - Debugging / QA only the added functionality
  - Errors minimization
  - Inherited maintenance: the sub-class inherits all the improvements made to the base class
  - Compactness: the code is smaller and easier to handle
  - Inheritance is typically part of the abstraction
- Obligations of the super-class:
  - Interface
  - API
  - Documentation.