Review

Last week
- Modules
- Next Programming Assignment

Outline
- Classes
- Encapsulation and Inheritance
- Initialization and Finalization
- Dynamic Method Binding
- Abstract Classes
- Simulating First-Class Functions

What is OOP? (part I)

The object idea:
- bundling of data (data members) and operations (methods) on that data
- restricting access to the data

An object contains:
- data members: arranged as a set of named fields
- methods: routines which take the object they are associated with as an argument
  (known as member functions in C++)

A class is a construct which defines the data and methods associated with all of its instances (objects).
What is OOP? (part II)

The inheritance and dynamic binding ideas:

- **inheritance**: classes can be extended:
  - by adding new fields
  - by adding new methods
  - by overriding existing methods (changing behavior)

  If class $B$ extends class $A$, we say that $B$ is a subclass (or a derived or child class) of $A$, and $A$ is a superclass (or a base or a parent class) of $B$.

- **dynamic binding**: wherever an instance of a class is required, we can also use an instance of any of its subclasses; when we call one of its methods, the overridden versions are used.

Information Hiding in Classes

Like modules, classes can restrict access to their data and methods

Unlike modules, classes must take inheritance into account in their access control

Three levels of access:

- **public**: accessible to everyone
- **protected**: accessible within the class and in any derived classes
- **private**: accessible only within the class

Members are private by default

In JAVA, "protected" means accessible within the class, derived classes, as well as the packages in which derived classes are declared.

A **friend** declaration allows a foreign class or subrouting access to private members

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Example in C++

class Point {
  double x, y; // private data members
public:
  void move (double dx, double dy) {
    x += dx; y += dy;
  }
  virtual void display () { ... }
};

class ColoredPoint : public Point {
  Color color;
public:
  Color getColor () { return color; }
  void display () { ... } // now in color!
};

---

Same thing in JAVA

class Point {
  private double x, y; // private data members
public:
  public void move (double dx, double dy) {
    x += dx; y += dy;
  }
  public void display () { ... }
}

class ColoredPoint extends Point {
  private Color color;
  public Color getColor () { return color; }
  public void display () { ... } // now in color!
}
Initialization and Finalization

A constructor is a special class method that is automatically called to initialize an object at the beginning of its lifetime.

A destructor is a special class method that is automatically called to finalize an object at the end of its lifetime.

Issues:
- choosing a constructor
- references and values
- execution order
- garbage collection

Choosing a Constructor

Most OOP languages allow a class to specify more than one constructor.

- **Overloading**: In C++, Java, and C#, constructors behave like overloaded methods. They must be distinguished by their numbers and types of arguments.
- **Named constructors**: In Smalltalk and Eiffel, constructors can have different names. Code that creates an object must name a constructor explicitly.

References and Values

In Java, variables can be references to objects, but cannot contain objects as values. As a result, every object must be created explicitly, triggering a call to the constructor.

In C++, variables can have objects as values, so it is a little more complicated to identify how and when constructors are called:

- If a variable is declared with no initial value, then the default constructor is called.
- If a variable is declared to be a copy of another object of the same type, the copy constructor is called.
- Otherwise, a constructor is called that matches the parameters passed to the variable declaration.
- Similar rules apply to objects created on the heap.

Constructor Example in C++

```cpp
class Point {
    double x, y; // private data members

public:
    // Default constructor
    Point () : x(0), y(0) {}

    // Copy constructor
    Point (const Point& p) : x(p.x), y(p.y) {}

    // Other constructor
    Point (double xp, double yp) : x(xp), y(yp) {}

    ...}

Point p1; // calls default constructor
Point p2(1,2); // calls last constructor
Point p3 = p2; // calls copy constructor
Point p4(p2); // same as above (syntactic variant)
```
Constructor Example in C++

class Point {
  double x, y;  // private data members

public:

  // Default constructor
  Point () : x(0), y(0) {}  

  // Copy constructor
  Point (const Point& p) : x(p.x), y(p.y) {}  

  // Other constructor
  Point (double xp, double yp) : x(xp), y(yp) {}  

...  
}

Point *p1, *p2, *p3;  // no calls to constructor
p1 = new Point();  // calls default constructor
p2 = new Point(*p1);  // calls copy constructor
p3 = new Point(1,2);  // calls last constructor

---

Constructors in JAVA

class Point {
  private double x, y;  // private data members

public Point () { this.x = 0; this.y = 0; }

public Point (double x, double y) {
  this.x = x;  
  this.y = y;
}
}

Point p1 = new Point();
Point p2 = new Point(2.0, 3.0);
Point p3 = p2;  // no constructor called

---

Execution Order

How do the constructors of base classes and derived classes interact?

Typically, we want to call the base constructor before the derived fields are initialized

Both C++ and JAVA provide mechanisms for doing this.
Destructors and Garbage Collection

When an object in C++ is destroyed, a destructor is called. A destructor is typically used to release memory allocated in the constructor.

For derived classes, destructors are called in the reverse order that the constructors were called.

In languages such as Java that have garbage collection, there is little or no need for destructors.

However, Java does provide an optional finalize method that will be called just before an object is garbage collected.

Example of Destructors in C++

```cpp
class String {
    char *data;
public:
    String(const char *value);
    ~String() { delete [] data; }
};
String::String(const char *value) {
    data = new char[strlen(value) + 1];
    strcpy(data, value);
}
```

Dynamic Method Binding

A key feature of object-oriented languages is allowing an object of a derived class to be used where an object of a base class is expected. This is called subtype polymorphism.

Now, consider the following code:

```cpp
ColoredPoint *cp1 = new ColoredPoint (2.0, 3.0, Blue);
Point *p1 = cp1;   // OK
p1->display ();
```

Which display method gets called?

- If the Point class method is called, it is an example of static method binding.
- If the ColoredPoint class method is called, it is an example of dynamic method binding.

Dynamic Method Binding

What are the advantages and disadvantages of static vs dynamic method binding?

- static is more efficient:
  - To support dynamic method binding, an object must keep an additional pointer to a virtual method table (or vtable).
  - dynamic method binding requires additional space, as well as an additional pointer dereference when calling a method.
- dynamic allows a subclass to override the behavior of its parent, a key feature that makes inheritance much more flexible and useful.

In C++ and C#, methods are bound statically by default.

The keyword virtual distinguishes a method that should be bound dynamically.

In Java, all methods are bound dynamically.
### Dynamic Method Binding

```cpp
class Point {
   double x, y;  // private data members

public:
   // Constructors
   Point () : x(0), y(0) {}  
   Point (const Point& p) : x(p.x), y(p.y) {}  
   Point (double xp, double yp) : x(xp), y(yp) {}  

   // Destructor  
   virtual ~Point () {}  

   virtual void move (double dx, double dy) {
       x += dx; y += dy;  
   }  

   virtual double distance (const Point& p) {
       double xdist = x - p.x, ydist = y - p.y;  
       return sqrt (xdist*xdist + ydist*ydist);  
   }  

   virtual void display () { ... }  
};
```

### Implementation: the vtable

A typical memory layout with dynamic method binding in C++; using `Point` as an example:

<table>
<thead>
<tr>
<th>Point instance</th>
<th>Point vtable</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>move</td>
</tr>
<tr>
<td>y</td>
<td>distance</td>
</tr>
<tr>
<td></td>
<td>display</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Point version</th>
</tr>
</thead>
</table>

For `ColoredPoint`, we have:

```cpp
class ColoredPoint : public Point {
   Color color;

public:
   // Constructors
   ColoredPoint (Color c) : Point(), color(c) { }  
   ColoredPoint (double x, double y,  
       Color c) : Point (x, y), color(c) { }  

   // Destructor
   ~ColoredPoint () {}  

   virtual Color getColor () { return color; }  

   virtual void display () { ... }  // now in color!  
};
```

### Implementation: the vtable

<table>
<thead>
<tr>
<th>ColoredPoint instance</th>
<th>ColoredPoint vtable</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>move</td>
</tr>
<tr>
<td>y</td>
<td>distance</td>
</tr>
<tr>
<td>color</td>
<td>display</td>
</tr>
<tr>
<td></td>
<td>getColor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ColoredPoint version</th>
</tr>
</thead>
</table>

Non-virtual member functions are never put in the vtable.
Abstract Classes

Another useful construct in object-oriented programming is the abstract class.

An abstract class contains at least one method which is abstract (called pure virtual in C++), meaning it has a declaration but no definition within the class.

It is not possible to declare an object of an abstract class as one of its methods has no definition.

Abstract classes are used as base classes in class hierarchies.

They are useful for defining APIs when the implementation is unknown or needs to be hidden completely.

A class, all of whose methods are abstract, is called an interface in Java and C#.

Comparison of Java and C++

<table>
<thead>
<tr>
<th>Java</th>
<th>C++</th>
</tr>
</thead>
<tbody>
<tr>
<td>methods</td>
<td>virtual member functions</td>
</tr>
<tr>
<td>public/protected/private</td>
<td>similar</td>
</tr>
<tr>
<td>static members</td>
<td>same</td>
</tr>
<tr>
<td>abstract methods</td>
<td>pure virtual member functions</td>
</tr>
<tr>
<td>interface</td>
<td>pure virtual class with no data</td>
</tr>
<tr>
<td>implementation of an</td>
<td>inheritance from an abstract</td>
</tr>
<tr>
<td>interface</td>
<td>class</td>
</tr>
</tbody>
</table>

Simulating a first-class function with an object

A simple first-class function:

```
fun mkAdder nonlocal = (fn arg => arg + nonlocal)
```

The corresponding C++ class:

```
class Adder {
    int nonlocal;
    public:
        Adder (int i) : nonlocal(i) { }
        int operator() (int arg) { return arg + nonlocal; }
    }
```

`mkAdder 10` is roughly equivalent to `Adder(10)`.
First-class functions strike back

A simple unsuspecting object (in JAVA, for variety):

```java
class Account {
    private float theBalance;
    private float theRate;

    Account (float b, float r) { theBalance = b; theRate = r; }

    public void deposit (float x) {
        theBalance = theBalance + x;
    }

    public void compound () {
        theBalance = theBalance * (1.0 + rate);
    }

    public float balance () { return theBalance; }
}
```

First-class functions strike back, part 2

The corresponding first-class function:

```scheme
(define (Account b r)
    (let ((theBalance b) (theRate r))
        (lambda (method)
            (case method
                ((deposit)
                    (lambda (x) (set! theBalance (+ theBalance x))))
                ((compound)
                    (set! theBalance (* theBalance (+ 1.0 theRate))))
                ((balance)
                    theBalance)))))

new Account(100.0, 0.05) is roughly equivalent to (Account 100.0 0.05).
```

OOP Pitfalls: the circle and the ellipse

A couple of facts:

- In mathematics, an ellipse (from the Greek for absence) is a curve where the sum of the distances from any point on the curve to two fixed points is constant. The two fixed points are called foci (plural of focus).  

- A circle is a special kind of ellipse, where the two foci are the same point.

If we need to model circles and ellipses using OOP, what happens if we have class Circle inherit from class Ellipse?

```java
class Ellipse {
    ...

    public move (double dx, double dy) { ... }

    public resize (double x, double y) { ... }
}

class Circle extends Ellipse {
    ...

    public resize (double x, double y) { ??? }
}
```

We can’t implement a resize for Circle that lets us make it asymmetric!
In Java, if class $B$ is a subclass of class $A$, then Java considers array of $B$ to be a subclass of array of $A$:

```java
class A { ... }
class B extends A { ... }

B[] b = new B[5];
A[] a = b; // allowed (a and b are now aliases)
a[1] = new A(); // Bzzzt! (Type error)
```

The problem is that arrays are mutable; they allow us to replace an element with a different element.