Case Study
Object-Oriented programming

Outline

- Prelude: Abstract Data Types
- The Object Model (Ada)
- Smalltalk

Ask not what you can do
for your classes,
Ask what your classes can do
for you.

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Prelude: Abstract Data Types

- Imperative programming paradigm
  - Algorithms + Data Structures = Programs [Wirth]
  - Produce a program by functional decomposition
    - Start with function to be computed
    - Systematically decompose function into more primitive functions
    - Stop when all functions map to program statements

Procedural Abstraction

- Concerned mainly with interface
  - Function
  - What it computes
  - Ignore details of how
  - Example: sort(list, length);

Data Abstraction

- Or: abstract data types
- Extend procedural abstraction to include data
  - Example: type float
- Extend imperative notion of type by:
  - Providing encapsulation of data/functions
  - Example: stack of int's
  - Separation of interface from implementation

Encapsulation

- **Definition**: *Encapsulation* is a mechanism which allows logically related constants, types, variables, methods, and so on, to be grouped into a new entity.

- Examples:
  - Procedures
  - Packages
  - Classes

Simple Stack in C

```
#include <stdio.h>

struct Node {
    int  val;
    struct Node* next;
};
typedef struct Node* STACK;

STACK stack = NULL;

int empty( ) {
    return stack == NULL;
}
```

```
int pop( ) {
    STACK tmp;
    int rslt = 0;
    if (!empty()) {
        rslt = stack->val;
        tmp = stack;
        stack = stack->next;
        free(tmp);
    }
    return rslt;
}

void push(int newval) {
    STACK tmp = (STACK)malloc(sizeof(struct Node));
    tmp->val = newval;
    tmp->next = stack;
    stack = tmp;
}

int top( ) {
    if (!empty())
        return stack->val;
    return 0;
}
```

A Stack Type in C

```
struct Node {
    int  val;
    struct Node* next;
};
typedef struct Node* STACK;

int empty(STACK stack);
STACK newstack( );
int pop(STACK stack);
void push(STACK stack, int newval);
int top(STACK stack);
```

Goal of Data Abstraction

- Package
  - Data type
  - Functions
- Into a module so that functions provide:
  - public interface
  - defines type

Generic Programming in Ada

```
generic
   type element is private;

package stack_pck is
   type stack is private;
   procedure push (in out s : stack; i : element);
   procedure pop (in out s : stack) return element;
   procedure isempty(in s : stack) return boolean;
   procedure top(in s : stack) return element;
```

- Similar to C++ templates

```
private
   type node;
   type stack is access node;
   type node is record
      val : element;
      next : stack;
   end record;
end stack_pck;
```

```
package body stack_pck is
   procedure push (in out s : stack; i : element) is
      temp : stack;
   begin
      temp := new node;
      temp.all := (val => i, next => s);
      s := temp;
   end push;
```

```
procedure pop (in out s : stack) return element is
    temp : stack;
    elem : element;
  begin
    elem := s.all.val;
    temp := s;
    s := temp.all.next;
    dispose(temp);
    return elem;
  end pop;
```

```
  procedure isempty(in s : stack) return boolean is
   begin
      return s = null;
   end isempty;

   procedure top(in s : stack) return element is
   begin
      return s.all.val;
   end top;
end stack_pck;
```

The Object Model

- Problems remained:
  - Automatic initialization and finalization
  - No simple way to extend a data abstraction

- Concept of a class
- Object decomposition, rather than function decomposition

Class

- **Definition**: A *class* is a type declaration which encapsulates constants, variables, and functions for manipulating these variables.

- A class is a mechanism for defining an ADT.

```
class MyStack {
    class Node {
        Object  val;
        Node next;
        Node(Object v, Node n) { val = v;
                 next = n; }
    }
    Node theStack;

    MyStack( ) { theStack = null; }

    boolean empty( ) { return theStack == null; }
```

```
Object pop( ) {
        Object result = theStack.val;
        theStack = theStack.next;
        return result;
    }

    Object top( ) { return theStack.val; }

    void push(Object v) {
        theStack = new Node(v, theStack);
    }
}
```

CONCEPTS IN OOP

- Constructor
- Destructor
- Client of a class
- Class methods (Java static methods)
- Instance methods

Concepts in OOP (II)

- OO program: collection of objects which communicate by sending messages
  - A invokes a method of B and pass params
  - A waits for return values from B
- Generally, only 1 object is executing at a time
- Object-based language (vs. OO language)
- Classes
  - Determine type of an object
  - Permit full type checking

Visibility

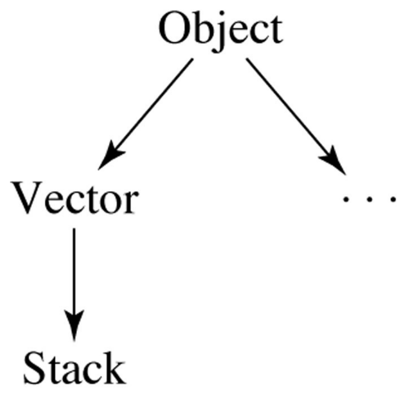
- public
- protected
- private

INHERITANCE (SUBTYPING)

- Class hierarchy
  - Subclass, parent or super class
- is-a relationship
  - A stack is-a kind of a list
  - So are: queue, deque, priority queue
- has-a relationship
  - Identifies a class as **a client of another class**
  - Aggregation
  - A class is an aggregation if it contains other class objects

Inheritance (II)

- In single inheritance, the class hierarchy forms a tree.
- Rooted in a most general class: *Object*
- Inheritance supports code reuse
- Remark: in Java a *Stack* extends a *Vector*
  - Good or bad idea?
  - Why?
- Single inheritance languages: Smalltalk, Java



Multiple Inheritance

- Allows a class to be a subclass of zero, one, or more classes.
- Class hierarchy is a directed graph
- Advantage: facilitates code reuse
- Disadvantage: more complicated semantics
  - Re: *Design Patterns* book mentions multiple inheritance in conjunction with only two of its many patterns.

Object Oriented Language

- **Definition**: A language is *object-oriented* if it supports
  - an encapsulation mechanism with information hiding for defining abstract data types,
  - virtual methods, and
  - inheritance

POLYMORPHISM

- Polymorphic - having many forms
- **Definition**: In OO languages *polymorphism* refers to the late binding of a call to one of several different implementations of a method in an inheritance hierarchy.

- Consider the call: `obj.m( );`
  - `obj` of type `T`
  - All subtypes must implement method `m( )`
  - In a statically typed language, verified at compile time
  - Actual method called can vary at run time depending on actual type of `obj`

  - Subtyping polymorphism

```
for (Drawable obj : myList)
        obj.paint( );
// paint method invoked varies
// each graphical object paints itself
// essence of OOP
```

Polymorphism (Cont'd)

- **Definition**: A subclass method is *substitutable* for a parent class method if the subclass's method performs the same general function.

- Thus, the *paint* method of each graphical object must be transparent to the caller. E.g.,
  - Button
  - Panel
  - Choice Box
- The code to paint each graphical object depends on the principle of *substitutability*.

Templates or Generics

- A kind of class generator
- Can restrict a Collections class to holding a particular kind of object
- **Definition**: A *template* defines a family of classes parameterized by one or more types.
- Prior to Java 1.5, clients had to downcast an object retrieved from a Collection class.

- Universal or parametric polymorphism: $\forall A.A \rightarrow A$

```
ArrayList<Drawable> list = new
ArrayList<Drawable> ();
...
for (Drawable d : list)
        d.paint(g);
```

Abstract Classes

- **Definition**: An *abstract class* is one that is either declared to be abstract or has one or more abstract methods.

- **Definition**: An *abstract method* is a method that contains no code beyond its signature.

- Any subclass of an abstract class that does not provide an implementation of an inherited abstract method is itself abstract.
- Because abstract classes have methods that cannot be executed, client programs cannot initialize an object that is a member an abstract class.
- This restriction ensures that a call will not be made to an abstract (unimplemented) method.

Expression Abstract Syntax

```
abstract class Expression { ... }
   class Variable extends Expression { ... }
   abstract class Value extends Expression { ... }
      class IntValue extends Value { ... }
      class BoolValue extends Value { ... }
      class FloatValue extends Value { ... }
      class CharValue extends Value { ... }
   class Binary extends Expression { ... }
   class Unary extends Expression { ... }
```

INTERFACES

- **Definition**: An *interface* encapsulates a collection of constants and abstract method signatures.
- An interface may not include either variables, constructors, or non-abstract methods.
- Difference between interface and abstract classes:
  - Interface:
    - All methods must be abstract
    - Only constants
  - Abstract class:
    - Some methods can be implemented
    - Objects can be declared

```
public interface Map {
    public abstract boolean containsKey(Object key);
    public abstract boolean containsValue(Object value);
    public abstract boolean equals(Object o);
    public abstract Object get(Object key);
    public abstract Object remove(Object key);
    ...
}
```

Interface and multiple inheritance

- Because it is not a class, an interface does not have a constructor, but an abstract class does.
- Some like to think of an interface as an alternative to multiple inheritance.
- Strictly speaking, however, an interface is not quite the same since it doesn't provide a means of reusing code; i.e., all of its methods must be abstract.
- An interface is similar to multiple inheritance in the sense that an interface is a type.
- A class that implements multiple interfaces appears to be many different types, one for each interface.

Virtual Method Table (VMT)

- How the appropriate virtual method is called at run time.
- At compile time the actual run time class of any object may be unknown.

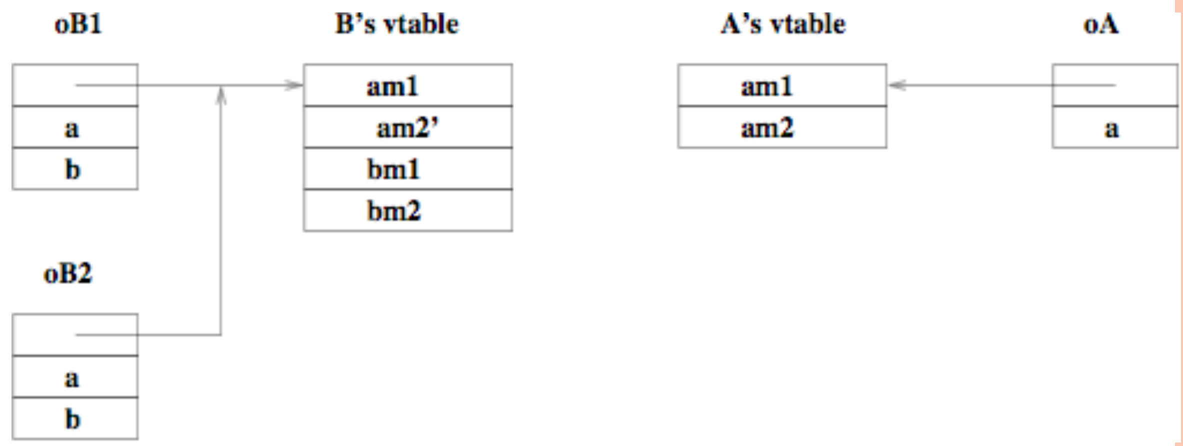
```
MyList myList;
...
System.out.println(myList.toString( ));
```

VMT (Cont'd)

- Each class has its own VMT, with each instance of the class having a reference (or pointer) to the VMT.
- A simple implementation of the VMT would be a hash table, using the method name (or signature, in the case of overloading) as the key and the run time address of the method invoked as the value.

- For statically typed languages, the VMT is kept as an array.
- The method being invoked is converted to an index into the VMT at compile time.

```
class A {
    Obj  a;
    void am1( ) { ... }
    void am2( ) { ... }
}
class B extends A {
    Obj  b;
    void bm1( ) { ... }
    void bm2( ) { ... }
    void am2( ) { ... }
}
```



Run Time Type Identification

- **Definition**: Run time type identification (RTTI) is the ability of the language to identify at run time the actual type or class of an object.
- All dynamically typed languages have this ability, whereas most statically typed imperative languages, such as C, lack this ability.
- At the machine level, recall that data is basically untyped.

- In Java, for example, given any object reference, we can determine its class via:
- Class c = obj.getClass( );

Reflection

- Reflection is a mechanism whereby a program can discover and use the methods of any of its objects and classes.

- Reflection is essential for programming tools that allow plugins (such as Eclipse -- www.eclipse.org) and for JavaBeans components.

- In Java the *Class* class provides the following information about an object:
  - The superclass or parent class.
  - The names and types of all fields.
  - The names and signatures of all methods.
  - The signatures of all constructors.
  - The interfaces that the class implements.

```
Class class = obj.getClass( );
Constructor[ ] cons = class.getDeclaredConstructors( );
for (int i=0; i < cons.length; i++) {
    System.out.print(class.getName( ) + "(" );
    Class[ ] param = cons[i].getParameterTypes( );
    for (int j=0; j < param.length; j++) {
        if (j > 0) System.out.print(", ");
            System.out.print(param[j].getName( );
    }
    System.out.println( ")" );
}
```

SMALLTALK

- The original object-oriented language
- Developed in 1970s at Xerox PARC
- Xerox Alto
  - Smalltalk system
  - OS
  - IDE
  - mouse based GUI
  - Steve Jobs visit - Macintosh

General Characteristics

- Simple language
- Most of the class libraries written in Smalltalk
- Everything is an object, even control structures
- Excluding lexical productions, grammar has 21 production rules (3 pages)

- The value of every variable is an object; every object is an instance of some class.
- A method is triggered by sending a message to an object.
  - The object responds by evaluating the method of the same name, if it has one.
  - Otherwise the message is sent to the parent object.
  - The process continues until the method is found; otherwise an error is raised.
- All methods return a value (object).

- Precedence
  - Unary messages, as in: `x negated`
  - Binary messages, as in: `x + y`
  - Keyword messages, as in: `Turtle go: length`
- In the absence of parentheses, code is evaluated from left to right.

- Examples:
  - x + y * z squared
  - a max: b - c
  - anArray at: i put: (anArray at: i + 1)

- By default, Smalltalk uses infinite precision, fractional arithmetic.
  - 1/3 + 2/6 + 3/9 evaluates to 1.

```
(a > b) ifTrue: [ max := a ]
        ifFalse: [ max :=  b ].
```

- [ ] - uninterpreted block
- A block is like an object, too
- Boolean methods: ifFalse: and ifTrue:
- ifTrue: If the object is the true object, it executes the code block it has been handed. If it is the false object, it returns without executing the code block.
- ifFalse: symmetrical

Blocks

```
sum := 0.
1 to: n do: [ :i | sum := sum + (a at: i) ].

sum := 0.
a do: [ :x | sum := sum + x ].

sum := 0.
i := 1.
[ i <= n ] whileTrue: [
    sum := sum + (a at: i).
    i := i + 1].
```

```
"True methods"
ifTrue: trueBlock ifFalse: falseBlock
        ^ trueBlock value
ifTrue: aBlock
        ^ aBlock value
ifFalse: aBlock
        ^ nil
ifFalse: falseBlock  ifTrue: trueBlock
        ^ trueBlock value
```

Examle: Polynomials

- Represent Polynomials: $3x^2 + 5x - 7$
- Representation: #(-7 5 3)
- Subclass of Magnitude

```
Magnitude subclass: #Polynomial
        instanceVariableNames: 'coefficient'
        classVariableNames:: ''
        poolDictionaries: ''

new
        "Unary class constructor: return 0*x^0"
        ^ self new: #( 0 )

new: array
        "Keyword class constructor"
        ^ (super new) init: array
```

```
init: array
    "Private: initialize coefficient"
    coefficient := array deepCopy

degree
    "Highest non-zero power"
    ^ coefficient size - 1

coefficient: power
    "Coefficient of given power"
    (power >= coefficient size) ifTrue: [ ^ 0 ].
    ^ coefficient at: power + 1
```

```
asArray
	^ coefficient deepCopy

= aPoly
	^ coefficient = aPoly asArray

!= aPoly
	^ (self = aPoly) not

< aPoly
	"not defined"
	^ self shouldNotImplement
```