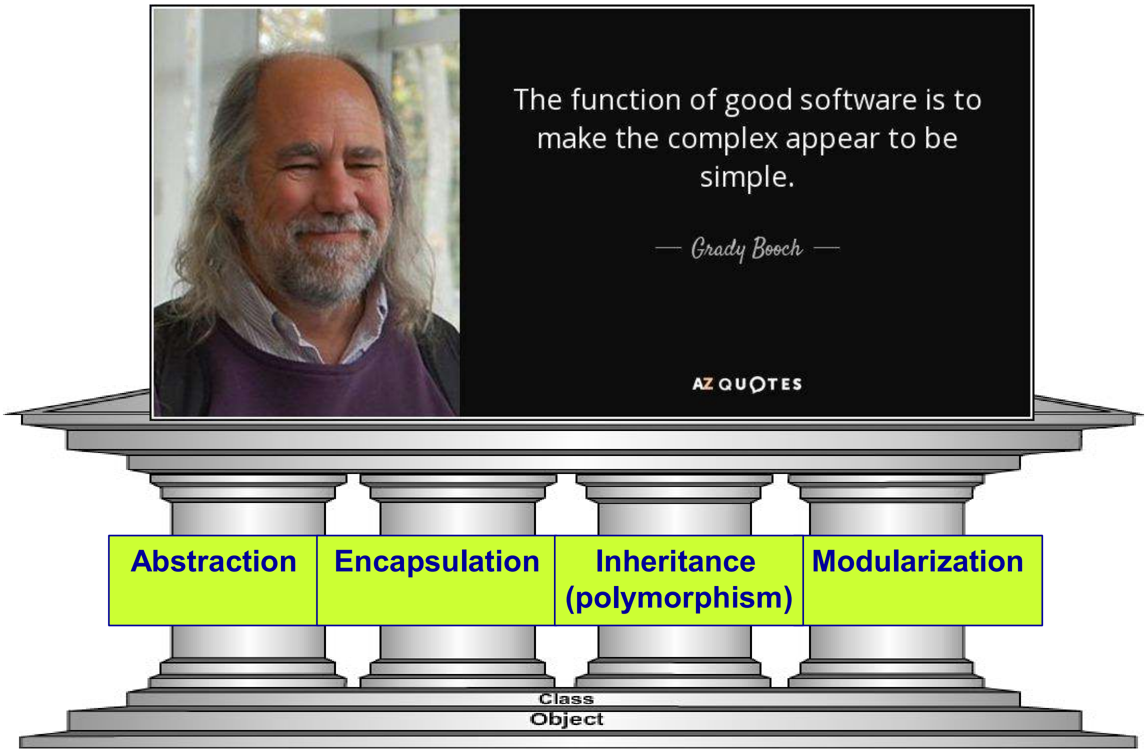
Object-Oriented Analysis and Design using UML and Patterns

Fundamentals of

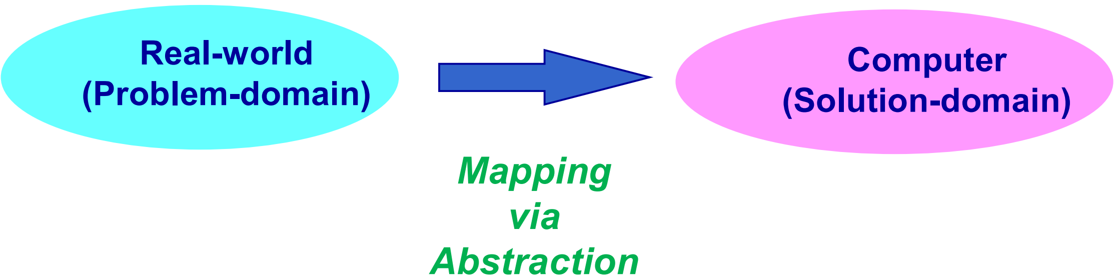
Object-Oriented Concepts

Four Pillars of Object-Orientation



Is Object-Oriented Programming… ?

If we see OO from the *evolutionary* perspective, *it is an* approach to mastering the software complexity



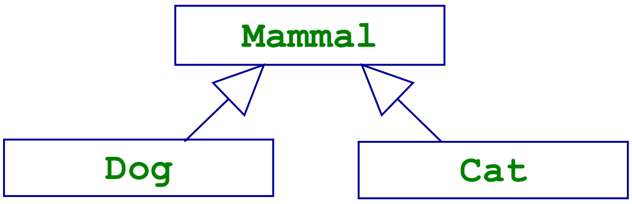
Assembly Language (Mnemonics)
Human-oriented Languages (High Level Languages)
Subprograms (Procedures or Functions)
Modules
Abstract Data Types
Objects

OO paradigm builds on three important concepts of objects, classes and inheritance

Objects

Classes

Inheritance



OO also requires 'polymorphism'
(i.e., dynamic binding)

Question 1

What is an Object?

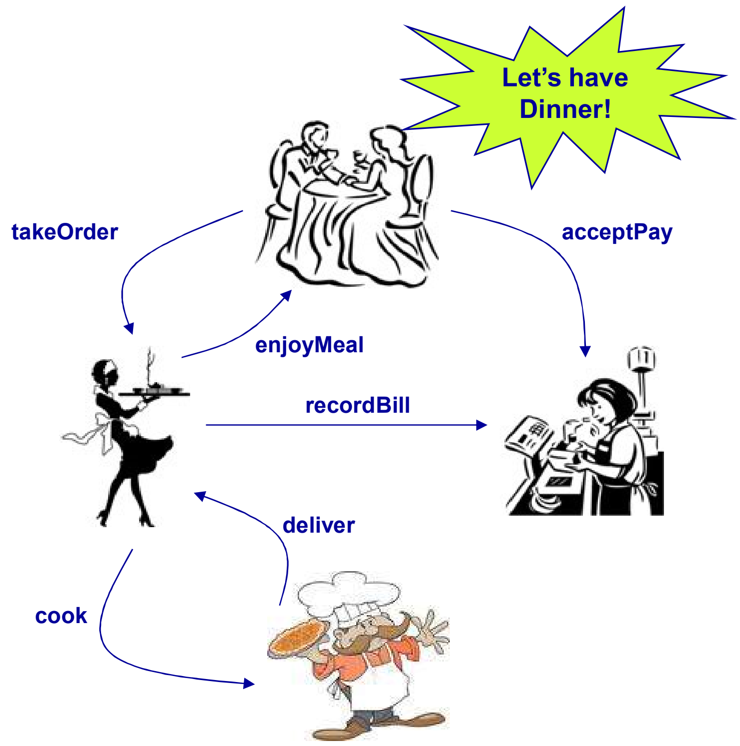
① **Instance of a class**
② **Encapsulated entity with state and behavior**
③ **Entity with unique identity**
④ **Things or concepts with crisp boundary**

Objects are building blocks of software systems

A program is a collection of interacting objects

Objects communicate by sending ‘messages’ to each other

In this way, they cooperate to complete a task



Objects are things or concepts with crisp boundaries and meaning *(for the problem at hand)*

Tangible Things

Customer
Store
Parking Lot
Car
Tire
…

Concepts & Processes

Strategy
Contract
Class Meeting
Finding a path through a maze
Sorting a card deck
…

Objects may have attributes that describe them

Are these also objects?

Color
Beauty
Hungry
Anger
Love
Time
Age
Address
…

Attributes

Objects must have externally observable behaviors as a result of performing operations

Every object has a **service** that an object offers to its clients (or **responsibility** that it performs for them)

The services/responsibilities are represented as a set of operations

The set of operations constitute an **interface** (or **type**) of an object

Objects may have states which could affect how objects act or react

Can you get cokes or snacks at any time from the machine? If not, why?

The behavior of the vending machine may depend on time or the order in which one operates on the machine.

This time-dependent behavior implies the existence of state within the vending machine.

The state of an object is determined by the current (usually dynamic) values of each of the attributes

Attributes can be:

Coins deposited,

Change,

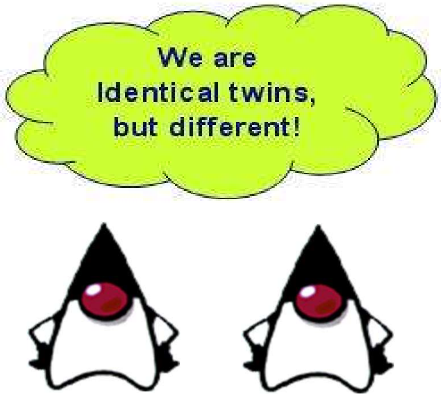
Height,

Current number for each items

etc.

It is good engineering practice to **encapsulate** the state of an object rather than expose it

Objects have unique identities



Identity is that property of an object that distinguishes itself from all other objects

How many button objects exit in the code?

```
class Button { ... };

Button  b1 = new Button();
Button  b2 = b1;
```

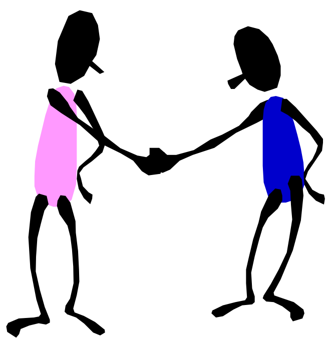
Do not confuse between the name (or handle) of an object and the object itself!

Objects perform actions by making requests of each other through a mechanism of messages

No object exists in isolation. Objects must collaborate with other objects by exchanging **messages**

A message is **a request for action**

An object may accept a message, and in return will perform an action and may return a result



Message passing is equivalent to **invoking an operation** (**method** in Java or **member function** in C++) on another object

In a message, there is a designated *receiver* (or *target*) that accepts the message

When we send a message to an object obj, the obj is a receiver object

```
// In C++, if obj is a pointer var
obj->msg();

// In C++, if obj is a ref. var
obj.msg();

// In Java, obj must be ref. var.
obj.msg();
```

The actual behavior performed by the receiver may be different, depending upon the type of the receiver.

→ ***Polymorphism!***

Ask not what you can do to your objects, but ask what your objects can do for you

Anthropomorphism
(i.e, live objects)

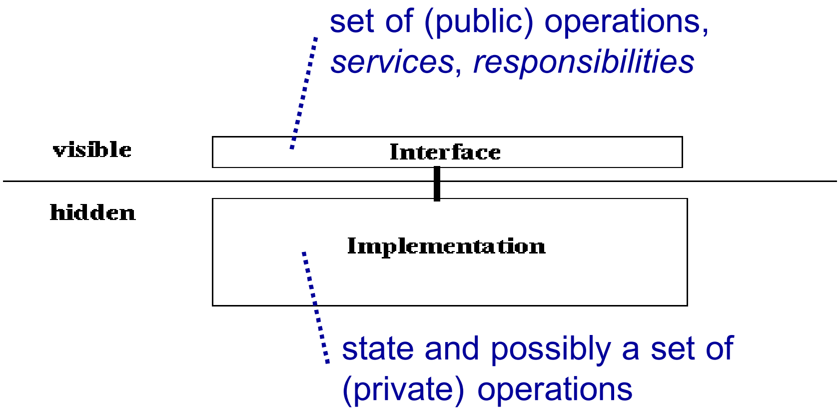
"Instead of a bit-grinding processor ... plundering data structures, we have a universe of well-behaved objects that courteously ask each other to carry out their various desires"
-- Dan Ingalls

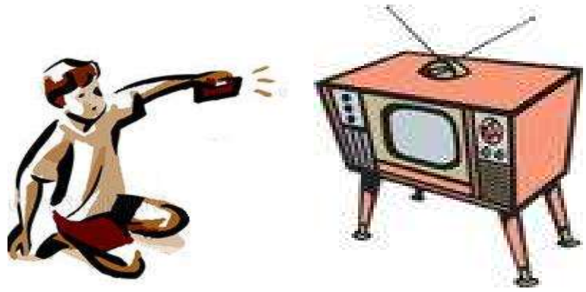
It is good engineering practice to encapsulate implementation details rather than expose it

Encapsulation:
separation of interface from implementation

Object is a black box. Its internal workings and parts are hidden.

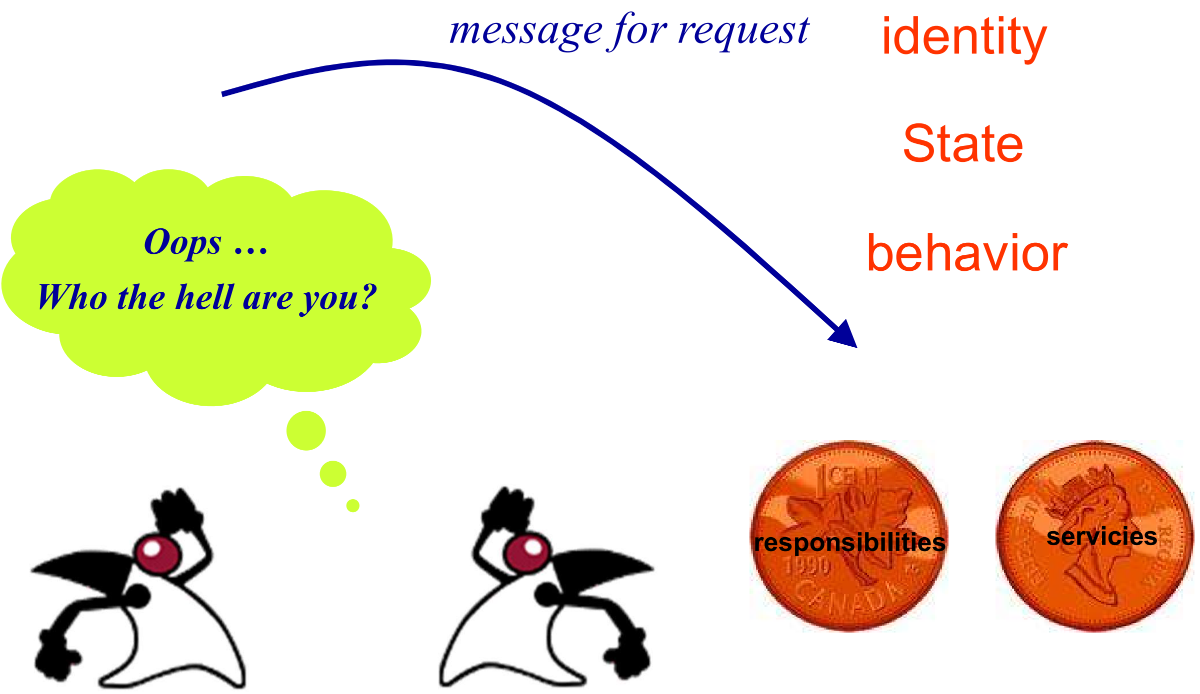
Helps code reuse and reliability
- strong cohesion
- loose coupling





Do not need to know how an object will perform actions, but need to know what messages it will understand

An object is an encapsulated entity with behavior, state, and unique identity



Question 2

What is a Class?

Why do we need classes in addition to objects?

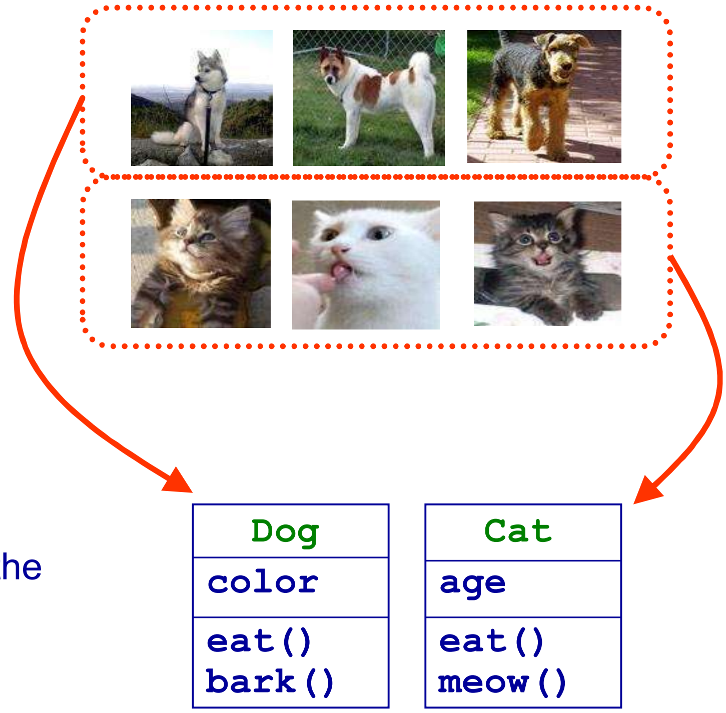
① Type
② Category
③ Repository for behavior and representation
④ Object template

A class is a group of objects with the same attributes, behavior, relationships, and semantics

There are too many objects in the real world, which is impractical to handle

Classifying objects factors out commonality among sets of similar objects
- describe what is common just once
- create any # of copies later

A class is a repository for behavior and the internal representation of the associated objects

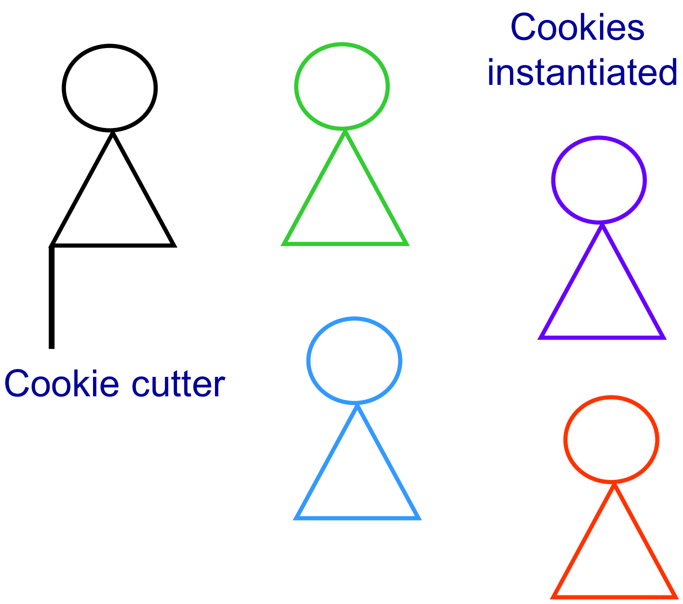


Objects are created from classes through the process of instantiation

Objects are actual **instances** of a class

Classes are cookie cutters that make cookies
- As cookie cutter is not a cookie by itself, a class is not an object by itself.

Classes are **factories** and objects are **products** from the factory.



The terms **instance** and **object** are interchangeable.

Instances created from the same class may or may not have the identical attribute values, but they are unique at all times

class

Student

Name: String
yearBorn: int
height: int

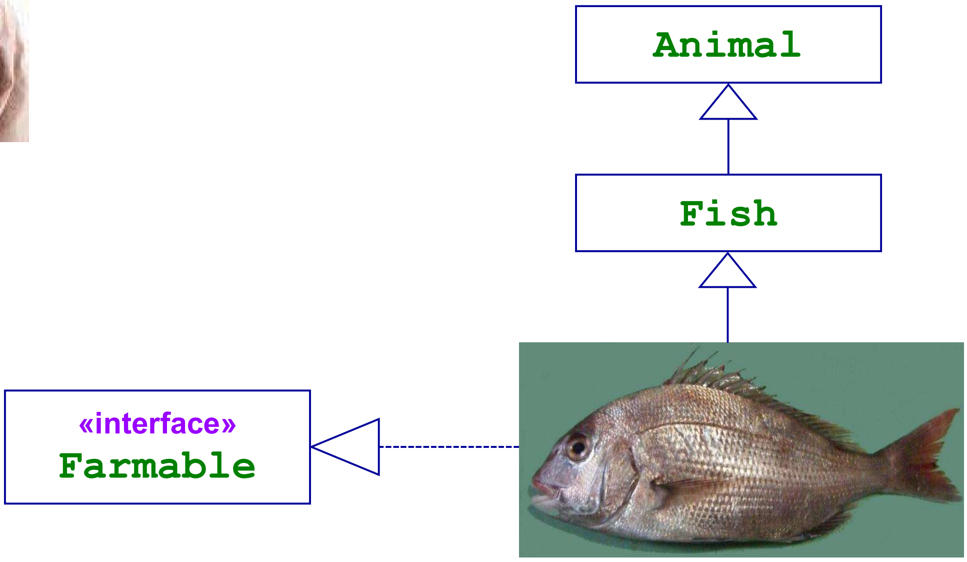
study()

object	object	object
s1:Student	s2:Student	s3:Student
Name="송중기"	Name="송혜교"	Name="송혜교"
yearBorn=1985	yearBorn=1981	yearBorn=1981
height=178	height=161	height=161

Student s1 knows how to do everything student s2 does, but s1 is not s2 or vice versa. Even the s2 and s3 are different.

Question 3

It is possible for a given object to have more than one types other than the type defined by its class?



An object's *interface* is a set of all signatures that can be sent to the object

A operation's **signature** is
type of its return value, → `void`
the operation's name, → `paintIcon(`
types of its parameters → `Component c,Graphics g,int x,int y )`

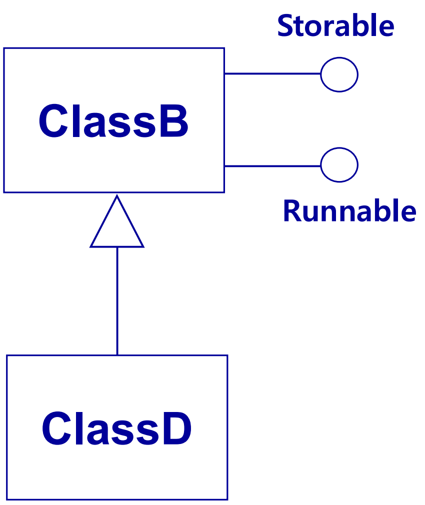
Icon Interface

```
int getIconHeight()
int getIconWidth()
void paintIcon(Component c,Graphics g,int x,int y)
```

An object's **type** is a name denoting only a particular interface

Since a class defines the operations an object can perform, it also defines the object's type

An object can have many types and objects of different classes can have the same type



Types of a:ClassD

ClassD, ClassB, Storable, Runnable

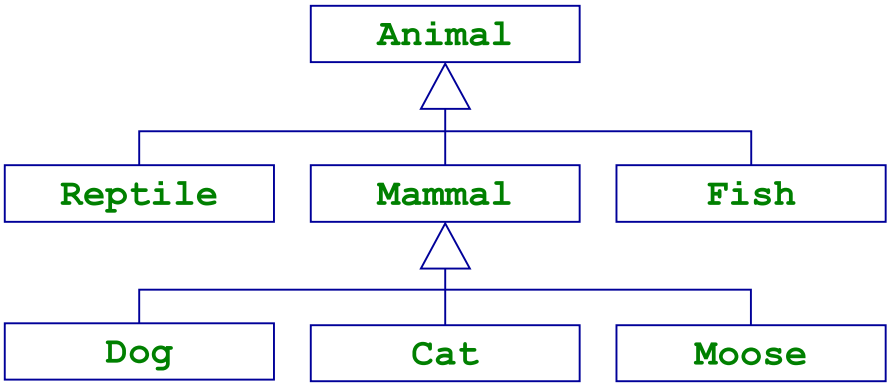
Both a:ClassD and b:ClassX are of type

Runnable

Classes might be organized into a tree called an inheritance hierarchy

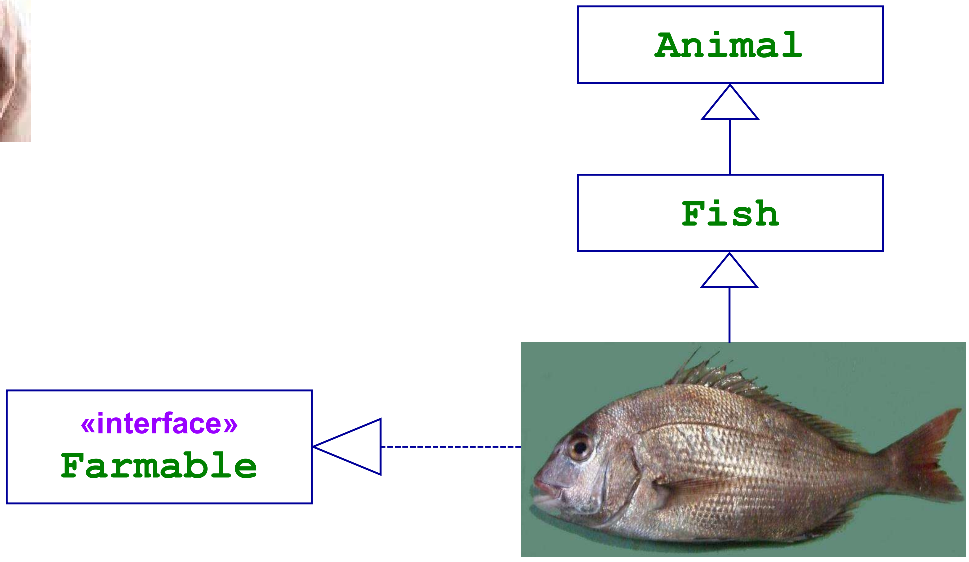
Inheritance allows us to arrange class definitions that reflect natural category hierarchies

Information (data and/or behavior) that can be found at a level in a class hierarchy is automatically applicable to lower levels of the hierarchy.



Question 4

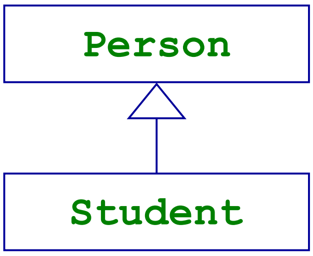
What is polymorphism and why is it important?



Question 5

If "Student" is defined to be a subclass of "Person", what does this hierarchy imply?

In other words, what kind of relationship does these two classes have and what is the intention of the designer for this hierarchy.



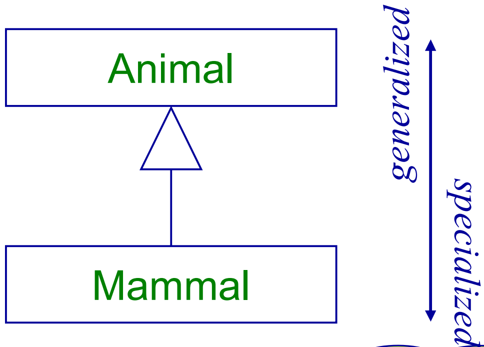
The single most important rule in OO is this: (Public) inheritance means *"is-a"* relationship (aka, *generalization/specialization* relationship)

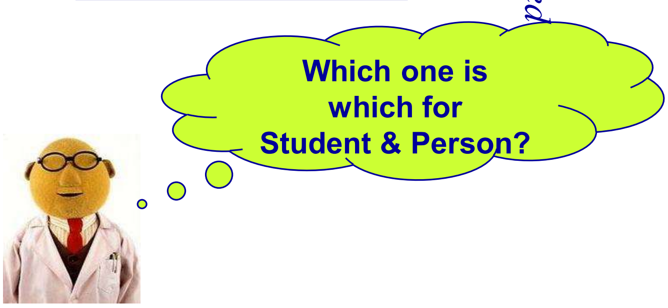
A Mammal *is an* Animal

A Student *is a* Person

Animal is called a **superclass** or **base class**

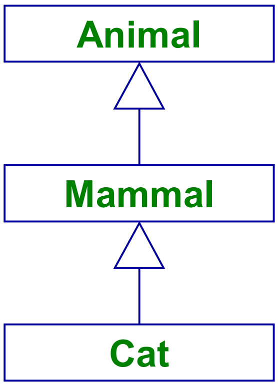
Mammal is called a **subclass** or **derived class**





A class can be a superclass as well as a subclass at the same time and the "is_a" relationship is transitive

A Mammal *is an* Animal

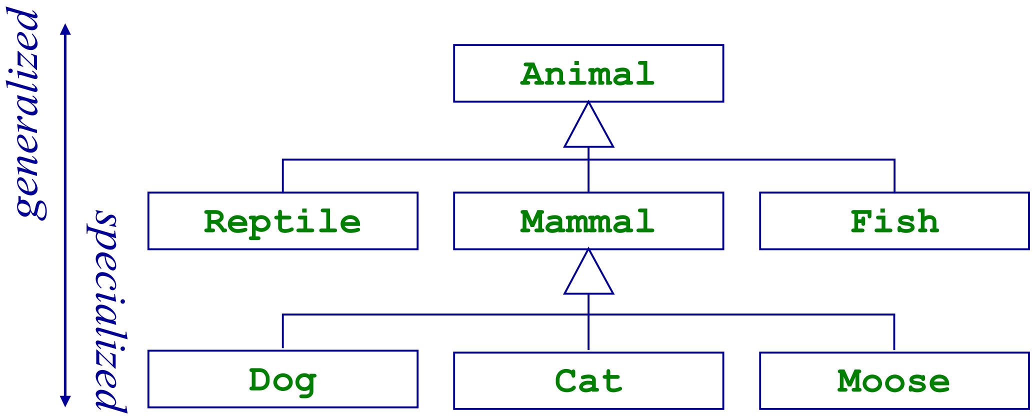


Mammal is a superclass of Cat and a subclass of Animal

A Cat *is a* Mammal

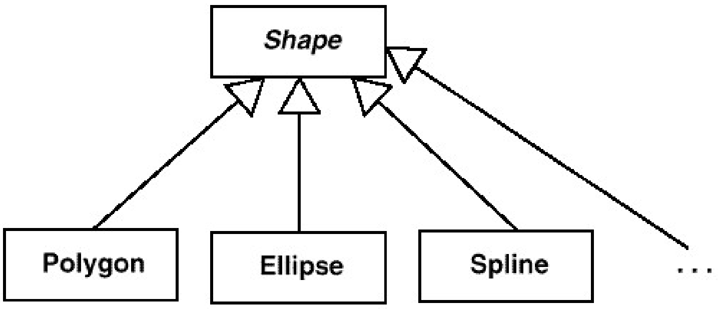
Transitivity: A Cat is an Animal, too

More than one classes can inherit from a given class

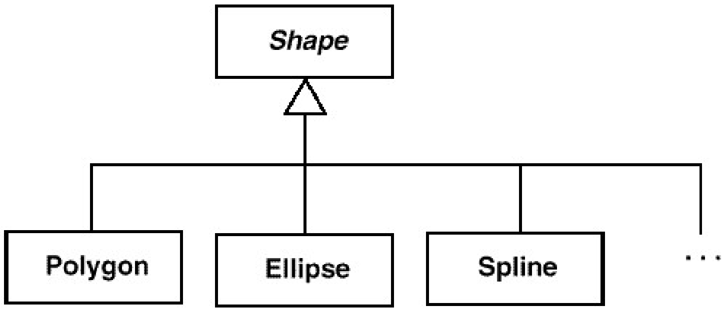


The root provides more general properties shared by all its descendents while the descendents typically add specializing properties which make them distinct among their siblings and their sibling's descendents

UML Notation

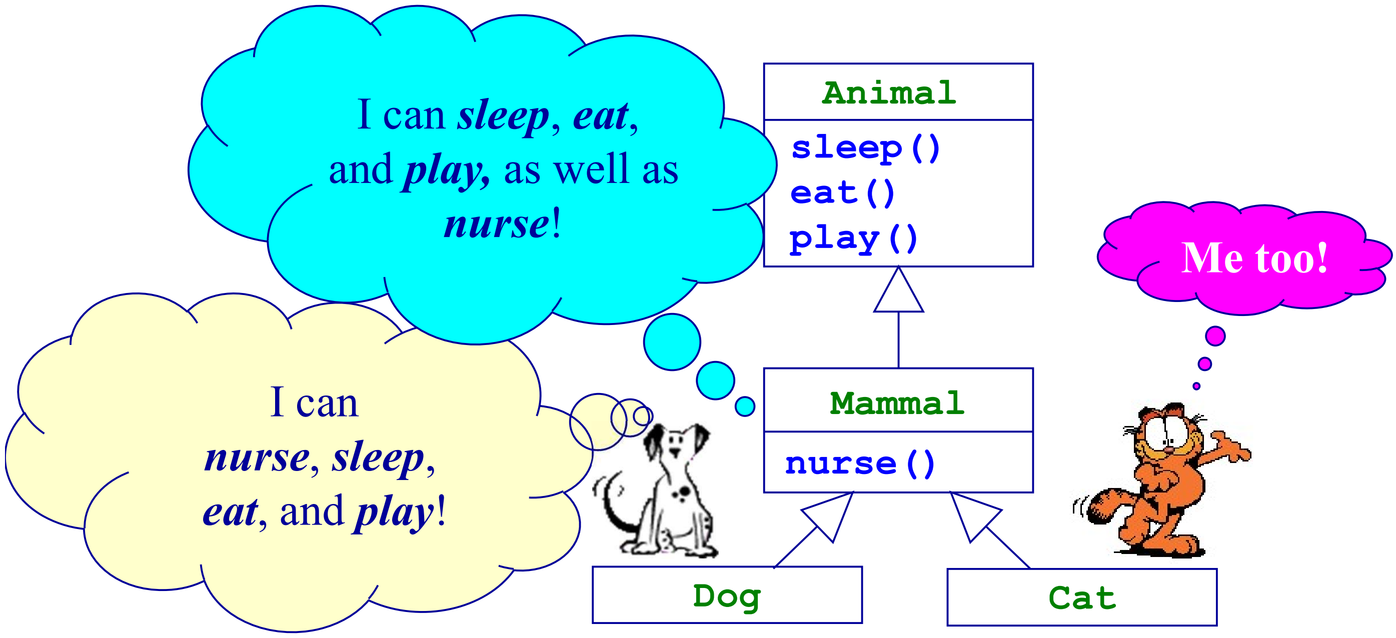


(a) Separate Target Style



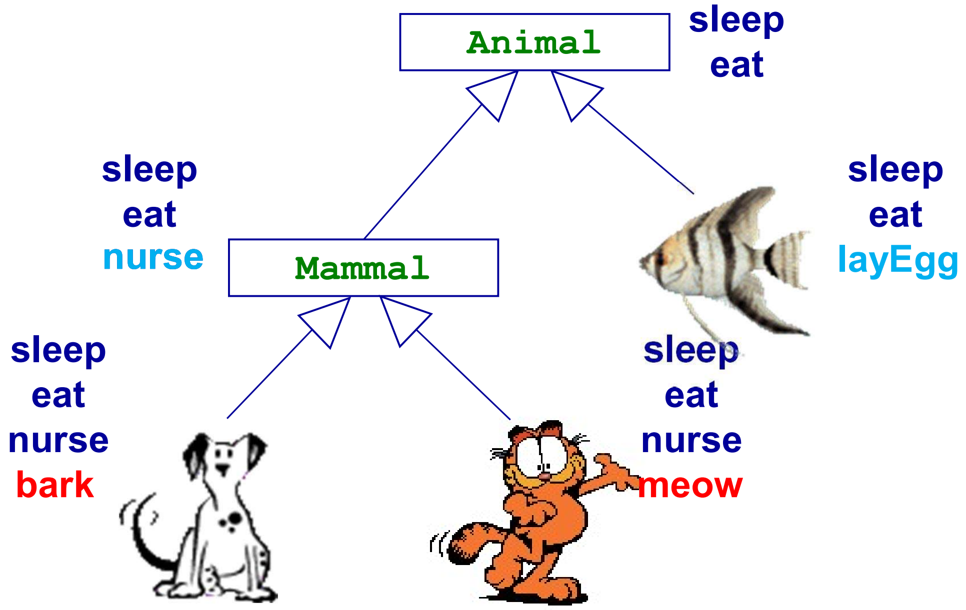
(b) Shared Target Style

Subclasses inherit all attributes and operations from its superclass and its ancestors



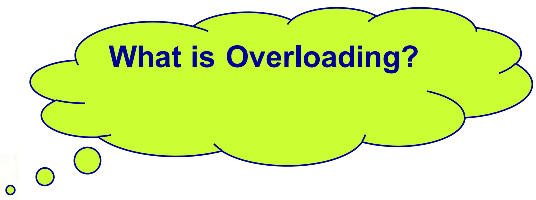
Information (data and/or behavior) that can be found at a level in a class hierarchy is automatically applicable to lower levels of the hierarchy

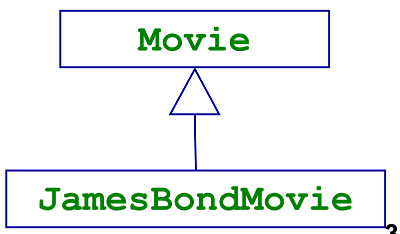
Superclass factors out members common to its subclasses



Subclasses can redefine inherited operations (Overriding)

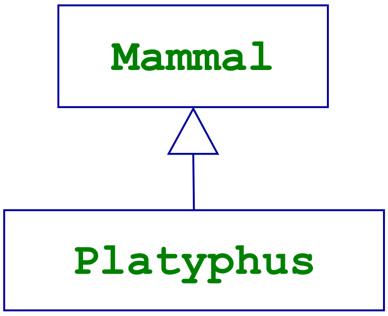
```
public class Movie extends Attraction {
  public int rating() {
    return scripting + acting + directing;
  }
}
public class JamesBondMovie extends Movie {
  public int rating() { // overriding
    return 10 + acting + directing;
  }
}
```





Operations must have the same signatures

One Big Mistake (?) in One of the Famous OO Books!



Subclasses can alter or override information inherited from parent classes:

- ➔ All mammals give birth to live young
- ➔ A platypus is an egg-laying mammal

The practical meaning of the *"is a"* relationship

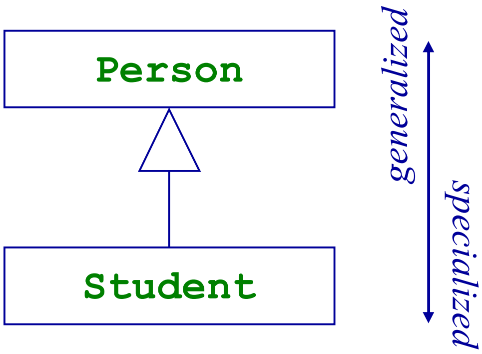
Every object of Student type is also an object of Person type, *but not vice-versa*

Person represents a more general concept than Student, and Student represents more specialized concept than Person

Anything that is true of an object of Person type is also true of an object of Student type, *but not vice-versa*

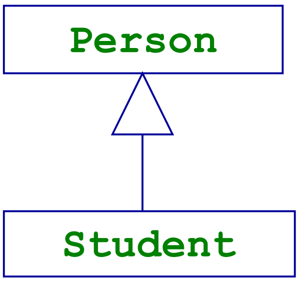
Student *is a* Person

```
class Person { ... };
class Student :
      public Person { ... }
```



Anything a superclass can do, a subclass can do as well

Anywhere an object of Person type can be used, an object of Student type can also be used just as well, *but not vice versa*
→ **Liskov Substitution Principle (LSP)**




```
class Person { ... };
class Student : public Person { ... }

void sleep(const Person& p);      // anyone can sleep
void study(const Student& s);     // only students study (?)

Person p;      // p is a Person
Student s;     // s is a Student

sleep(p);     // OK, p is a Person
sleep(s);     // OK, s is a Student & a Student is-a Person

study(s);     // OK
study(p);     // Error! - p is not a Student
```


A pointer (or reference) to a subclass can be implicitly converted to a pointer (or reference) to a superclass, but *not vice versa*

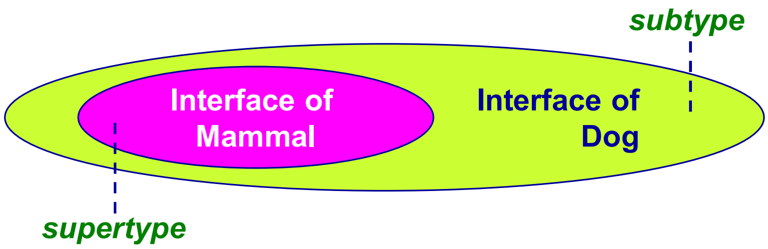
```
Student s;
Person* pPtr = &s;   // OK

Person p;
Student* sPtr = &p;
```

Error! - needs explicit casting
`sPtr = dynamic_cast<Student*>(&p)`

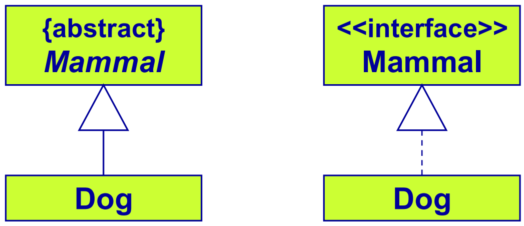
Subclass designers decide what to share: Interface or Implementation?

A type is a **subtype** of another if its interface contains the interface of its **supertype**



Subtyping uses inheritance as a mechanism for **interface sharing**

- enforces the "**is_a**" relationship
- also called **interface inheritance**

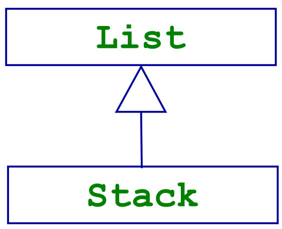


Most common mechanism for interface sharing

Subclass designers decide what to share: Interface or Implementation? (Cont'd)

Subclassing uses inheritance as a mechanism for **implementation sharing** (i.e., code and representation sharing)

- enforces "**implemented in terms of**" relationship
- also called **class inheritance** or **implementation inheritance**



The interface of List should not be visible to the clients of Stack!

Superclass designers must decide what to pass down for each operation when gets inherited.

```
class Shape {
public:
   virtual void draw() const = 0;          // pure virtual
   virtual void error(const string& msg);  // virtual
   int objectID() const();                 // nonvirtual
}

class Circle : public Shape { ... };
class Rectangle : public Shape { ... };
```

Inheritance comes in two flavors at function-level:

- inheritance of **function interface only** and

- inheritance of **function interface & implementation**

As a class designer, we need to explicitly specify our intention using appropriate types of member functions (or methods)

Pure virtual function: `virtual void draw() const = 0;`

To have derived class inherit a **function interface only**

Virtual function: `virtual void error(const string& msg);`

To have derived classes inherit **a function interface as well as a default implementation**

Nonvirtual function: `int objectID() const();`

To have derived classes inherit **a function interface as well as a mandatory implementation**

A reference (or pointer) variable has two types associated with it

Static type

- the type declared at program
- fixed and never changed

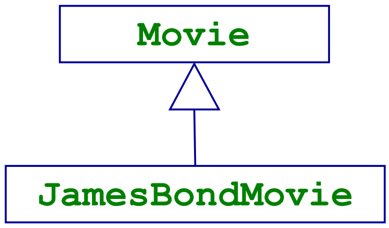
Dynamic type

- the type of object it actually refers to
- can be changed during lifetime

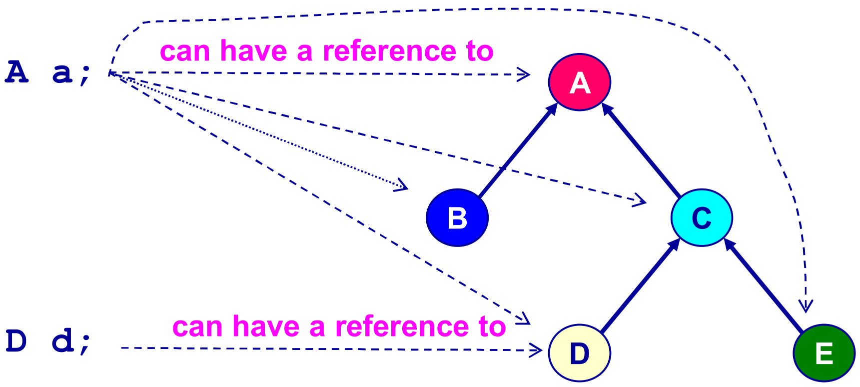
Example:

```
Movie m = new Movie();
m = new JamesBondMovie();

JamesBondMovie jm;
jm = new JamesBondMovie();
m = jm;
jm = m; // error!
```



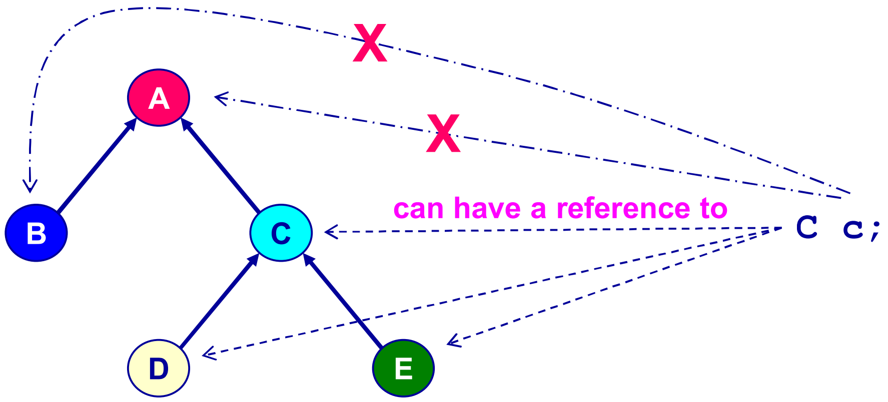
A subclasses can be assigned to its superclass, but not *vice versa*



Rule: A reference variable of type *A* (e.g., Movie) can have a reference to an instance of any subclass *extended* from *A* (e.g.,a JamesBondMovie)

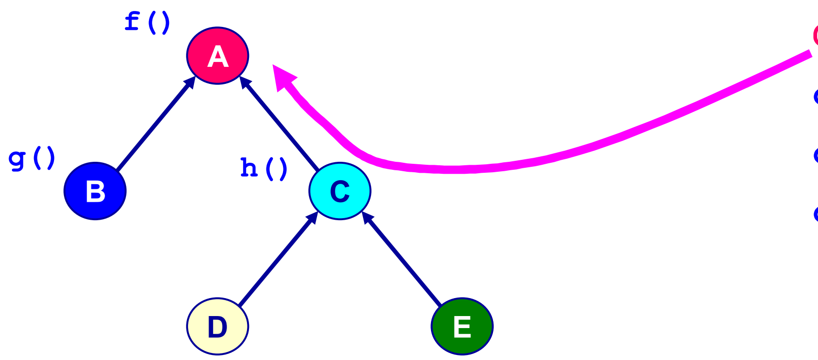
```
A a = new A(); // OK
a = new C();   // OK
B b = new B(); // OK
          …
a = b;         // OK
```

A superclass cannot be assigned to its subclass




```
A a = new A(); // OK
C c = new C(); // OK
a = c;    // OK
…
c = a;    // Error!
```


When a message is sent to a receiver object, the compiler checks its legality by performing an operation lookup using static type




```
C obj = new C();
obj.h();     // OK
obj.f();     // OK
obj.g();     // illegal!
```

The compiler searches up **starting from the static type**
until it finds the invoked operation

A subclass can do anything a superclass can do, but not vice versa

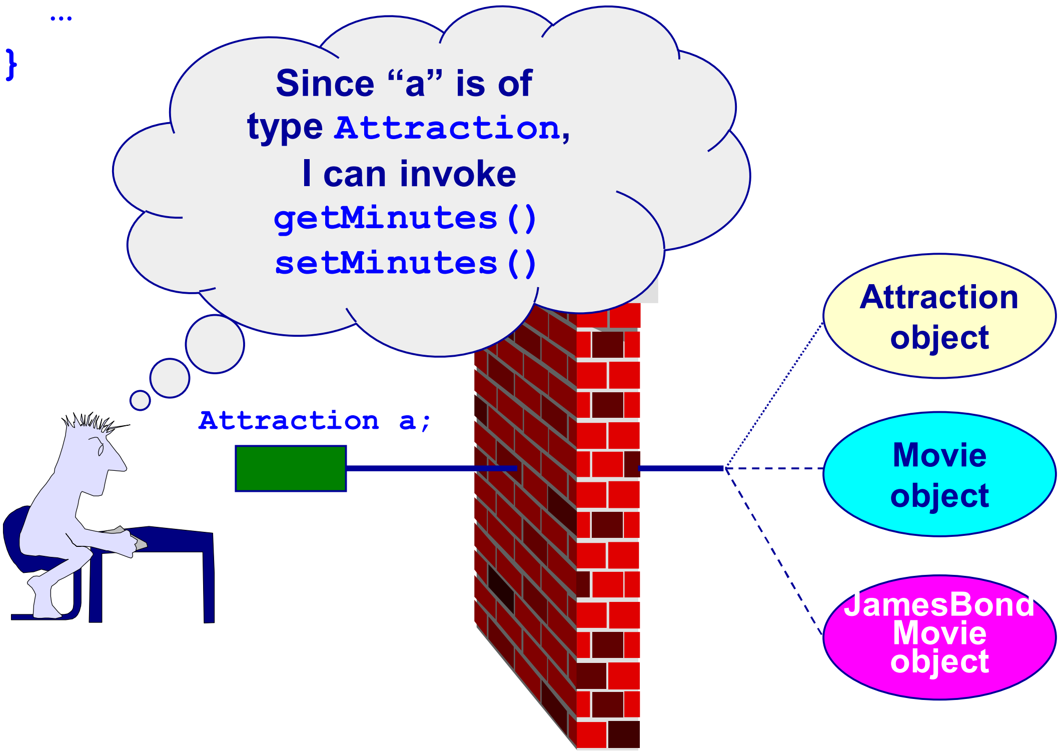
```
void someMethod(Attraction attraction) {
  int minutes = attraction.getMinutes();
  …
  attraction.setMinutes(minutes);
}
```

Since user of an object can access it's operations only through a reference variable, all she knows is the set of operations defined in the class of the variable's static type

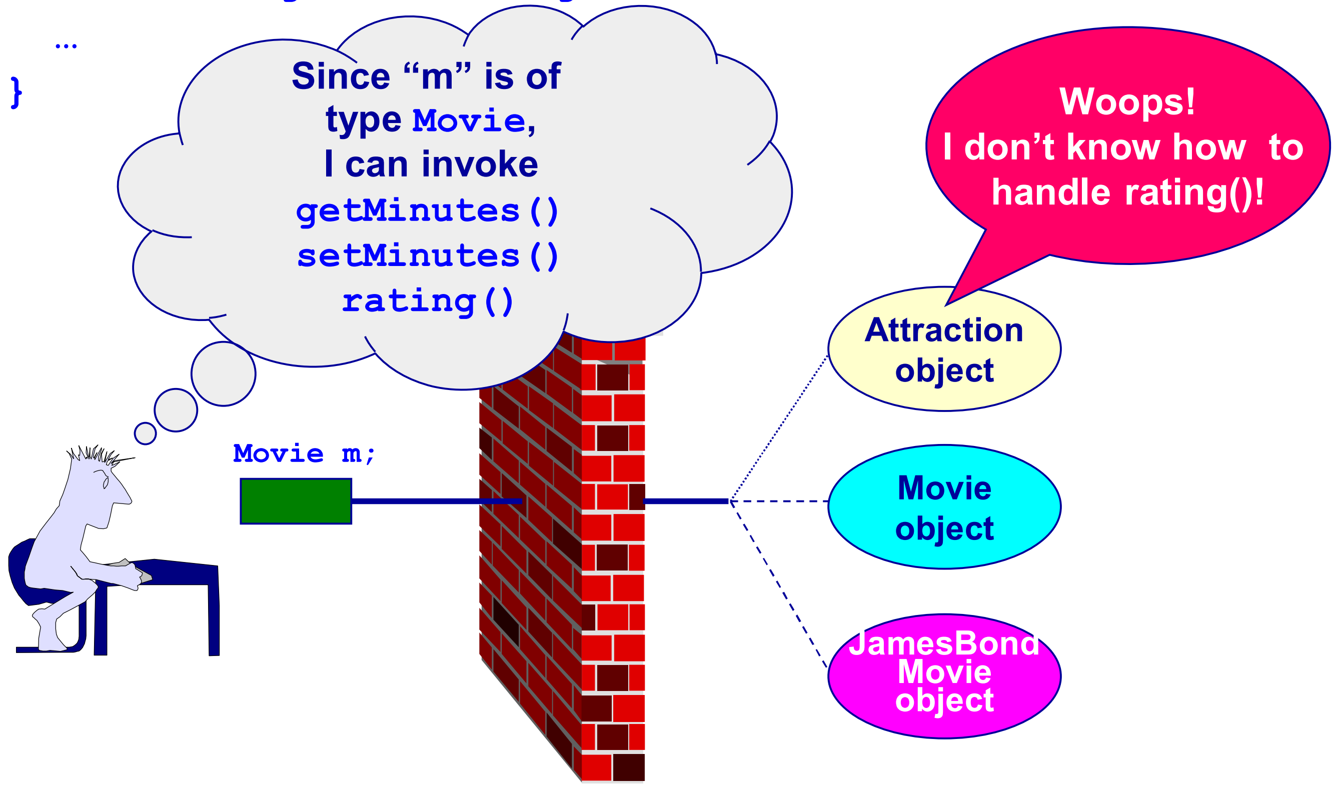
A subclass inherits operations from all of its ancestors

Therefore, it is safe to send a message for its superclass to an instance of a subclass, but *not vice versa*.

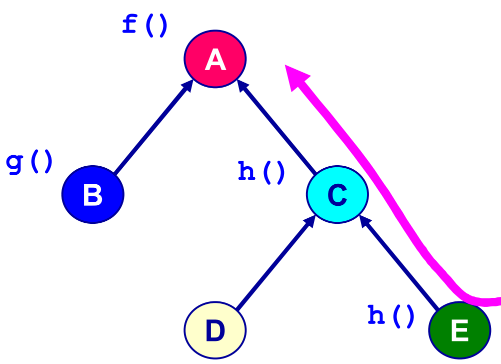

```
void someMethodA(Attraction a) {
  int minutes = a.getMinutes();
  …
}
```



```
void someMethodB(Movie m) {
  int rating = m.rating();
  …
}
```



When a message is sent to a receiver, the runtime selects an operation using dynamic type




```
C obj = new E();
obj.h();      // E's h()
obj.f();      // A's f()
obj.g();      // illegal!
C obj = new C();
obj.h();      // C's h()
```

The runtime searches up **starting from the dynamic type** until it finds the first invoked operation

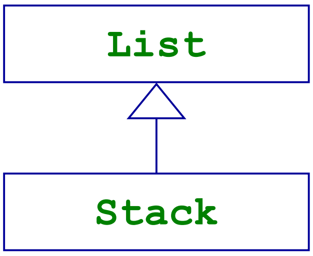
Question 7

Consider an inheritance hierarchy in which "Stack" is defined as a subclass of "List".

Item insertions and deletions can be performed only at the top of the Stack, whereas both operations are permitted at either front or rear of the List.

What do you think of this hierarchy design?

```
class Stack extends List {
        void push(Object o) { insert_front(o); }
        void pop() { delete_front(); }
        Object top() { return first(); }
}
```

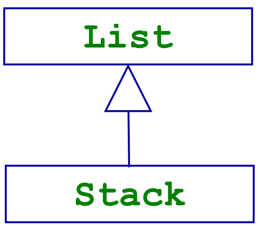


Subclass designers decide what to share: Interface or Implementation? (Cont'd)

Subclassing uses inheritance as a mechanism for *implementation sharing* (i.e., code and representation sharing)

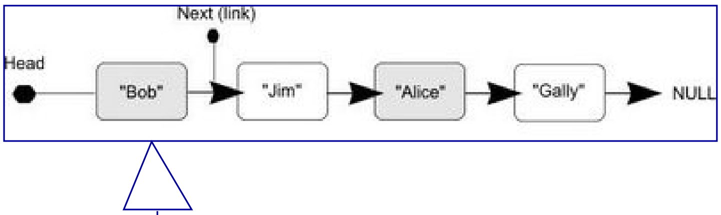
- enforces *"implemented in terms of"* relationship

- also called *class inheritance* or *implementation inheritance*



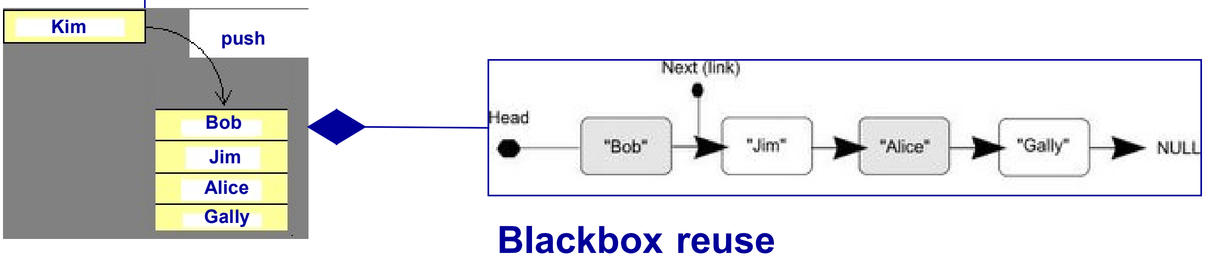
The interface of List should not be visible to the clients of Stack!

The two most common techniques for reusing functionality are *class inheritance* and *object composition*



Whitebox reuse

- internals of parent classes are often visible to subclasses



Blackbox reuse

- no internal details of objects are visible

Fragile Base Class (FBC) Problems: Example I

Seemingly unharmful modification to base class can cause a significant problem!

Beware of self-recursion!

```
Bag = class                              CountingBag = class
    b : bag of char                      inherits Bag
                                             n : int
    init ≙ b := ⟦ ⟧                          init ≙ n := 0; super.init
    add(val x : char) ≙                      add(val x : char) ≙
        b := b ∪ ⟦x⟧                             n := n + 1; super.add(x)
    addAll(val bs : bag of char) ≙
        while bs ≠ ⟦ ⟧ do
            begin var y | y ∈ bs·
                self.add(y);
                bs := bs − ⟦y⟧
            end
        od
    cardinality(res r : int) ≙               cardinality(res r : int) ≙
        r := |b|                                 r := n
end                                      end

        Bag′ = class
            b : bag of char
            init ≙ b := ⟦ ⟧
            add(val x : char) ≙ b := b ∪ ⟦x⟧
            addAll(val bs : bag of char) ≙ b := b ∪ bs
            cardinality(res r : int) ≙ r := |b|
        end
```

Fragile Base Class (FBC) Problems: Example II

Consider a call sequence
obj.n ; obj.m

Do not modify inherited attributes!

$$\begin{array}{ll} C \;=\; \textbf{class} \\ \quad x : int := 0 \\ \quad m \;\widehat{=}\; x := x + 1 \\ \quad n \;\widehat{=}\; x := x + 2 \\ \textbf{end} \end{array} \qquad \begin{array}{ll} \textit{DerivedC} \;=\; \textbf{class} \\ \quad \textbf{inherits } C \\ \\ \quad n \;\widehat{=}\; x := x + 5 \\ \textbf{end} \end{array}$$

$$\begin{array}{l} C' \;=\; \textbf{class} \\ \quad x : int := 0; y : int := 0 \\ \quad m \;\widehat{=}\; y := y + 1; x := y \\ \quad n \;\widehat{=}\; y := y + 2; x := y \\ \textbf{end} \end{array}$$

methods of C' implicitly maintain an invariant, $x = y$.

Question 7

Are these two codes equivalent in terms of their behavior?

```java
// In JAVA
class Foo {
    private String x = null;
    public Foo(String val) { x = val; }
    public int length() {
          System.out.println("Foo");
          return x.length();
    }
}

class Bar extends Foo {
    private int cache = 0;
    public Bar(String val) {
          super(val);
          cache = val.length();
    }
    public int length() {
          System.out.println("Bar");
          return cache;
    }
}
```

```cpp
// In C++
class Foo {
private:
    const char* x = 0;
public
    Foo(const char* val) { x = val; }
    int length() {
          cout << "Foo" << endl;
          return ::strlen(x);
    }
};

class Bar : public Foo {
private:
    int cache = 0;
public:
    Bar(const char* val) : Foo(val) {
          cache = ::strlen(val);     }
    int length() {
          cout << "Bar" << endl;
          return cache;  }
};
```

Actually, the determination of what behavior to perform may be made at compile-time or at run-time

At compile-time

- static binding or early binding
- static functions in Java/C++
- nonvirtual functions in C++

At run-time

- dynamic binding or late binding
- virtual functions in Java/C++

Even if we send the same message to objects, the behavior can be different depending on the receiver object -- *polymorphism*

Poly (multi) + *Morphism* (form), i.e., a fancy word for multi-forms

When a method must *accept* an instance of superclass as a parameter, it can accept the instance of any subclasses

Likewise, when a method must *return* an instance of superclass, it can return the instance of any subclasses

Question 8

What do you think is the real power and/or advantages of object technology?

① Code reuse
② Cost savings
③ Increased productivity
④ Elegantly tackle complexity & create easy adaptability

The real power and advantage of OT is *its capacity to tackle complex systems* and *to support easily adaptable systems*, lowering the cost and time of change

The Corporate Use of OT, Dec 1997, Cutter Group.
Prioritized reasons for adopting OT:

1. Ability to take advantage of new operating systems and tools
2. Elegantly tackle complexity & create easy adaptability
3. Cost savings
4. Development of revenue-producing applications
5. Encapsulation of existing applications
6. Improved interfaces
7. Increased productivity
8. Participation in "the future of computing"
9. Proof of ability to do OO development
10. Quick development of strategic applications
11. Software reuse

To obtain flexible and reusable systems, it is better to base the structure of software on the objects rather than on the actions

Rationale behind OO paradigm:

In general, systems evolve, functionality changes, but data objects, interfaces, and components relations tend to remain relatively stable over time.

Use it for large systems &
for systems that change often

Any other benefits?

It is essential to decompose the complex software system into smaller and smaller parts, each of which may then refine independently (i.e., *stepwise refinement*)

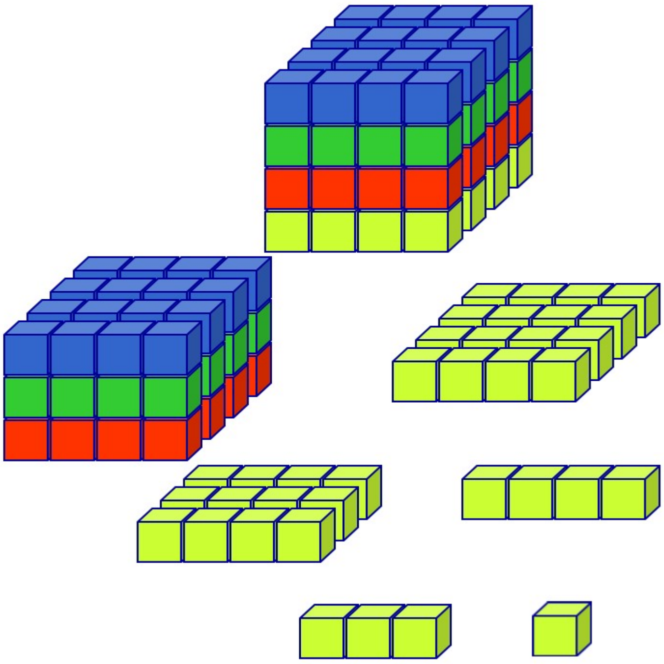
Maximum number of chunks of information an individual can simultaneous comprehend is the order of 7 ± 2

--- *Miller (1956)*

The technique of mastering complexity has been known since ancient times:

Divide and Conquer

-- Dijkstra (1979)



Structured vs. Object-Oriented Decompositions

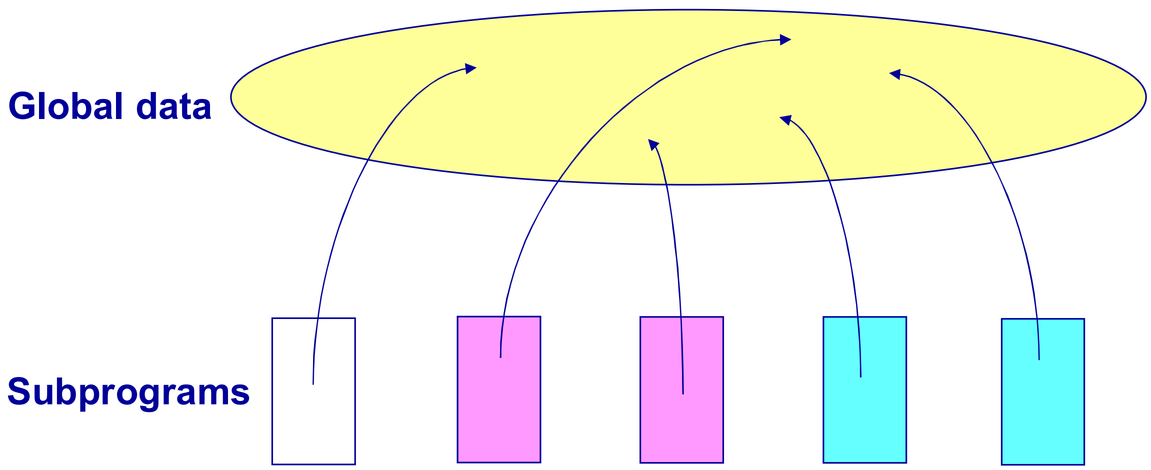
Structured Decomposition

- Organize a system around procedures/functions
- *Program = (Algorithms + Data Structures)*
- SA/SD/SP

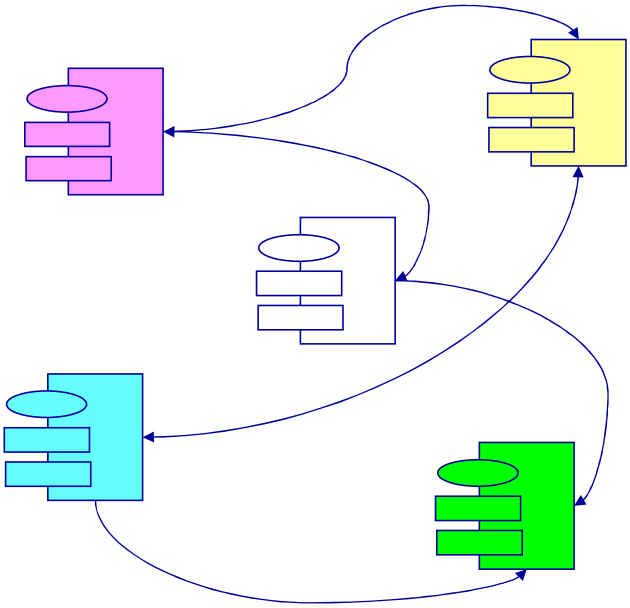
Object-Oriented Decomposition

- Organize a system around objects
- *Object = (Algorithm + Data Structures)*
- *Program = (Object + Object + ...)*
- OOA/OOD/OOP

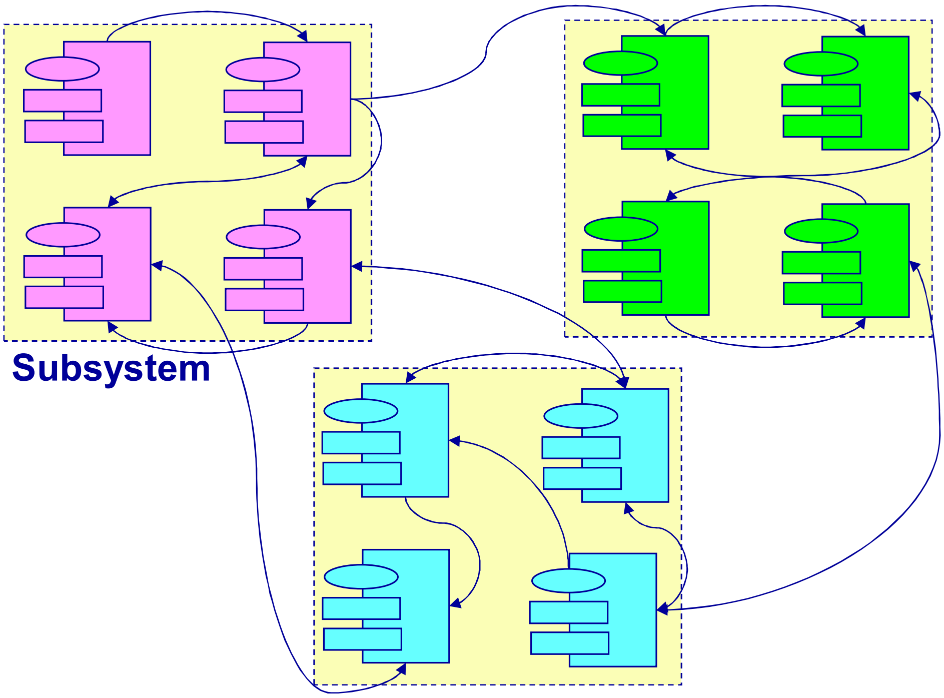
Design Structure Based on Subprograms



Design Structure Based on Objects
(Small Scale)



Design Structure Based on Objects
(Large Scale)



Reuse is not usually achieved or worthwhile at the object-level

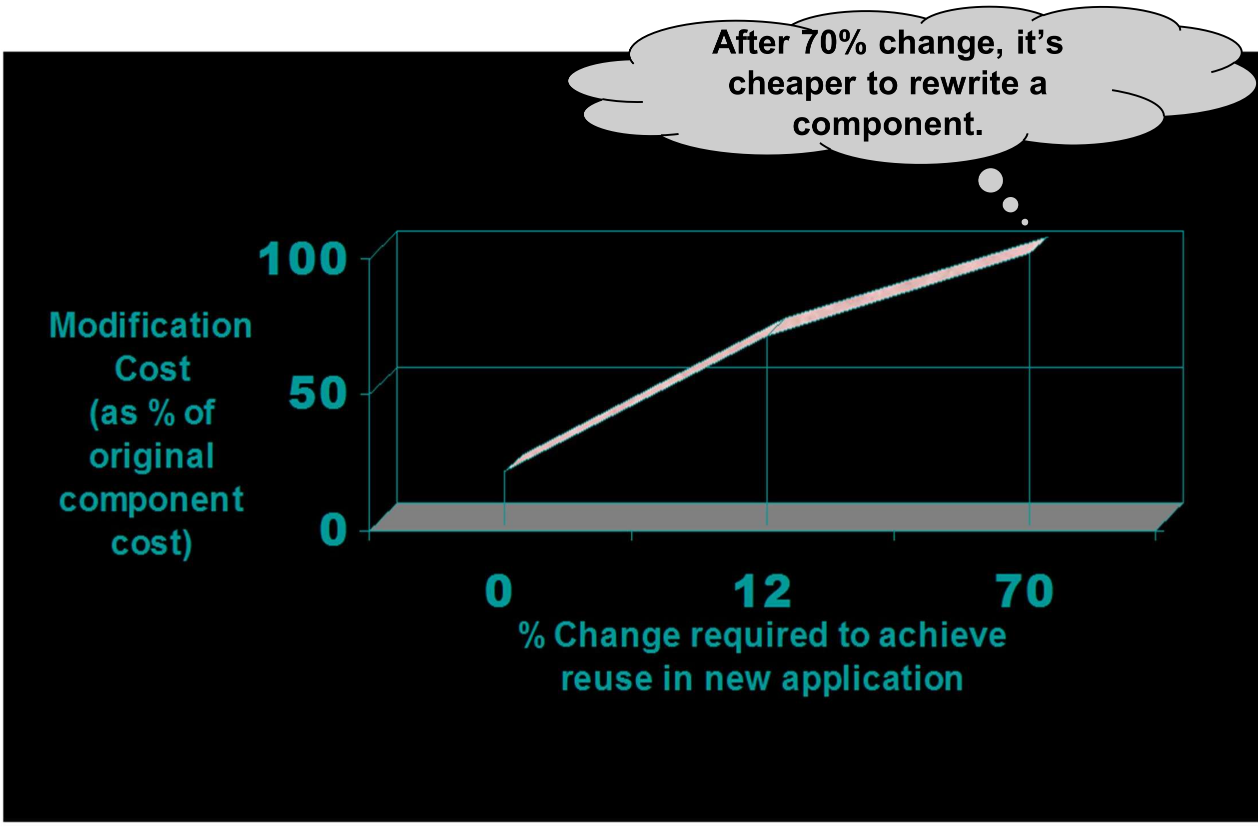
Research shows no relationship between increased reuse and collecting a library of reusable components from prior projects.

-- Communications of the ACM, pp 75-87 June, 1995

Focus on:

- **A culture of *framework* creation and use.**
- **Reuse of architecture, analysis and *design patterns***

Reuse at What Level?



Design pattern is a description of a *problem*/*solution* pair in a certain *context*

"Each pattern describes a *problem* which occurs over and over again in our environment, and then describes the core of the *solution* to that problem, in such a way that you can use this solution a million times over, without ever doing it the same time twice."

-- Christopher Alexander

Design Pattern Example: Adapter Pattern

Name: ***Adapter***

Also known as: Wrapper

Context: Client objects call methods of a Supplier object

Problem: Client objects expect another interface than the Supplier provides

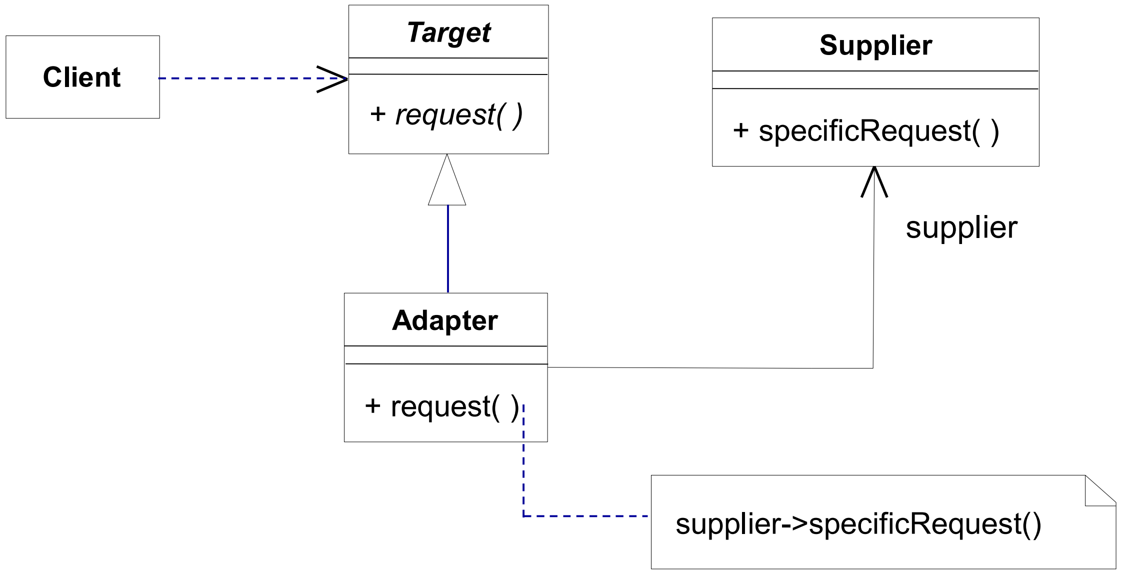
Solution: Use an Adapter object which adapts one interface to the other

Solution alternatives:

Class adapter
(relies on multiple inheritance like C++ or Eiffel, or interface inheritance like Objective C or Java)

Object adapter
(relies on single inheritance and delegation)

Object Adapter Solution



A framework is a class library, but more than an ordinary toolkit (such as math, file i/o, data structures …)

An integrated set of cooperating classes

A *semi-complete application*: abstract framework classes are specialized in the application

Inversion of control

The "main event loop" is often in the framework, rather than in the application code

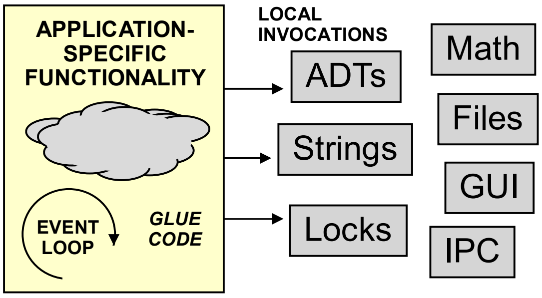
Code in the framework can invoke code in the application by dynamic binding

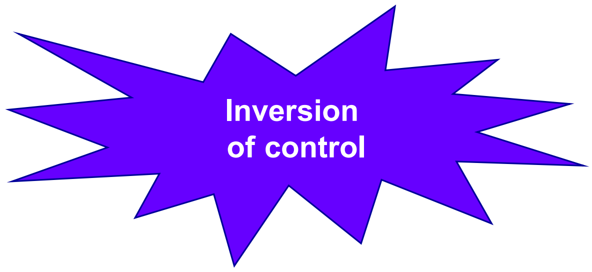
Domain-specific

**business,
telecommunications,
windows system,
databases,
etc.**

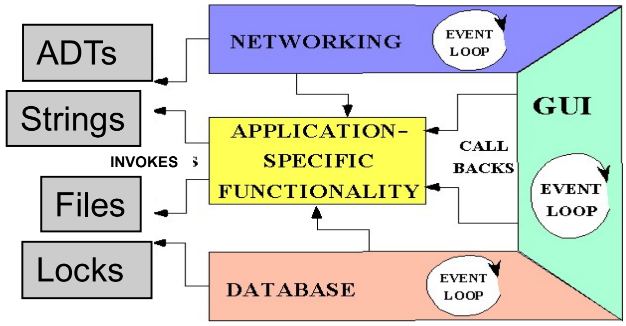
Hollywood Principle: Don’t call me, we’ll call you!

Class Library Architecture





Framework Architecture

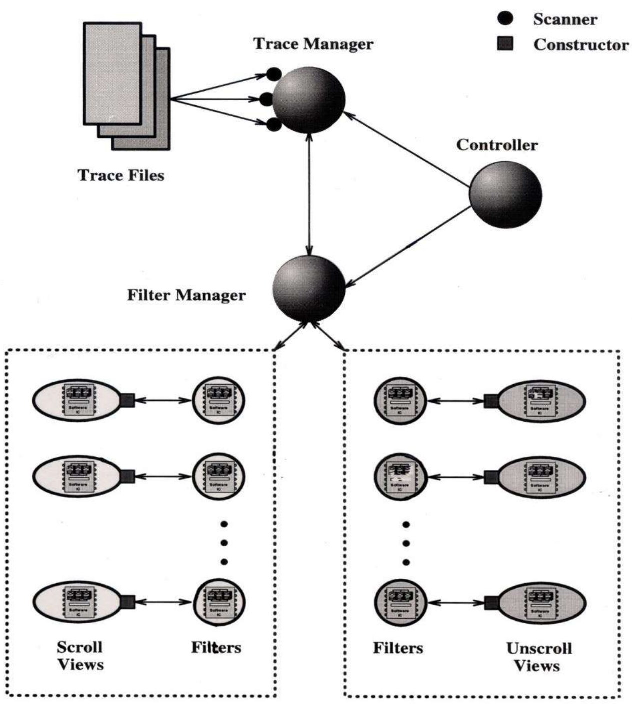


Frameworks allow us to reuse design and code

Framework: family of similar applications

Very fast application development

Powerful parameterization mechanism (subclassing and dynamic binding)



Claims

Today, (architectural & design) patterns make the most effective technique of conducting and training OOD!

Want to know how to develop highly **reusable**, **flexible**, **extensible**, and **maintainable** software products with minimum efforts and cost.

Question 9

What are two most important underlying design principles behind GoF patterns?

OO Design Principle (I):
Program to an interface, not an implementation!

OO Design Principle (II)
Favor object composition over class inheritance

Designing for Change

Creating an object by specifying a class explicitly
Abstract Factory, Factory Method, Prototype
Dependence on specific operations
Chain of Responsibility, Command
Dependence on hardware and software platforms
Abstract Factory, Bridge
Dependence on object representations or implementations
Abstract Factory, Bridge, Memento, Proxy
Algorithmic dependencies
Builder, Iterator, Strategy, Template Method, Visitor
Tight Coupling
Abstract Factory, Bridge, Chain of Responsibility, Command, Façade, Mediator, Observer
Extending functionality by subclassing
Bridge, Chain of Responsibility, Composite, Decorator, Observer, Strategy
Inability to alter class conveniently
Adapter, Decorator, Visitor

Exercises

1. Consider the following declaration:

   class B extends A { ... }   // Assume public inheritance used

   What this declaration implies? Select all that apply.

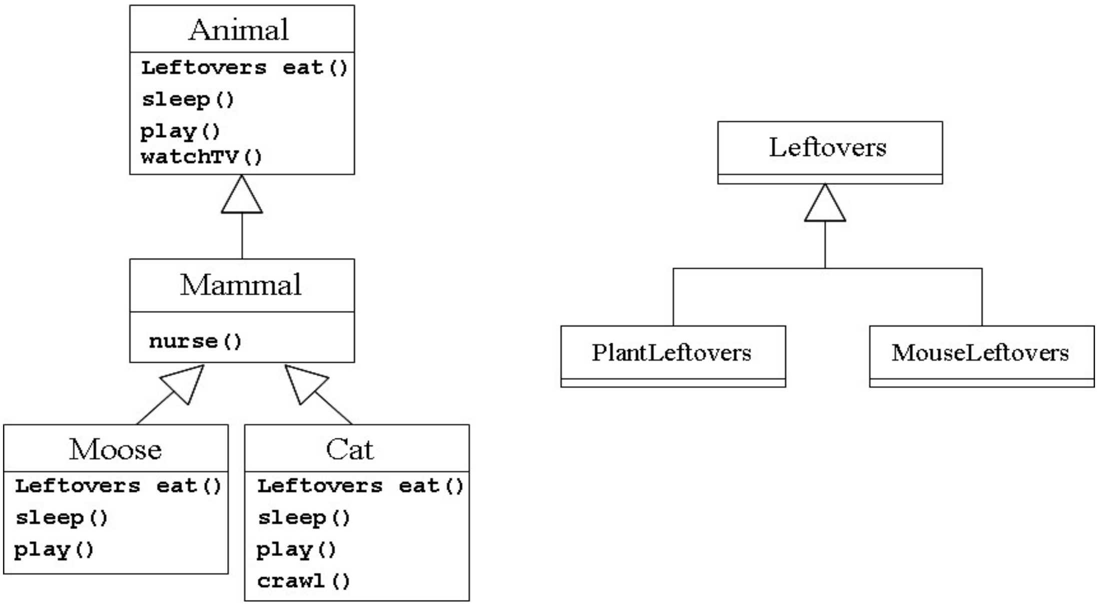
① Every object of type B is also an object of type A, but not vice-versa.

② Anything that is true of an object of type B is also true of an object of type A, but not vice-versa.

③ A represents a more general concept than B, and B represents a more specialized concept than A.

④ Anywhere an object of type B can be used, an object of type A can be used as well, but not vice-versa.

Consider the following class diagrams. All the operations are public.



6.	PlantLeftovers r = new Leftovers();	(a)________________
7.	Animal anim;	
	Moose myMoose = new Moose();	
	anim = myMoose;	(a)________________
	anim.eat();	(b)________________
	myMoose = anim;	(c)________________
8.	Cat myCat = new Cat();	
	MouseLeftover rem = myCat.eat();	(a)________________

※ Consider the following method ***foo*** and answer either "***Yes***" or "***No***"

```
void foo(Mammal m) { ... }
```

9.	Is it legal to call *m.watchTV()* in *foo*?	(a)________________
	Is it legal to call *m.crawl()* in *foo*?	(b)________________