LINGI2252 – PROF. KIM MENS

SOFTWARE MAINTENANCE & EVOLUTION

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SOFTWARE REUSE & OBJECT-ORIENTED PROGRAMMING

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A. SOFTWARE REUSE

REUSABILITY [DEFINITION]

Reusability is a general engineering principle whose importance derives from the desire to **avoid duplication** and to **capture commonality** in undertaking classes of inherently similar tasks.

> Source: **Peter Wegner**, "Capital-Intensive Software Technology", in Chapter 3 of *Software Reusability, Volume I : Concepts and Models*, ACM Press, **1989**.

Software reusability is the degree to which a software module or other work product can be used in more than one software system.

Reusable: pertaining to a software module or other work product that can be used in more than one computer program or software system.

SOFTWARE REUSE [DEFINITION]

Software reuse

> The reapplication of a variety of kinds of knowledge about one system to another in order to reduce the effort of developing or maintaining that other system.

This "reused knowledge" includes artefacts such as domain knowledge, development experience, requirements, architectural components, design artefacts, code, documentation, and so forth.

Source: *Software Reusability, Volume I : Concepts and Models*, Eds. Biggerstaff & Perlis, ACM Press, 1989.

REUSABLE COMPONENT [DEFINITION]

Software reuse

The process of implementing new software systems using existing software information.

Reusable component

A software component designed and implemented for the specific purpose of being reused.

Component can be requirement, architecture, design, code, test data, etc.

Source: Kang & al., *Feature-Oriented Domain Analysis (FODA): Feasibility Study*, Technical Report CMU/SEI-90-TR-21, 1990.

SOFTWARE REUSE [EXAMPLE]

Using **functions** available in some library.

- E.g., C libraries are collections of precompiled functions that have been written to be reused by other programmers.

Reusing **classes** from another object-oriented program.

Adapting the **modules** of a software system with a very similar functionality (member of a same "family").

Reusing the **architecture** or **design** of a software system when porting it to a new language.

WHY REUSE?

Economic justification:

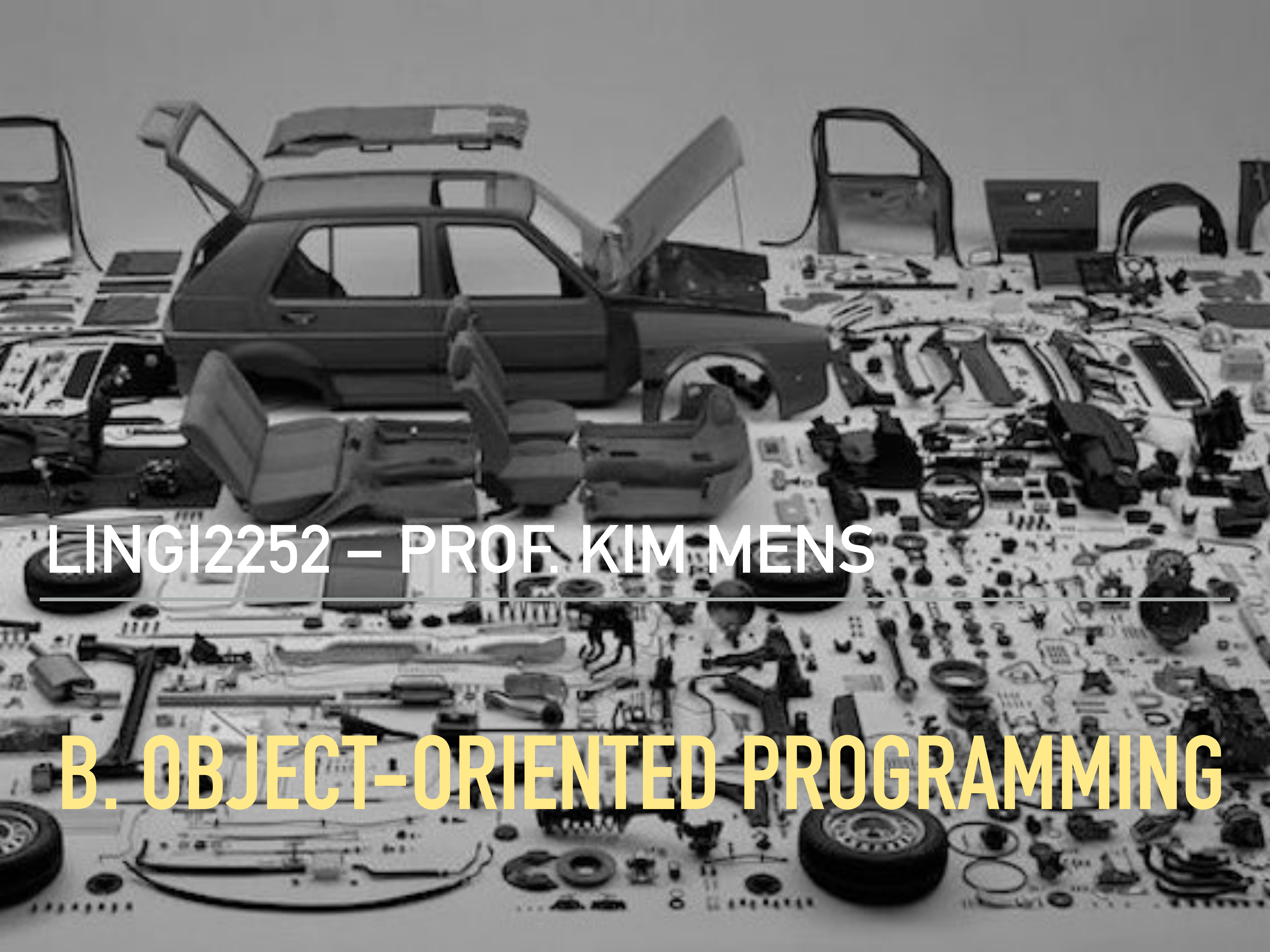
- **more productive** by avoiding double work
- **better quality** by reusing good solutions

Intellectual justification:

- **stand on each other's shoulders**
- don't reinvent or reimplement old stuff
- focus on what's new and relevant

SOME REUSE TECHNIQUES

- Programming abstractions and mechanisms
  - procedural and data abstraction
  - encapsulation and information hiding
  - code sharing and reuse mechanisms
- Design patterns
- Software architecture
- Software libraries & application frameworks
- Generative programming & model-driven development



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B. OBJECT-ORIENTED PROGRAMMING

OBJECT-ORIENTED PROGRAMMING PROMOTES MODULARITY AND REUSE

It is often "claimed" that object-oriented programming

- is a better way of writing **more modular** programs
- leverages **code sharing** and **design reuse**
- **minimises maintenance** costs

Thanks to its *abstraction mechanisms*

ABSTRACTION MECHANISMS

Encapsulation

keep data and operations that act on this data together

Information hiding

isolate and hide design and implementation choices

Polymorphism

allow for different implementations of a same design to co-exist

Code sharing

capture and exploit similarities in data and behaviour (through inheritance)

KEY OBJECT-ORIENTED CONCEPTS

Objects & Classes

Methods & Messages

Polymorphism & Dynamic Binding

Hierarchies of classes

Method overriding, self & super calls

Abstract classes & methods

Different kinds of inheritance

- Single, Multiple, Interfaces, Mixins

DISCLAIMER

ALTHOUGH WHAT FOLLOWS MAY SEEM LIKE A CRASH COURSE IN OO

OUR FOCUS WILL LIE ON THE MECHANISMS IT PROVIDES FOR ACHIEVING MODULARITY, MAINTAINABILITY, SHARING AND REUSE

TWO MAIN PRINCIPLES OF OBJECT-ORIENTED PROGRAMMING

Everything is an object

Objects respond only to messages

SMALLTALK'S INFLUENCE

Smalltalk is a pure object-oriented language

Was a source of inspiration to many OO languages

- **Ruby** is heavily inspired on Smalltalk
- **Objective-C** and **Swift** heavily inspired on Smalltalk
- **Java** is heavily influenced by Smalltalk

DISCLAIMER

THIS SESSION MAY CONTAIN TRACES OF SMALLTALK CODE (FOR DIDACTIC PURPOSES)

KEY OBJECT-ORIENTED CONCEPTS

- Objects & Classes
- Methods & Messages
- Polymorphism & Dynamic Binding
- Hierarchies of classes
- Method overriding, self & super calls
- Abstract classes & methods
- Different kinds of inheritance
  - Single, Multiple, Interfaces, Mixins

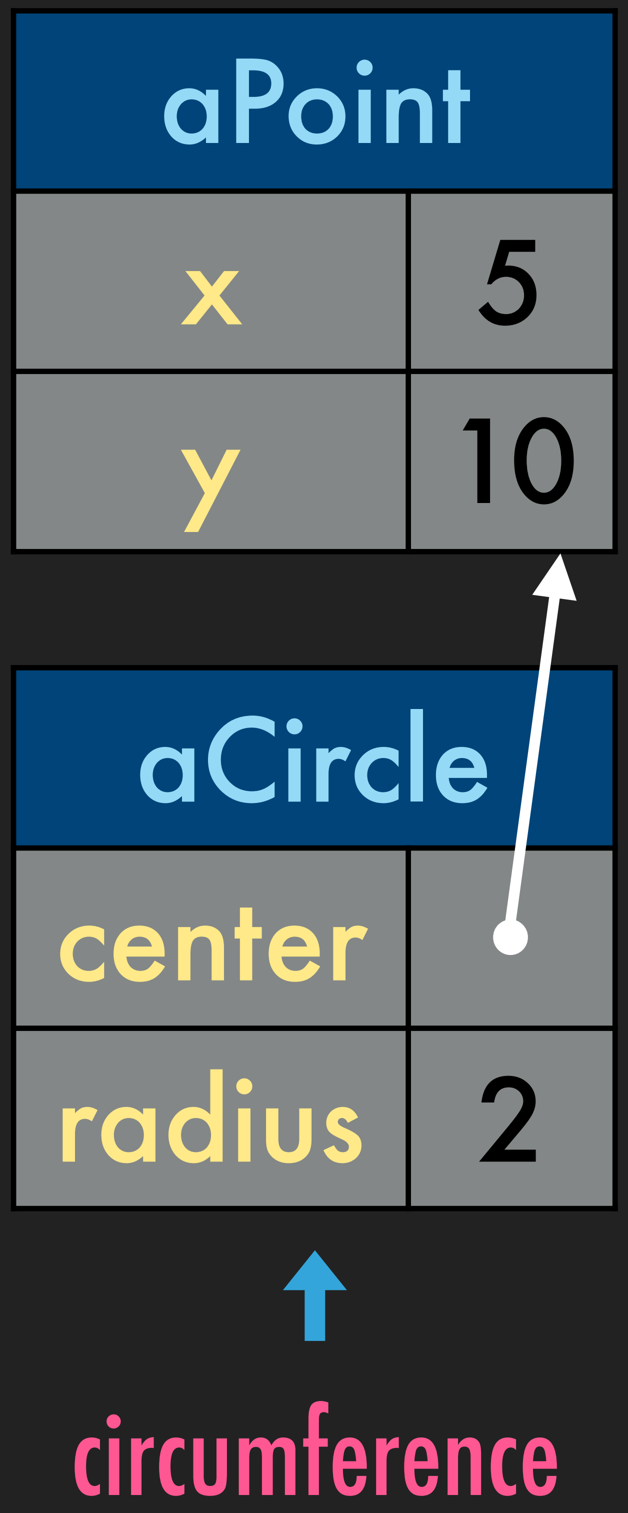
OBJECTS ENCAPSULATE DATA

Every object has its own data or state

- Values stored in the objects
- (but variables declared in classes)

Data is encapsulated

- Protected from the outside world
- Only accessible through messages



CLASSES ENCAPSULATE BEHAVIOUR

Classes

- *declare the state* of objects
  (but objects contain the actual values)
- *define the behaviour* of objects
  - method implementations
  - shared among all objects of a class
  - can manipulate the state directly

Behaviour is encapsulated

- invoked by sending message to an object

Circle	
center	*(Point)*
radius	*(Number)*
surface	$\pi.radius^2$
circumference	$2.\pi.radius$

CLASSES ARE FACTORIES OF OBJECTS

- A class is a “factory” for producing objects of the same type
  - e.g., with a Circle class you can create many circle objects
- Every object is an instance of the class from which it was created
- A class is a blueprint for objects that share behaviour and state
  - All objects of a class behave in a similar fashion in response to a same message
  - Enables **reuse of behaviour**

CLASSES & OBJECTS PROMOTE MODULARITY

Through encapsulation

of both behaviour and state

- grouping behaviour with the data it acts upon
- facilitates modularity, code reuse and maintenance

CLASSES & OBJECTS PROMOTE REUSE

Classes are fine-grained reusable components

that enable sharing and reuse of structure and behaviour

even across applications

- for example via application frameworks
- or reusable class hierarchies

KEY OBJECT-ORIENTED CONCEPTS

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METHODS & MESSAGES (RECAP)

- Objects (not functions or procedures) are the main building blocks of OO
- Objects communicate through **message** passing
  - Objects exhibit behaviour in response to messages sent to them
- The actual behaviour is implemented in **methods**
  - Methods specify what behaviour to perform on objects
  - Methods can manipulate the objects’ internal state

POLYMORPHIC METHODS

A same message can be sent to objects of different classes

aCircle.surface   aRectangle.surface

Different objects can react differently to the same message

- different classes can provide different implementations for methods with the same name

  Circle > surface = π.radius²

  Rectangle > surface = (bottom-top).(right-left)

Responsibility of *how* to handle the message is decided by the object (depending on the class to which it belongs)

- This is called "**polymorphism**"

ADVANTAGES OF POLYMORPHISM

- Cleaner, **more maintainable** code
    - Less ≠ method names
    - Less need for conditionals
    - More implementation freedom
        - Each class can decide how best to implement a method
    - Locality
        - Every object/class is responsible for its own actions
        - Easy to change the implementation by another one

EXAMPLE OF POLYMORPHISM

Procedural style vs. object-oriented style

Example:

- Write some code that calculates the sum of the surfaces of a collection of different shape objects
- $\text{surface(collection)} = \Sigma_{\text{shape} \in \text{collection}}\ \text{surface(shape)}$

EXAMPLE OF POLYMORPHISM (PSEUDOCODE)

Procedural style (no polymorphism)

```
circleSurface(c) = π.radius(c)²

rectangleSurface(r) = (bottom(r) - top(r)) * (right(r) - left(r))

surface(collection) : Real
       total = 0
       ∀ shape ∊ collection :
              if ( shape == Circle ) then
                     total = total + circleSurface(shape)
              else if ( shape == Rectangle ) then
                     total = total + rectangleSurface(shape)
       return total
```

EXAMPLE OF POLYMORPHISM (PSEUDOCODE)

OO style (using polymorphism)

```
Circle {
  Point center ; Real radius ;
  Real surface() : { π.radius² }
}
Rectangle {
  Real bottom, top, right, left;
  Real surface() : { (bottom-top)*(right-left) }
}
Real surface(collection) : {
        total = 0
        ∀ shape ∈ collection : total = total + shape.surface()
        return total
}
```

EXAMPLE OF POLYMORPHISM (PSEUDOCODE)

OO style (using polymorphism)

```
Real surface(collection) : {
      total = 0
      ∀ shape ∈ collection : total = total + shape.surface()
      return total
}
```

Advantages:

- Adding a new shape does not require to change the existing implementation
- No need to know the kind of objects it manipulates as long as they all share a common interface

LATE BINDING

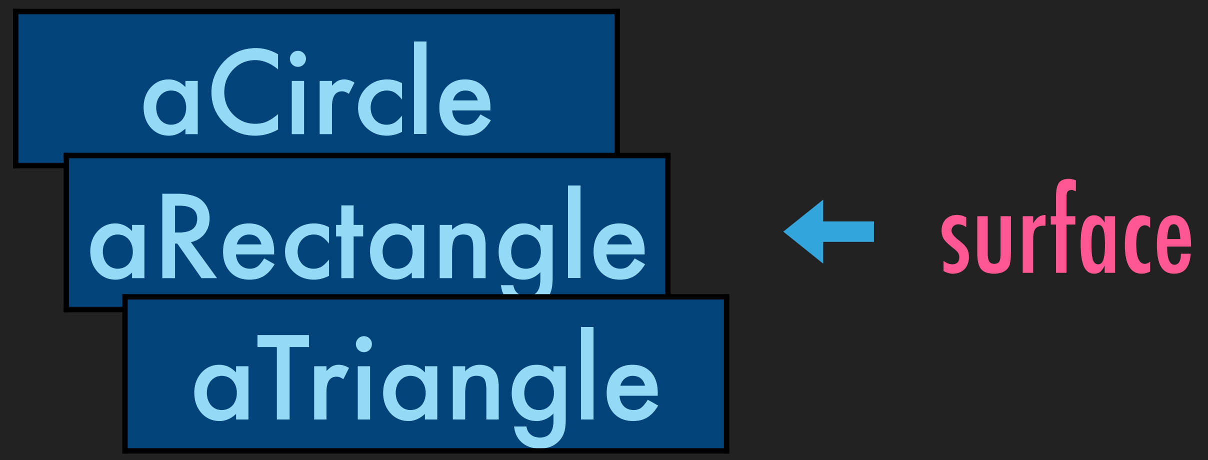
When sending a message, the actual receiver of a message is not necessarily known until run-time

Mapping of messages to methods is deferred until run-time

- depending on which object actually received the message
- we call this **late binding** or **dynamic binding**

Most traditional languages do this at compile time (static binding)

Smalltalk uses late binding



EXAMPLE OF LATE BINDING (PSEUDOCODE)

```
abstract Shape {
  abstract Real surface() : { }
}
Circle inherits Shape {
  Point center ; Real radius ;
  Real surface() : { π.radius² }
}
Rectangle inherits Shape {
  Real bottom, top, right, left;
  Real surface() : { (bottom-top)*(right-left) }
}
test() : {
 Shape shape;
 shape = new Circle(new Point(0,0), 2);
 print(shape.surface());
 shape = new Rectangle(10,10,30,50);
 print(shape.surface())
}
```

polymorphic methods

late bound messages

STATIC VS. DYNAMIC BINDING IN JAVA

Smalltalk uses dynamic binding (a.k.a. late binding)

For Java it depends

- Binding of **overridden methods** happens at runtime (**dynamic**)
- Binding for **overloaded** methods at compile time (**static**)
- Binding of **private**, **static** and **final** methods at compile time (**static**)
  - since these methods cannot be overridden.

Sources:

- http://beginnersbook.com/2013/04/java-static-dynamic-binding/
- http://stackoverflow.com/questions/19017258/static-vs-dynamic-binding-in-java

LATE BINDING EXAMPLE (JAVA)

Apart from syntactic differences and the lack of type declarations in Smalltalk, this example could be recreated nearly “as is” in Smalltalk.

In fact for Smalltalk you could even create an example that doesn’t require inheritance.

Example of Dynamic Binding in Java

```
public class DynamicBindingTest
{
 public static void main(String args[])
  {
    Vehicle vehicle = new Car(); //here Type is vehicle but object will be Car
    vehicle.start();       //Car's start called because start() is overridden met
  }
}

class Vehicle
  {
    public void start()
      {
           System.out.println("Inside start method of Vehicle");
      }
  }
class Car extends Vehicle
  {
    @Override
    public void start()
     {
       System.out.println("Inside start method of Car");
     }
}
```

Output: Inside start method of Car

Source: http://stackoverflow.com/questions/19017258/static-vs-dynamic-binding-in-java

LATE BINDING EXAMPLE IN JAVA

The method call vehicle.start() is dynamically bound to the overridden Car > start() method

Because even though vehicle is typed as being of class Vehicle, it is determined at runtime that it contains an object of type Car

and because the method start() is overridden

Example of Dynamic Binding in Java

```
public class DynamicBindingTest
{
 public static void main(String args[])
  {
    Vehicle vehicle = new Car(); //here Type is vehicle bu
    vehicle.start();       //Car's start called because st
  }
}

class Vehicle
  {
    public void start()
      {
           System.out.println("Inside start method of Vehi
      }
  }
class Car extends Vehicle
  {
    @Override
    public void start()
     {
       System.out.println("Inside start method of Car");
     }
}
```

Output: Inside start method of Car

STATIC BINDING EXAMPLE IN JAVA

Static Binding Example in Java

```
public class StaticBindingTest
{
 public static void main(String args[])
   {
     Collection c = new HashSet();
     StaticBindingTest et = new StaticBindingTest();
     et.sort(c);
   }
   //overloaded method takes Collection argument
  public Collection sort(Collection c)
   {
    System.out.println("Inside Collection sort method");
    return c;
   }
  //another overloaded method which takes HashSet argument which is sub class
  public Collection sort(HashSet hs)
  {
    System.out.println("Inside HashSet sort method");
    return hs;
   }
}
```

Output: Inside Collection sort method

Source: http://stackoverflow.com/questions/19017258/static-vs-dynamic-binding-in-java

This example cannot be recreated in Smalltalk since Smalltalk has no method overloading.

(Nor does it have final methods or private methods.)

STATIC BINDING EXAMPLE IN JAVA

The method call et.sort(c) is statically determined by the compiler to refer to the sort(Collection) method

Even though c is an object of type HashSet and the sort(HashSet) method is more specific

Because c is statically determined to have type Collection

and the method sort is overloaded, not overridden

Static Binding Example in Java

```
public class StaticBindingTest
{
 public static void main(String args[])
   {
     Collection c = new HashSet();
     StaticBindingTest et = new StaticBindingTest();
     et.sort(c);
   }
   //overloaded method takes Collection argument
  public Collection sort(Collection c)
   {
    System.out.println("Inside Collection sort method");
    return c;
   }
  //another overloaded method which takes HashSet argument
  public Collection sort(HashSet hs)
  {
    System.out.println("Inside HashSet sort method");
    return hs;
   }
}
```

Output: Inside Collection sort method

CLASSES & OBJECTS PROMOTE MODULARITY

Through information hiding

- restricted access to objects through a well-defined interface
  - users of an object only know the set of messages it will accept
  - they do not know *how* the actions performed in response to a message are carried out
  - This is the responsibility of the receiving object (through polymorphism)
- improves modularity by hiding implementation details
  - How the data is represented internally
  - How the behaviour is implemented in terms of that data

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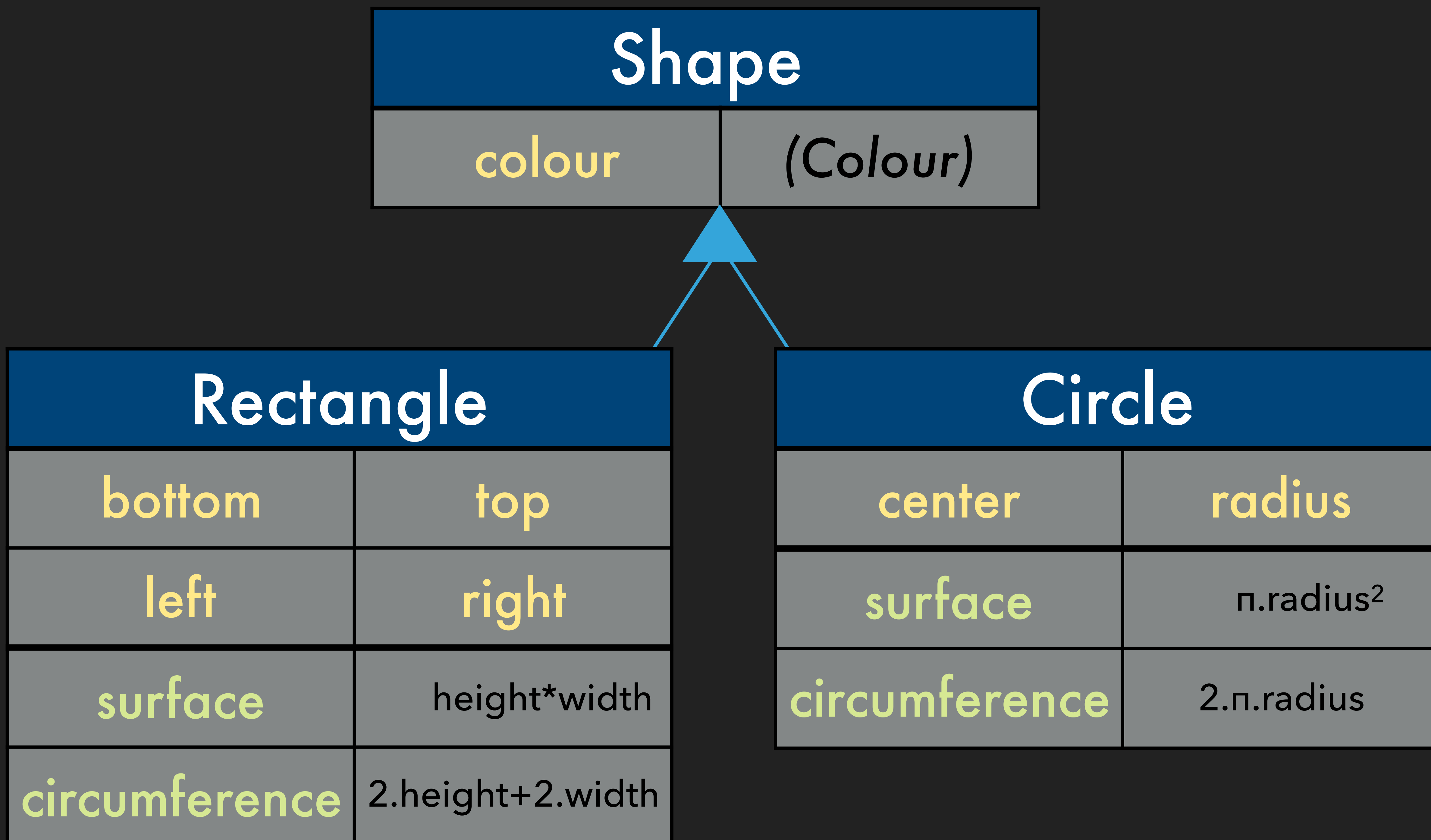
HIERARCHIES OF CLASSES



HIERARCHIES OF CLASSES

Classes are typically organised into hierarchical structures

Information (data/behaviour) associated with classes higher in the hierarchy is automatically accessible to classes lower in the hierarchy

Each subclass **specialises** the definition of its ancestors

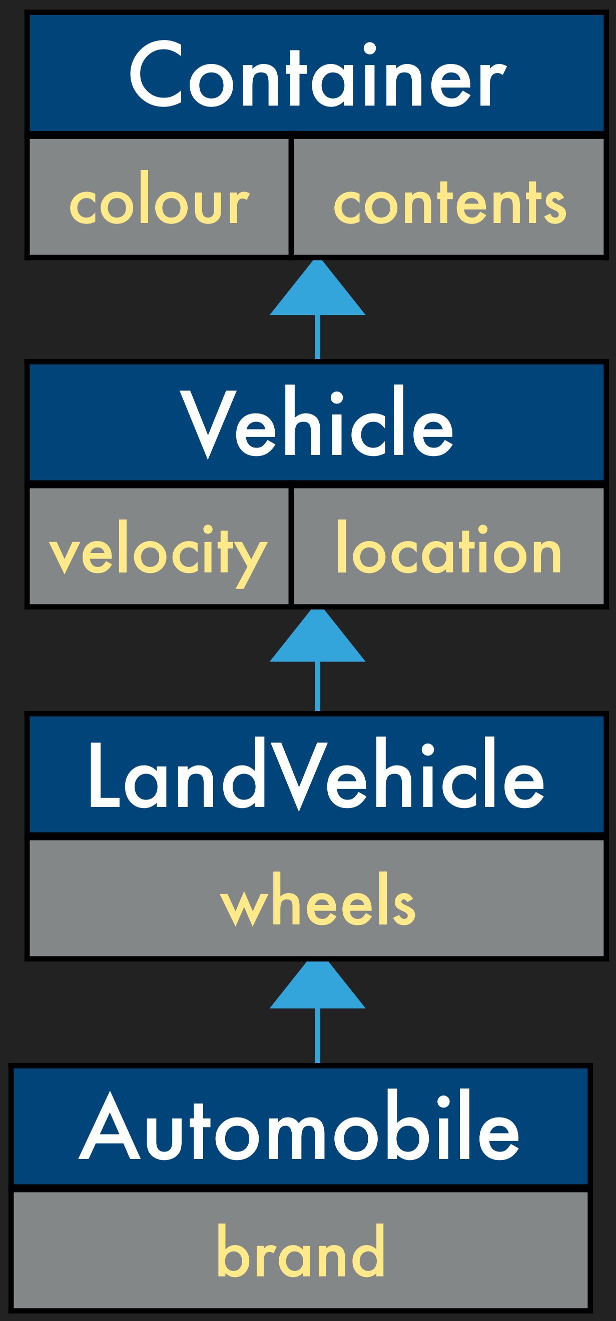
- subclasses can use ancestor’s behaviour and state
- subclasses can add new state and behaviour
- subclasses can specialise ancestor behaviour
- subclasses can override ancestor’s behaviour

HIERARCHIES OF CLASSES

Inheritance is a powerful incremental reuse mechanism

- Often you don't want to rewrite everything; you just want some small changes to what exists
- Classes are the units of reuse
- Inheritance is the reuse mechanism
  - e.g., *extends* keyword in Java :
    class Automobile extends LandVehicle
- Class hierarchies are ideal for sharing declarations and implementation among classes
  - Object's state and behavioural description is broken into pieces and distributed along specialisation paths

Promotes encapsulation, modularity, and reusability



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SELF AND SUPER CALLS

Methods use:

- self calls to reference the receiver object
  - this keyword in Java, self in Smalltalk
- super to reference their implementor's parent

Attention ! Key issue in object-oriented programming:

- self = late/dynamically bound
  - method lookup starts again in the class of the receiver object
- super = statically bound
  - method lookup starts in the superclass of the class of the method containing the super expression;
  - *not* in the superclass of the receiver class

SELF REFERS TO THE RECEIVER CLASS

```
SomeSuperclass {
    void printMyself : {
      self.print
      }
    void print : {
        display("Printed in superclass. ")
    }
}
SomeSubclass inherits from SomeSuperclass {
    void print : {
        super.print
        display("Printed in subclass.")
    }
}
SubSubclass inherits from SomeSubclass {
}
test : {
    s = new SubSubclass()
    s.printMyself
    }
}
```

self refers to the receiver object

receiver class is SubSubclass

self will dynamically look up methods starting from this class

METHOD OVERRIDING

Subclasses can re-implement methods that are already implemented in superclasses

- *enables fine-grained reuse*
- clients do not have to know this (encapsulation and polymorphism)

An overridden method

- can either **overwrite** a method with a completely new implementation
- or can **specialise** the behaviour of the method defined in its superclass
  - special keyword for accessing the superclass : super

EXAMPLE OF METHOD SPECIALISATION

```
SomeSuperclass {
    void print : {
        display("Printed in superclass. ")
    }
}
SomeSubclass inherits from SomeSuperclass {
    void print : {
        super.print
        display("Printed in subclass.”)
    }
}
test : {
    s = new SomeSubclass()
    s.print
    }
}
```

overridden method (points to `void print` in SomeSuperclass)

overriding method (points to `void print` in SomeSubclass)

specialises overridden method using super keyword (points to `super.print`)

After calling test, the program prints:
Printed in superclass. Printed in subclass.

SUPER IS NOT THE SUPERCLASS OF THE RECEIVER CLASS

```
SomeSuperclass {
    void print : {
        display("Printed in superclass. ")
    }
}
SomeSubclass inherits from SomeSuperclass {
    void print : {
        super.print
        display("Printed in subclass.")
    }
}
SubSubclass inherits from SomeSubclass {
}
test : {
    s = new SubSubclass()
    s.print
    }
}
```

After calling test, the program prints:
Printed in superclass. Printed in subclass.

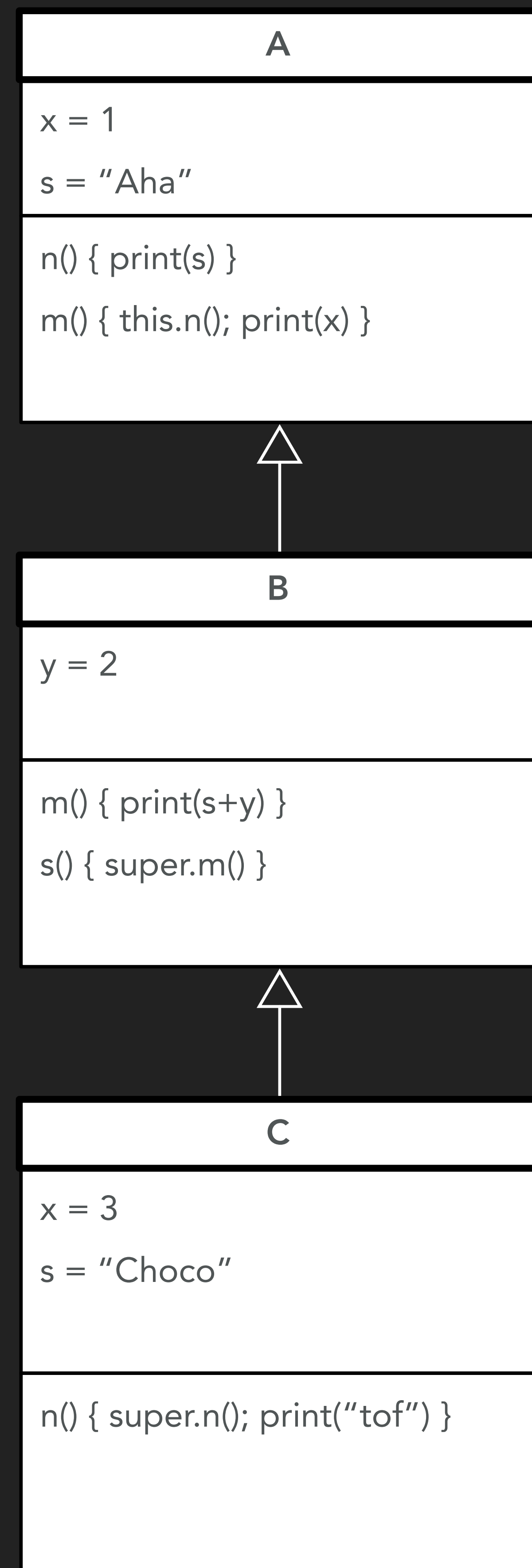
super statically refers to this class

receiver class is SubSubclass

if super would refer to the super class of the receiver class, we would get a loop

HOMEWORK

PREDICT THE RESULT OF THESE METHOD INVOCATIONS



A a = new A();

a.n();

a.m();

a.s();

B b = new B();

b.n();

b.m();

b.s();

C c = new C();

c.m();

c.n();

c.s();

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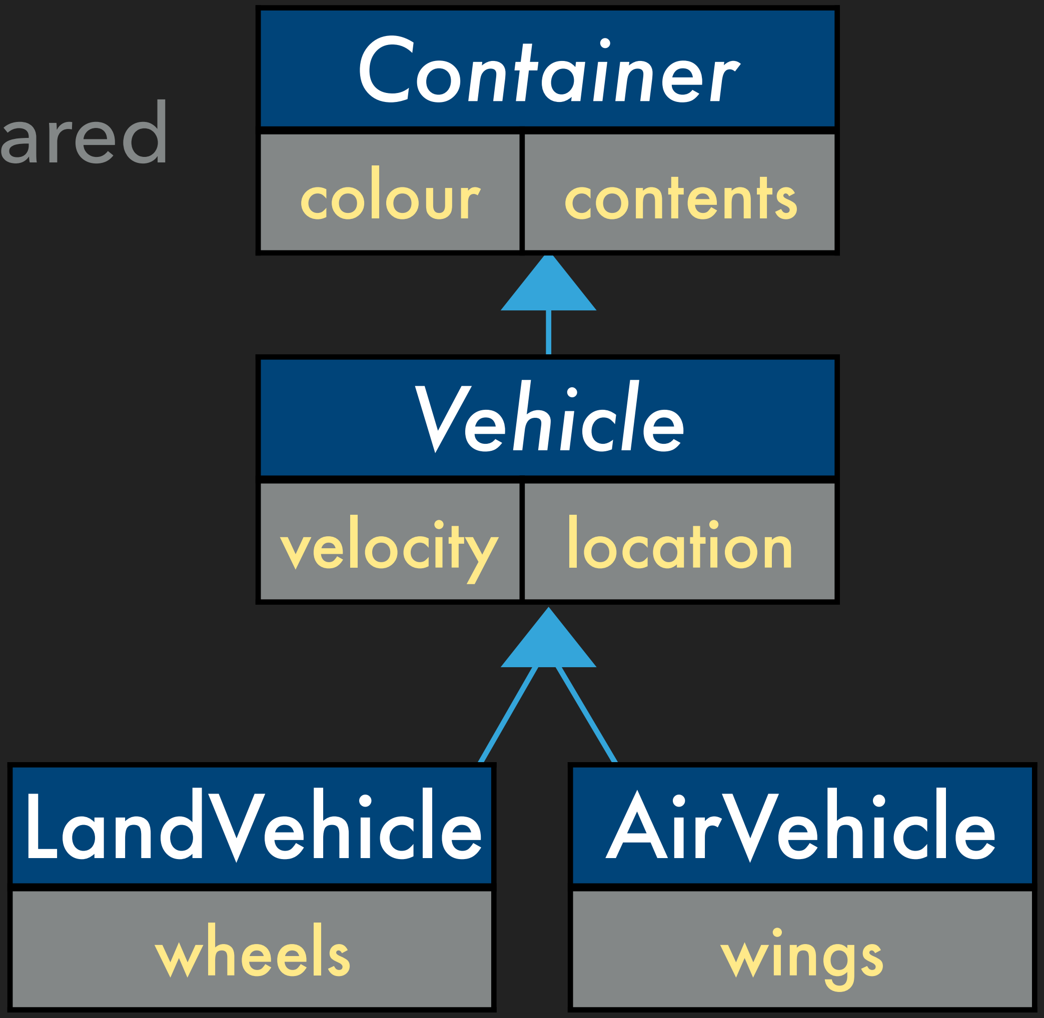
CONCRETE VS. ABSTRACT CLASSES

Abstract Class

- Holds on to common characteristics shared by other classes
- Not expected to have instances

Concrete Class

- Contains complete characterisation of actual objects of that class
- Expected to have instances



ABSTRACT CLASSES AND ABSTRACT METHODS

cannot be instantiated (in Java)

but can provide some method implementations

- methods of which the implementation is shared by all subclasses
- methods with a default implementation to be specialised by subclasses
- methods with a partial implementation to be completed by a subclass (e.g., *template method pattern*)

typically have at least one **abstract method**

- a method with an empty implementation that must be provided by each subclass

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KINDS OF INHERITANCE

Different kinds of inheritance

- Single: 1 superclass
- Multiple: 1 or more superclasses
- Interface
- Mixin modules

SINGLE INHERITANCE

Organises classes in tree structures

Every class has a unique superclass

There is a root class, typically called Object

SINGLE INHERITANCE PROBLEMS

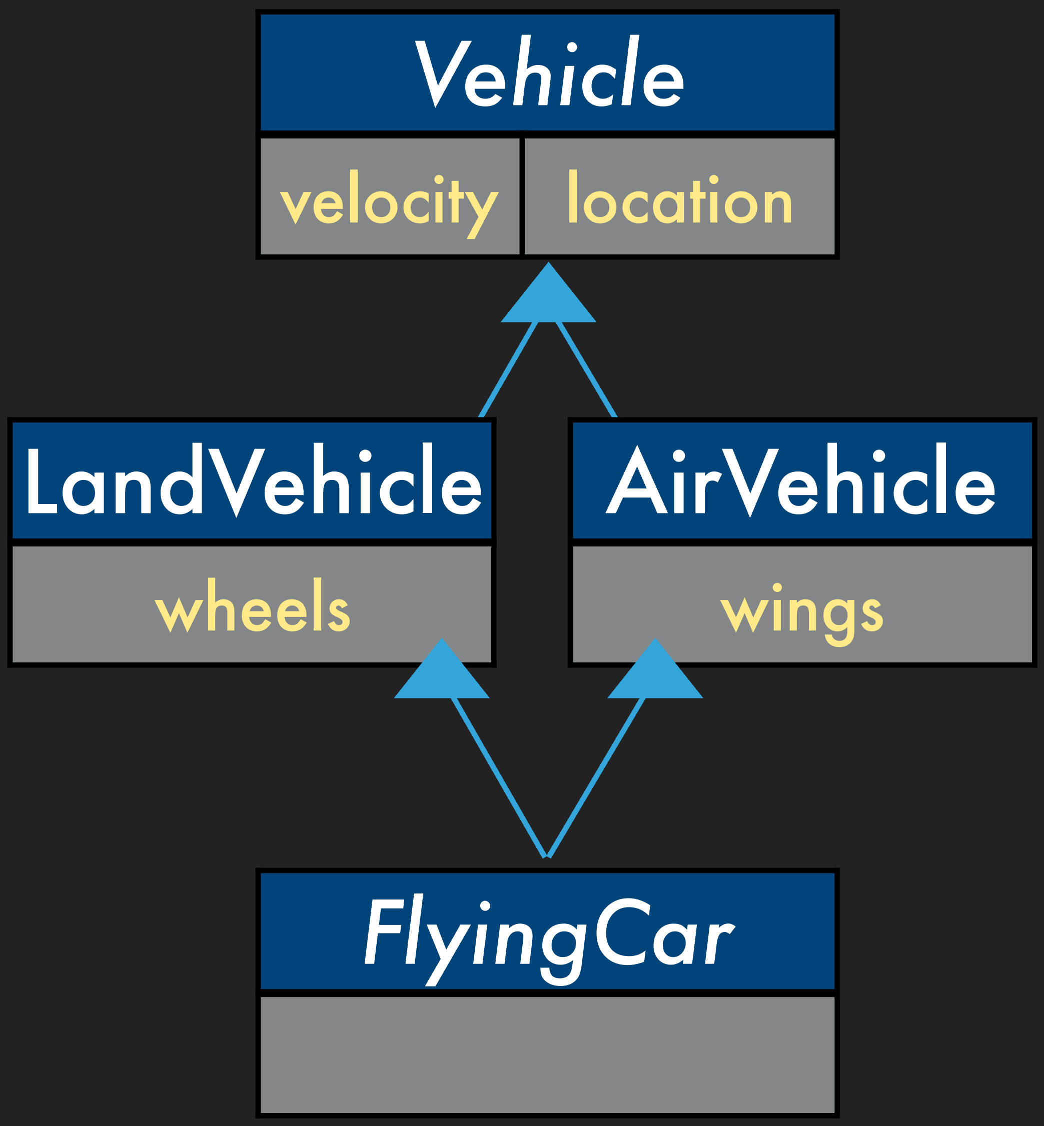
- Classes can play several roles
  - Factories from which instances can be created
  - Units of reuse
- Inheritance can play several roles
  - code reuse
  - design reuse
- These roles can conflict
- Multiple inheritance to the rescue… ?

MULTIPLE INHERITANCE

Sometimes it is convenient to have a class which has multiple parents

- Some languages, like C++, support multiple inheritance

Subclasses inherit instance variables and methods from all parents



https://en.wikipedia.org/wiki/Multiple_inheritance

THE DIAMOND PROBLEM

A problem arises when the same methods or variables are inherited via different paths

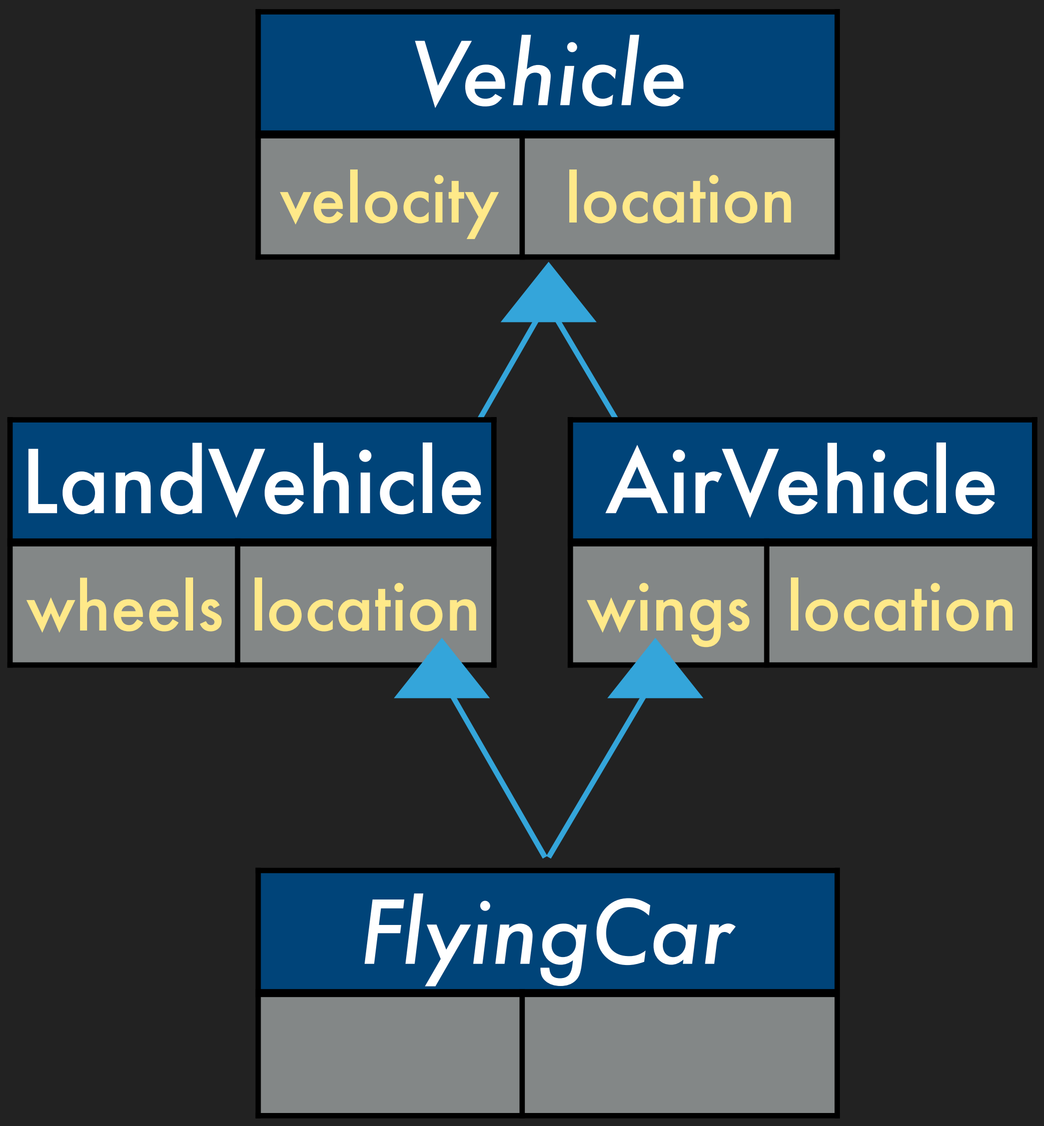
- e.g. what version of location method to use when called on FlyingCar?

duplicated behaviour

- can be solved through manual overriding
- or through linearisation

duplicated state

- harder to solve



INTERFACES

Java has single inheritance

Java **interfaces** were introduced to provide some of the functionality of true multiple inheritance

You can inherit from one class and from multiple interfaces simultaneously

Interfaces are like abstract classes with no fields or method implementations

No diamond problem since interfaces contain no data or behaviour

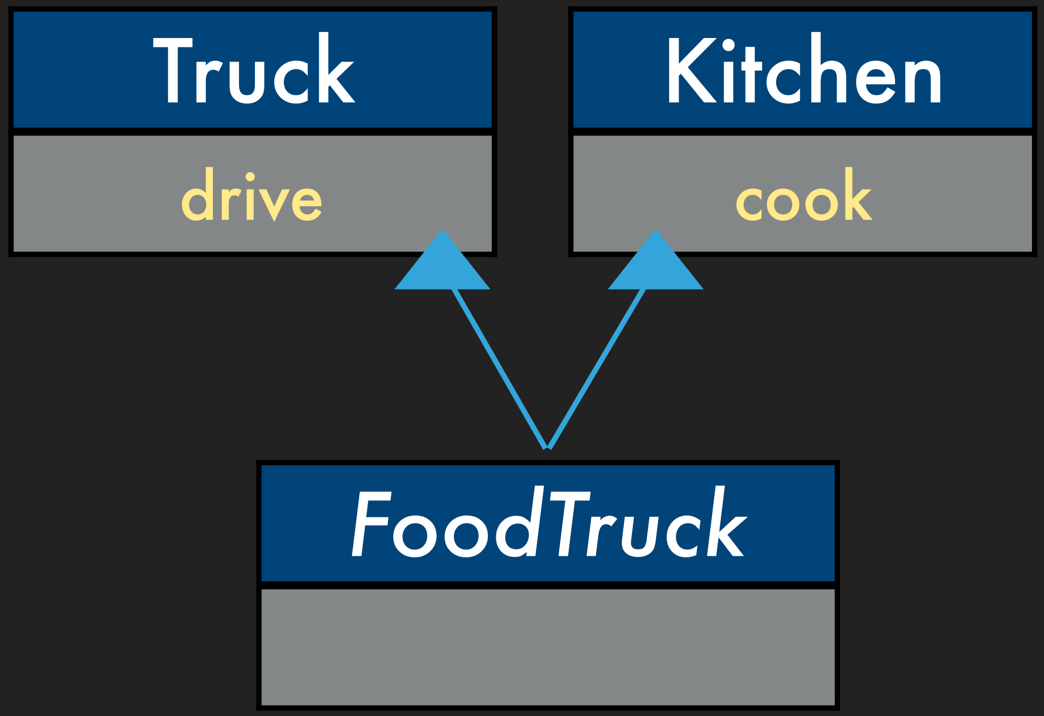
http://stackoverflow.com/questions/3556652/how-do-java-interfaces-simulate-multiple-inheritance

EXAMPLE OF USING INTERFACES

If Java has no multiple inheritance
then how should I do something like this?

```
class FoodTruck extends Truck, Kitchen {
}
```

```
foodTruck.drive();
foodTruck.cook(pizza);
```



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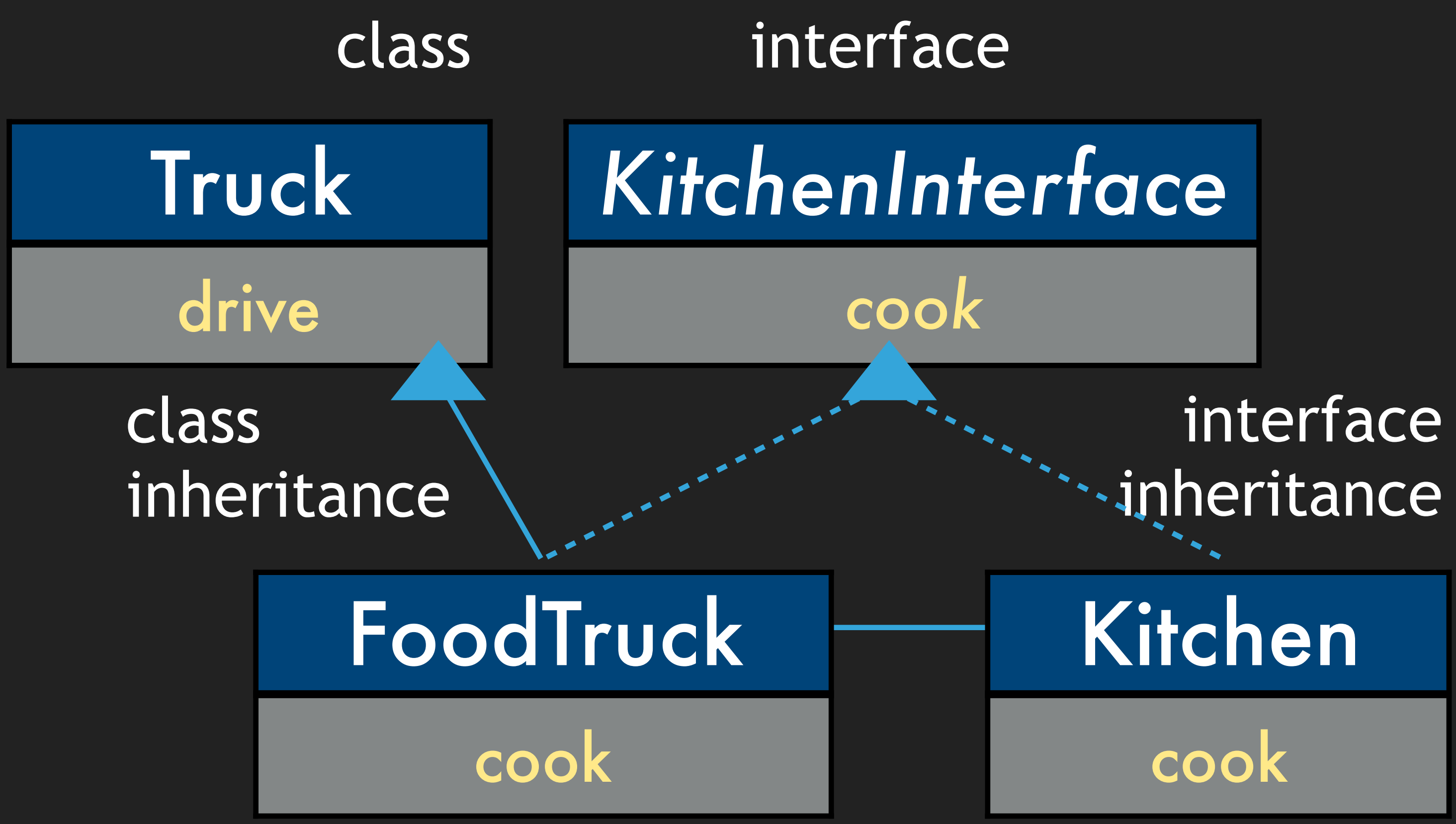
EXAMPLE OF USING INTERFACES

```
class FoodTruck extends Truck implements KitchenInterface {
   Kitchen kitchen;
   public void cook(Food foodItem) {
      kitchen.cook(foodItem);
   }
}

foodTruck.drive();
foodTruck.cook(pizza);
```



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MIXINS

Factoring out the increment when subclassing

Mixins can be seen as the “increment” that needs to be applied to a class

Mixin composition is an operation that applies a mixin to a class to produce a more specialised class

Typically, mixin composition is linearised

- this can cause problems:
  - composition order important
  - introducing extra mixin can change behaviour

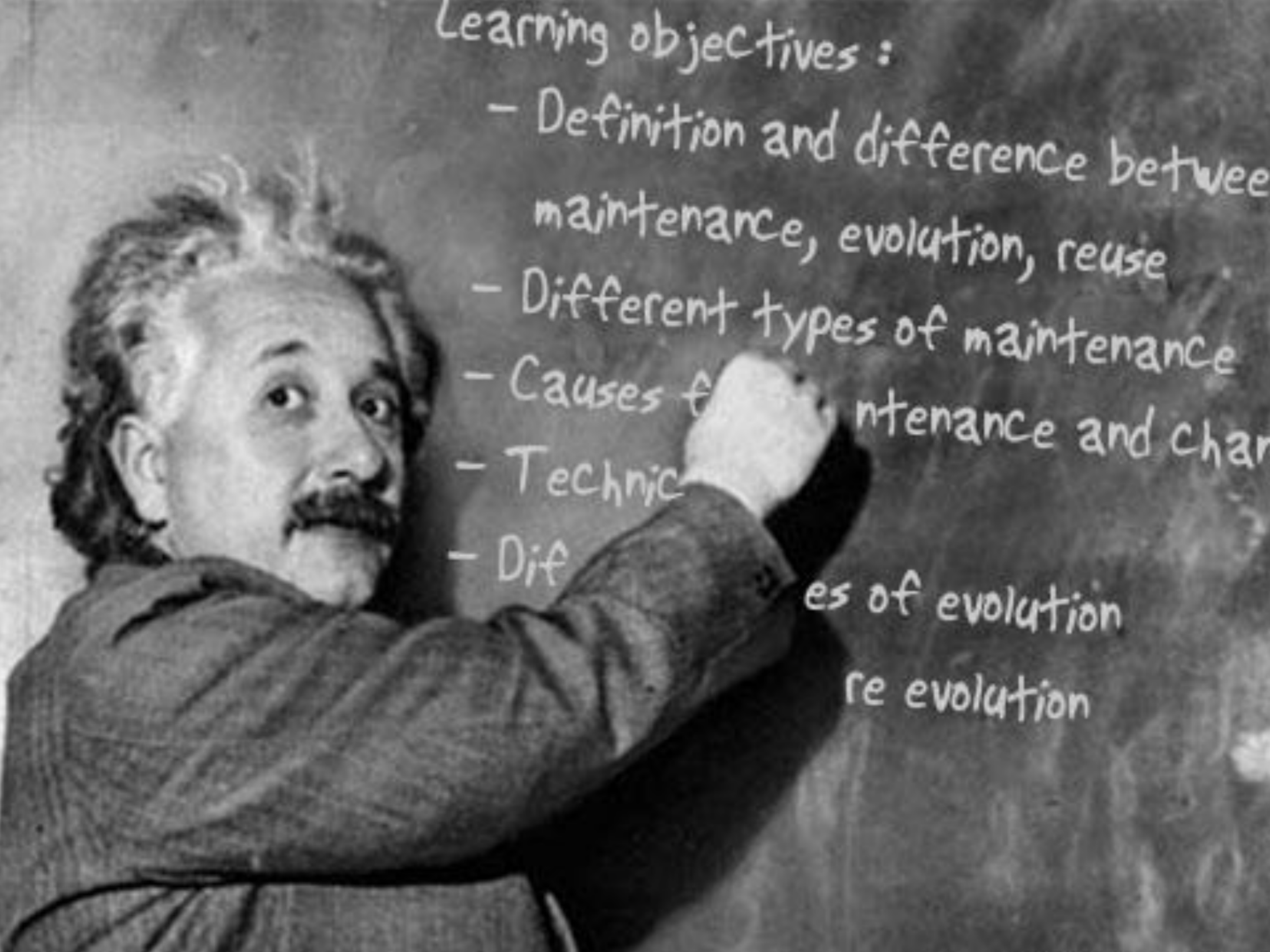
Example: mixin modules in Ruby

CONCLUSION

- OO promotes maintainability by viewing programs as collections of loosely connected objects
    - Each object is responsible for specific tasks
    - It is through the interaction of objects that computation proceeds
    - Objects can be defined and manipulated in terms of the messages they understand and ignoring the implementation details
- OO promotes the development of reusable components
    - By reducing the interdependency among individual software components
    - Such components can be created and tested as independent units in isolation from the rest of the software system
    - Reusable software components permit to treat problems at a higher level of abstraction

ABSTRACTION MECHANISMS (REVISITED)

- Encapsulation
  - objects contain their own data as well as the methods that work on that data
- Information hiding
  - clients of an object know only the set of messages it can receive
  - implementation details of how it processes these messages remain hidden to external clients
- Polymorphism
  - cleaner and more maintainable code by delegating responsibilities and implementation choices to the objects
- Code sharing
  - classes enable sharing behaviour among objects
  - class hierarchies and inheritance enable reuse of class definitions


Learning objectives :
- Definition and difference betwee
maintenance, evolution, reuse
- Different types of maintenance
- Causes f
ntenance and char
- Technic
- Dif
es of evolution
re evolution

LEARNING OBJECTIVES

- definitions of reusability, software reuse and reusable component
- how object-oriented programming promotes modularity, maintainability and reuse
- encapsulation, information hiding, polymorphism and code sharing
- key object-oriented concepts: object, classes, methods, messages, inheritance
- polymorphism and dynamic binding
- method overriding, self and super calls
- abstract classes and methods
- different kinds of inheritance: single, multiple, interfaces, mixins

POSSIBLE QUESTIONS

16. Define and illustrate the notions of software reuse, reusability and reusable components.
17. Give two economic and two intellectual justifications for software reuse. Explain in detail.
18. Give (and explain) at least 3 different software reuse techniques seen throughout the course.
19. How and why does object-oriented programming promote modularity and maintainability?
20. Explain the object-oriented techniques of encapsulation, information hiding, polymorphism and code sharing and how they relate to software reusability.

POSSIBLE QUESTIONS

21. Explain, using a concrete example, what **polymorphism** and **dynamic binding** is, and how it can lead to more **maintainable** code.

22. Explain on a concrete example the concepts of **method overriding, self and super calls**.

23. How can **abstract classes and methods** improve reusability? Explain and illustrate with a concrete example.

24. Explain, using a concrete example, how a **multiple inheritance** problem could be modelled in terms of single inheritance on classes and interfaces in Java.