Object-Oriented Programming

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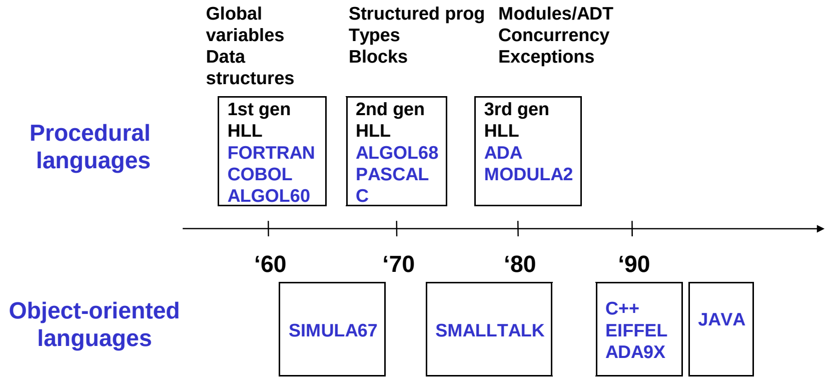
Learning objectives

- Define the object-oriented (OO) paradigm
  - What are objects and classes?
- Understand the differences between procedural approach and OO
  - What is encapsulation?
- Understand the fundamental concepts of OO
  - What are interfaces, messages, and inheritance?
- Appreciate the benefits of OO
  - What are modularity, reuse, and maintainability?

Programming paradigms

- Procedural (Pascal, C,…)
- Object-Oriented (C++, Java, C#,…)
- Functional (LISP, Haskell, SQL,…)
- Logic (Prolog)

Languages timeline



Global variables Data structures

Structured prog Types Blocks

Modules/ADT Concurrency Exceptions

Procedural languages

1st gen HLL FORTRAN COBOL ALGOL60

2nd gen HLL ALGOL68 PASCAL C

3rd gen HLL ADA MODULA2

‘60 ‘70 ‘80 ‘90

Object-oriented languages

SIMULA67

SMALLTALK

C++ EIFFEL ADA9X

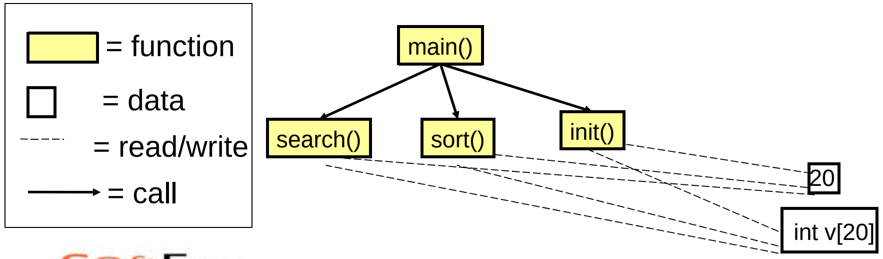
JAVA

Procedural

```
int vect[20];
void sort() { /* sort */ }
int search(int n){ /* search */ }
void init() { /* init */ }
// …
int i;
void main(){
   init();
   sort();
   search(13);
}
```

Modules and relationships

- Modules:
  - Data
  - Function (Procedure)
- Relationships
  - Call
  - Read/write

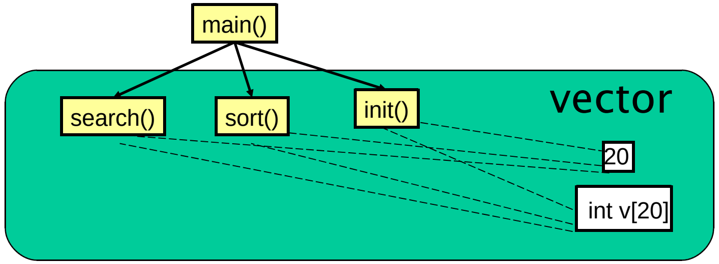


Problems

- There is no syntactic relationship between:
  - Vectors (int vect[20])
  - Operations on vectors (search, sort, init)
- There is no control over *size*:
  for (i=0; i<=20; i++) { vect[i]=0; };
- Initialization
  - Actually performed?

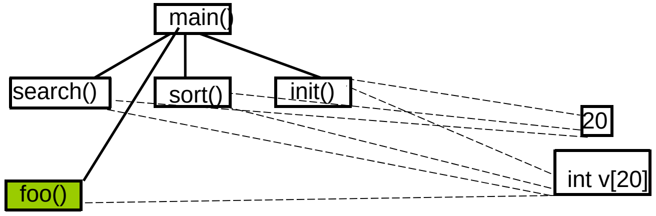
The vector

- It’s not possible to consider a vector as a primitive and modular concept
- Data and functions cannot be modularized properly



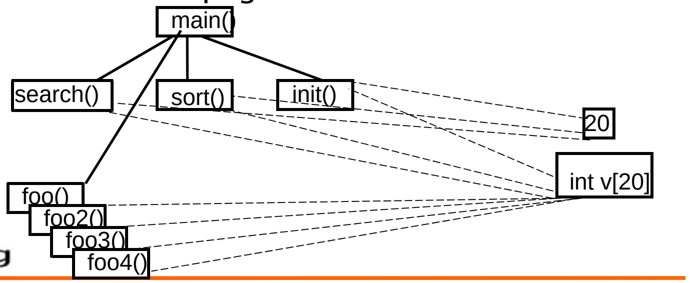
Procedural - problems

- No constraints on read/write relationships
- External functions can read/write vector’s data



Procedural - On the long run

- (All) functions may read/write (all) data
- As time goes by, this leads to a growing number of relationships
- Source code becomes difficult to understand and maintain
  - Problem known as “Spaghetti code”



What is OO?

- Procedural Paradigm
  - Program defines data and then calls subprograms acting on data
- OO Paradigm
  - Program creates objects that encapsulate the data and procedures operating on data
- OO is simply a new way of organizing a program
  - Cannot do anything using OO that can’t be done using procedural paradigm

Why OO?

- Programs are getting too large to be fully comprehensible by any person
- There is need of a way of managing very-large projects
- Object Oriented paradigm allows:
  - programmers to use large blocks of code
  - without knowing all the picture
- Makes code reuse a real possibility
- Easier maintenance and evolution of code

Why OO?

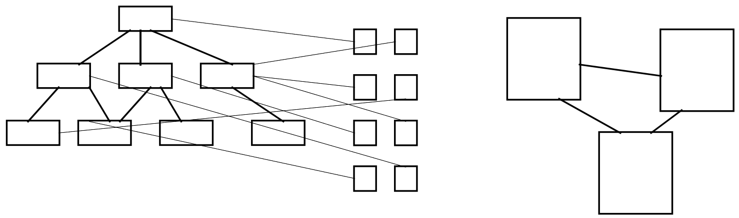
- Benefits only occur in larger programs
- Analogous to structured programming
  - Programs < 30 lines, spaghetti is as understandable and faster to write than structured
  - Programs > 1000 lines, spaghetti is incomprehensible, probably doesn’t work, not maintainable
- Only programs > 1000 lines benefit from OO really

An engineering approach

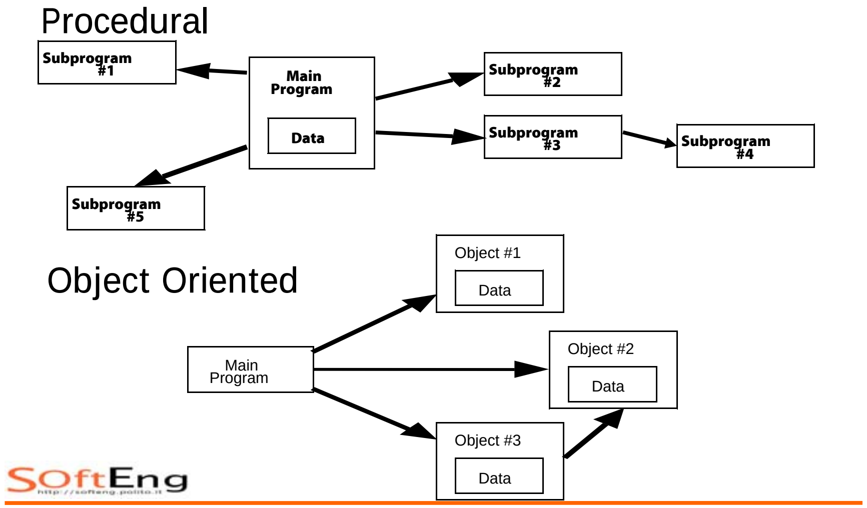
- Given a system, with components and relationships among them, we have to:
  - Identify the components
  - Define component interfaces
  - Define how components interact each other through their interfaces
  - Minimize relationships among components

An engineering approach

- Objects introduce an additional abstraction layer
- More complex system can be built



Procedural vs. OO



Procedural

Subprogram #1

Main Program

Data

Subprogram #2

Subprogram #3

Subprogram #4

Subprogram #5

Object Oriented

Object #1

Data

Main Program

Object #2

Data

Object #3

Data

Object-Oriented approach

- Defines a new component type
  - Object (and class)
  - Data and functions on data are within the same module
  - Allows defining a more precise interface
- Defines a new kind of relationship
  - Message passing
  - Read/write operations are limited to the object scope

Object-Oriented approach

```
class Vector {

    //data
    private int v[20];

    //interface
    public Vector() {
        for(int i=0; i<20; i++) v[i]=0;
    }
    public sort(){  /*sort*/ }
    public search(int c){ /*search*/ }
}
```

Object-Oriented approach

- Use of the class Vector:

```
Vector v1 = new Vector();
Vector v2 = new Vector();
v1.sort();
v1.search(22);
```

Object-Oriented approach

```
/*Example in C language */
int vect[20];
int i;
void sort(int [] v, int size) { … };
int search(int [] v, int size, int c)
   { … };

void main() {
  for (i=0; i<20; i++) {
   vect[i]=0;
  }
  sort(vect, 20);
  search(vect, 20, 33);
}
```

```
/*The same example in Java */
class Vector {
  private int v[20];
  public Vector() {
    for (int i=0; i<20; i++) v[i]=0;
  }
  public sort()            {  /*sort*/ }
  public search(int c) {/*search*/}
}
```

```
/* The same main() in Java */
int main() {
  Vector v1 = new Vector();
  Vector v2 = new Vector();
  v1.sort();
  v1.search(22);
}
```

Class and object

- Class (the description of object structure, i.e. *type*):
  - Data (ATTRIBUTES or FIELDS)
  - Functions (METHODS or OPERATIONS)
  - Creation methods (CONSTRUCTORS)
- Object (class instance)
  - State and identity

Class and object

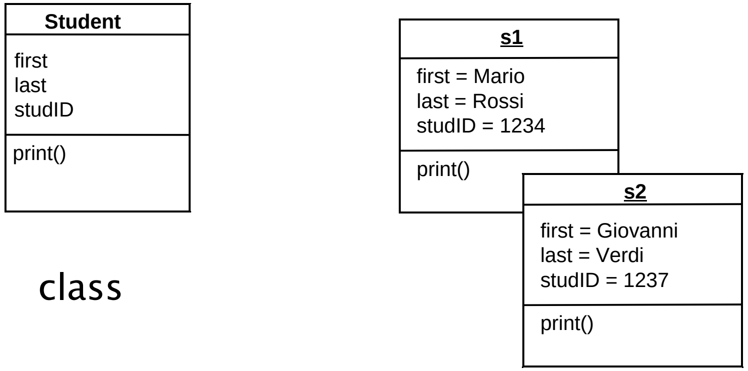
- A class is like a type definition
  - No data is allocated until an object is created from the class
- The creation of an object is called instantiation. The created object is often called an instance
- No limit to the number of objects that can be created from a class
- Each object is independent. Changing one object doesn't change the others

Example

```
▪ Class car {
     string bodyColor;
     void turnOn() {…}
  }
```

- mikeCar:Object [bodyColor := “blue”]
- joeCar:Object [bodyColor := “red”]
- maryCar:Object [bodyColor := “blue”]

UML



Student
first
last
studID
print()

s1
first = Mario
last = Rossi
studID = 1234
print()

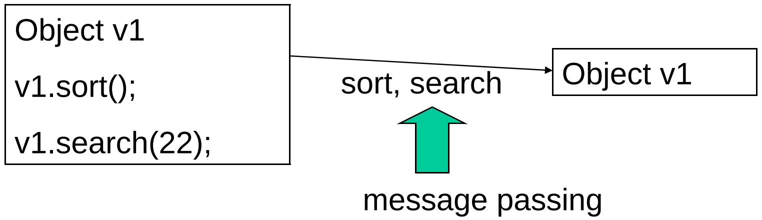
s2
first = Giovanni
last = Verdi
studID = 1237
print()

class

objects

Message passing

- Objects communicate by message passing
  - Not by procedure call
  - Not by direct access to object’s local data



Object v1

v1.sort();

v1.search(22);

sort, search

Object v1

message passing

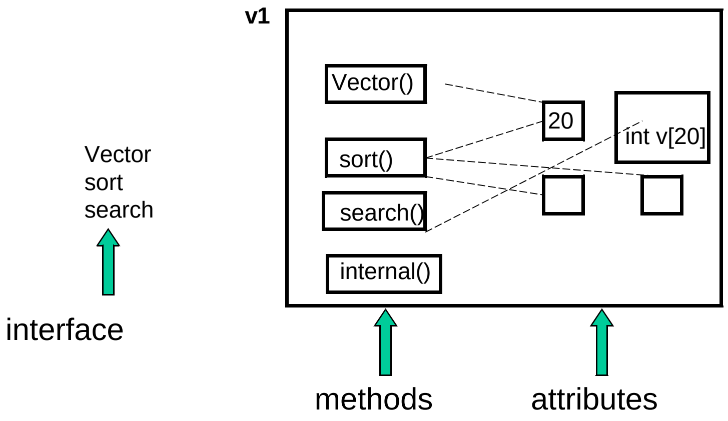
Message

- A message is a service request
  - search, sort
- A message may have arguments
  - A value or an object name
- Examples
  - search(21)
  - search(joeCar)

Interface

- Set of messages an object can receive
- Any other message is illegal
- The message is mapped to a function within the object
- The object is responsible for the association (message, function)

Interface



v1

Vector()

sort()

search()

internal()

20

int v[20]

Vector
sort
search

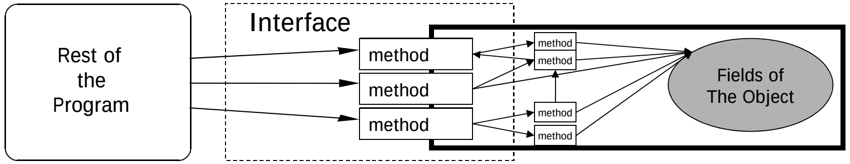
interface

methods

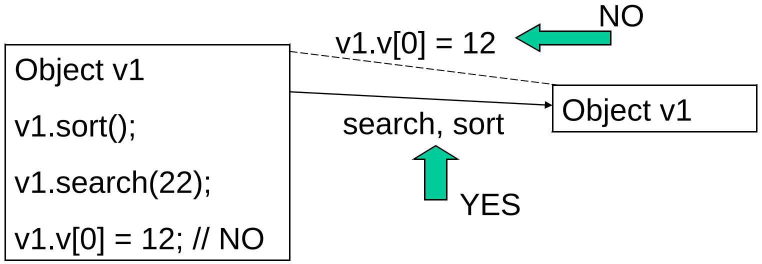
attributes

Interface (simple)

- The interface of an object is simply the subset of methods that other “program parts” are allowed to call
  - Stable



Encapsulation


```
Object v1
v1.sort();
v1.search(22);
v1.v[0] = 12; // NO
```

- Read/write operations can only be performed by an object on its own data
- Between two objects data are exchanged through message passing

Benefits of encapsulation

- To use an object, the user need only comprehend the interface. No knowledge of the internals are necessary
- Self-contained. Once the interface is defined, the programmer can implement the interface (write the object) without interference of others

Benefits of encapsulation

- Implementation can change at a later date without rewriting any other part of the program (as long as the interface doesn't change)
- Changes in the data mean changing code in one location, rather than code scattered around the program (error prone)

Encapsulation in real life

- PhoneBook
  - Allows user to enter, look up and delete names and phone numbers
  - Implemented using an array
  - Maximum 100 names in the phone book
- PhoneBook object
  - Hidden Data
    - array
  - Interface
    - add, delete, lookUp

Encapsulation in real life

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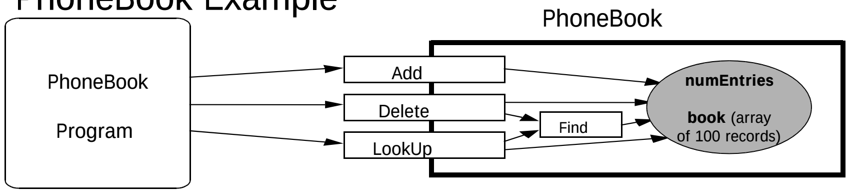
PhoneBook Example



Encapsulation in real life

- The PhoneBook object is successful. It is used in hundreds of applications across the company
- It only holds 100 records! It now must upgraded to hold unlimited number of records
- How do we do so without breaking all the other programs in the company?

Encapsulation in real life

- The interface does not need to change. Thus there is no need to change any of the programs using PhoneBook object
- If this had been programmed in the procedural paradigm, each program that used the phone book would have had a copy of the data array and would have to have been extensively modified to be upgraded

Inheritance

- A class can be a sub-type of another class
- The inheriting class contains all the methods and fields of the class it inherited from plus any methods and fields it defines
- The inheriting class can override the definition of existing methods by providing its own implementation
- The code of the inheriting class consists only of the changes and additions to the base class

Example

```
▪ Class Employee{
     string name;
     double wage;
     void incrementWage(){…}
  }
▪ Class Manager extends Employee{
     string managedUnit;
     void changeUnit(){…}
  }
▪ Manager m = new Manager();
  m.incrementWage(); // OK, inherited
```

Overriding

```
▪ Class Vector{
     int vect[20];
     void add(int x) {…}
  }
▪ Class OrderedVector extends Vector{
     void add(int x){…}
  }
```

Why inheritance

- Frequently, a class is merely a modification of another class. In this way, there is minimal repetition of the same code
- Localization of code
  - Fixing a bug in the base class automatically fixes it in the subclasses
  - Adding functionality in the base class automatically adds it in the subclasses
  - Less chances of different (and inconsistent) implementations of the same operation

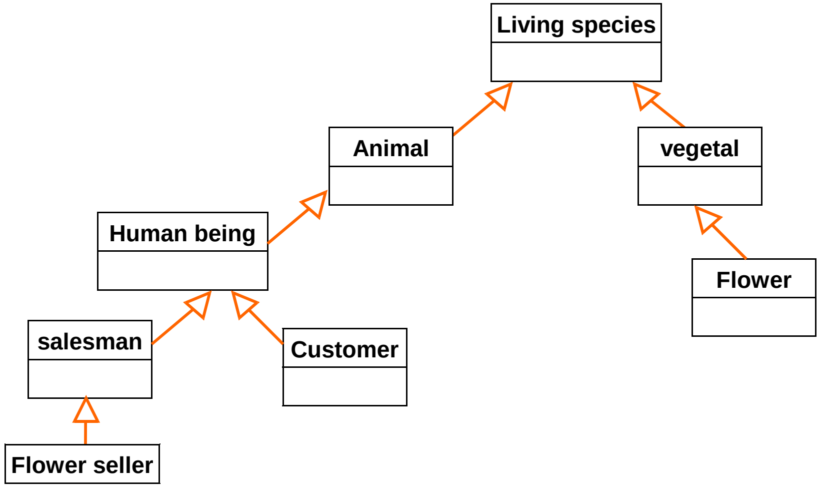
Inheritance terminology

- Class one above
  - Parent class
- Class one below
  - Child class
- Class one or more above
  - Superclass, Ancestor class, Base class
- Class one or more below
  - Subclass, Descendent class, Derived class

Inheritance in real Life

- A new design created by the modification of an already existing design
  - The new design consists of only the changes or additions from the base design
- CoolPhoneBook inherits PhoneBook
  - Add mail address and cell number

Example of inheritance tree



Living species

Animal

vegetal

Human being

Flower

salesman

Customer

Flower seller

Inheritance and polymorphism

```
▪ Class Employee{
    private string name;

    public void print(){
      System.out.println(name);
    }
  }
▪ Class Manager extends Employee{
    private string managedUnit;

    public void print(){ //overrides
      System.out.println(name); //un-optimized!
      System.out.println(managedUnit);
    }
  }
```

Inheritance and polymorphism

-
  ```
  void printEmployee(Employee e){
    e.print();
  }
  ```

- `Employee e1 = new Employee();`
- `Employee e2 = new Manager(); //ok, is a`
- `printEmployee(e1); // name`
- `printEmployee(e2); // name and unit`

Wrap-up session

- Class
  - Data structure (most likely private)
  - Private methods
  - Public interface
- Objects are class instances
  - State
  - Identity

Wrap-up session

- The key role of interfaces
- Objects communicate by means of messages
- Each object manages its own state (data access)

Wrap-up session

- Abstraction
  - The ability for a program to ignore some aspects of the information it's manipulating, i.e. the ability to focus on the essential
  - Each object in the system serves as a model can perform work, report on and change its state, and "communicate" with other objects in the system, without revealing *how* these features are implemented
- Example
  - Vector of integers implemented as an array or a linked list

Wrap-up session

- Encapsulation
  - Also called *information hiding*
  - Ensures that objects cannot change the internal state of other objects in unexpected ways
  - Only the object's own methods are allowed to access its state
  - Each type of object exposes an *interface* to other objects that specifies how other objects may interact with it
- Do not brake it, never ever! …Unless you know what you are doing!
  - Loosens up relationships among components

Wrap-up session

- Inheritance
  - Objects defined as sub-types of already existing objects. They share the parent data/methods without having to re-implement
- Specialization
  - Child class augments parent (e.g. adds an attribute/method)
- Overriding
  - Child class redefines parent method
- Implementation/reification
  - Child class provides the actual behaviour of a parent method

Wrap-up session

- Polymorphism
  - The same message can produce different behavior depending on the actual type of the receiver objects (late binding of message/method)

Wrap-up session

- Benefits of OO
  - Modularity (no spaghetti code)
  - Maintainability
  - Reusability