Lecture 01
Object-Oriented Programming
Short review

Object-Oriented Concurrent Programming, 2019-2020

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Contents

1 Object-Oriented Programming

Programming

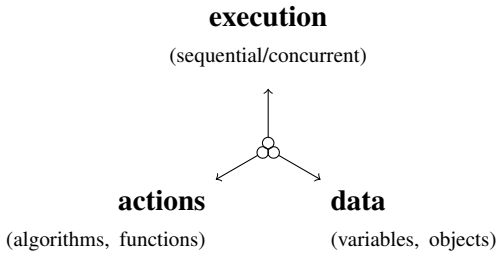
- *Programming* can be defined as the act of creating, developing and implementing *solutions* to problems that can be *executed* by *computers*.
- These solutions are called *programs*.

Imperative Programming

- We can roughly separate two ways to solve problems and prescribe programs: one designated as *declarative* (functional, logical), and another *imperative* (procedural, object-oriented).
- Imperative programming differs from the declarative one because there is a *explicit* notion of a mutable *state*.
- An imperative program can be seen as a sequence of *commands* (or orders) which will change the state of the running system until the desired objectives are achieved.
- In imperative programming there are two dominant methodologies/languages:
  - *Procedural Programming* (`Pascal`, `C`);
  - *Object-Oriented Programming* (`Java`, `C++`, `Eiffel`).
- This course's goal is OO programming, hence we will (for the moment) stay focus only on imperative programming approaches.

Data and Functions

- A program contains mechanisms that allow to *execute* certain *actions* on *data*.
- These are the *three forces* involved in computing:



- When you have to design the basic architecture of a program, the question arises as to whether it should be based on functions (actions) or data?
- It is in the answer to this question that essentially distinguishes procedural programming and object-oriented programming.

- It is rather easy to see that in theory, and if we ignore the fundamental aspect of abstraction, the two approaches are clearly dual to each other.
- However, in practice, the qualities of the programs developed by each of them are usually quite different.

The *Top-Down* procedural approach

- The *top-down* approach is based on the idea that a program is a stepwise refinement of the abstract function that defines it.
- The design and implementation of a program becomes a successive reduction in the functional abstraction until the entire program is expressed directly in the imperative instructions of the language or the use of functions of its libraries.
- It is a logical, systematic, well organized, and disciplined method.
- However, this approach suffers from the following problems:
  - It does not take into account the evolutionary nature of the software;
  - It is highly questionable whether a program should be defined by a function;
  - The priority given to functional abstraction has the consequence that data structures are often relegated to a minor secondary plan;
  - The *top-down* approach does not promote reuse;

Why use data

- In general, functions are not a stable part of programs, hence to base the structure of programs on them can lead to radical changes only due to small changes in requirements (for example, if we move to a batch type interface for a more interactive one).
- *Compatibility*: It is difficult to combine actions if there is no compatibility in the data structures shared by them. Why not try combining data structures?
- *Reuse*: The *Bottom-Up* approach together with the data abstraction characteristic of OOP makes it easier to reuse and adapt existing modules.
- *Continuity*: Over time data structures, at least if viewed at an adequate level of abstraction, are in fact the stable aspects in a system.

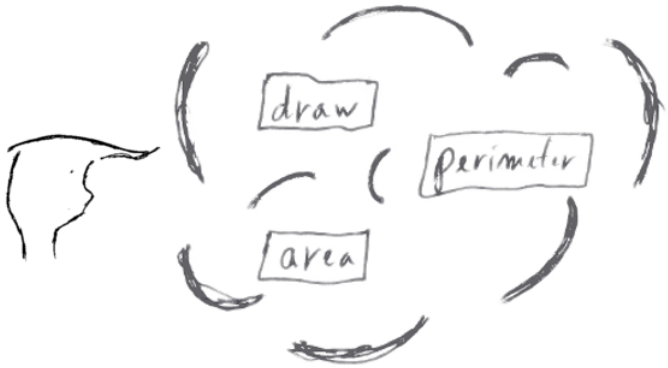
Object-Oriented Project

- In structured procedural programming the construction of programs is done from “top-to-down”, identifying the functions of the programs and decomposing them step-by-step to a full implementation.
- In object-oriented programming, the construct is "bottom-to-up", identifying and constructing the “objects” (or rather, the classes) involved in the problem, composing them to a full implementation.

To Think OO: The strategy to start to think OO is to organize the program structure around the *data* involved in the problem, making use of proper abstraction, and not primarily about what the program does.

Example problem: a paint alike to handle geometric shapes

Example problem: Procedural approach



Example: a procedural approach to the perimeter of figures

```
double perimeter(Figure f) {
   double result = 0;
   switch(f.type) {
      case RECTANGLE:
         result = ...
```

```
            break;
         case CIRCLE:
            result = ...
            break;
         case SQUARE:
            result = ...
            break;
      }
      return result;
}
```

Example problem: Object-Oriented approach

Example: an OO approach to the perimeter of figures

```
class Figure {
   abstract double perimeter();
}

class Rectangle extends Figure {
   double perimeter() {
      return ...
   }
}

class Circle extends Figure {
   double perimeter() {
      return ...
   }
}

class Square extends Rectangle {
   ...
}
```

2 OOP: The mechanics

What are “Objects”?

- Object: data structure + operations
- Object: implementation of an Abstract Data Type (ADT)

Abstract Data Type: An Abstract Data Type is a data type defined only by the operations that are applicable to it and its properties (semantics)!

Object-Oriented Programming: Object Oriented Programming is the construction of software systems as structured collections of Abstract Data Types.

Information Hiding

- Information hiding expresses the possibility of objects to explicitly define a set of exported services to external users (or hide a set of internal services).
- The object's ADT defines the services to export.
- Mutable object variables should never be exported.
- This is one of the essential mechanisms of OOP to achieve data abstraction.

Inheritance

We can view the inheritance mechanism from two different perspectives: as a module and as a type. As a module, inheritance is a mechanism of reuse and extension, allowing the construction of new objects only by the difference from other existing ones. As a type, inheritance is a mechanism of abstraction and specialization, characteristics resulting from subtype polymorphism and dynamic binding.

Command-Query separation

- We can view objects as machines with an internal state (opaque) and to which we can apply commands and observe its state.
- It is very different to observe the state of a machine (query) and invoke an operation that can modify it (command).
- The first is associated with the mathematical notion of function and the second with the imperative notion of command or procedure.

3 Design by Contract

DbC: Summary

- Make the *semantics* (defined in the ADT) of the objects part of the *interface* and, if possible, to make it verifiable (statically or at runtime).
- This semantics is expressed by *assertions*: *invariant* of the object; *precondition*, and *postcondition* of each of its services.
- Here, the abstraction of data ceases to have a purely syntactic meaning (thus, only based on the goodwill and discipline of the programmers) to become a more complete, possibly verifiable, ADT.

3.1 DbC: What For!

By far the biggest challenge facing a programmer is to ensure the **correction** of the produced code! Rigorous and systematic techniques are required for developing programs that maximize this quality criterion, specially when complex problems are involved. In this sense, the use of the mechanisms usually found in OO languages – objects, polymorphism, inheritance, information hiding - is manifestly insufficient. The **meaning of code**, at the various levels of abstraction, that exists in the mind of the programmer should be part of the code itself. Moreover, it would be important that this meaning should not serve only for **documentation**, but also help in **checking and debugging** the developed software. The ambiguity that so many times exist on which part of the code to assign the **responsibility** of a particular correction guarantee should also be eliminated. If all this is added the possibility of having intelligent **fault detection and tolerance** mechanisms, we have a global picture about what Design by Contract can offer us.

3.2 Assertions

There are no magic recipes to ensure program correction. However, the path in this direction is very clear: to reduce discrepancies between specification and implementation. Why not then try to include the first in the second? **Assertions** serve exactly this purpose.

- An *assertion* is a boolean expression, if possible, executable that expresses a property of the code.

We may regard it as the (incomplete) computational achievement of mathematical predicates. An assertion expresses a property that must be true **whenever** it is "executed" by the program.

```
void print(int[] list) {
   for(int i = 0; i < list.length; i++) {
      assert i < list.length;
      out.print(" "+list[i]);
   }
   assert !(i < list.length);
}

boolean isPrime(int n) {
   boolean result = true;
   for(int i = 3; result && i*i <= n; i+=2) {
      assert result && i*i <= n;
      result = (n % i != 0);
   }
   return n == 2 || result;
}
```

Preconditions and Postconditions

An assertion expresses always the responsibility of the code that is upstream. Thus, depending on its location we can assign the responsibilities to the various entities of a program. In the case of functions or methods, if the assertion is located at the beginning, the responsibility for its guarantee is from the caller (clients), so we will be in the presence of a **precondition**. On the other hand, if the assertion is located at the end of the function, the responsibility is of the function itself, so we will be in the presence of a **postcondition**.

```
double sqrt(double x) {
    // precondition:
    assert x >= 0: "Negative x";

    double result; (...)

    // postcondition:
    assert Math.abs(result*result-x) < MAX_ERROR;

    return result;
}
```

Class Invariants

In object-oriented programming, the entity par excellence in building and structuring programs is the **class** (as an object type). However, in class design there is usually interest in ensuring that certain properties are always valid when using their objects. For example, in a class that implements a *calendar date*, it makes perfect sense (since it greatly simplifies the code that uses it) not to allow objects whose day-month-year state does not correspond to a valid date. Thus it makes sense to associate an assertion that expresses this semantics. This assertion is called a **class invariant**, and in practice, it is a condition that must occur in stable times of objects. These states correspond to the points at which objects are externally usable. That is, immediately after the execution of one of its constructors, and before and after the execution of any of its public services.

3.3 Class Contract

	Obligations	**Benefits**
Client	Satisfy the precondition of each service invoked.	Guarantee that both the class invariant the invoked service postcondition are verified when the service terminates.
Class	Ensure that the class invariant is verified at stable times. Ensure that, at the end of the execution of each of its services its postcondition is verified.	When a services is invoked, the precondition is verified.

3.4 DbC in Java

The Java language does not adequately support Design by Contract. Some of its main shortcomings are the following:

- Does not distinguish between different types of assertions;
- There is no support for the definition of class invariants;
- Assertions are not part of the class interface;
- There is no inheritance of contracts;
- Documentation applications (`javadoc`) don't extract class contracts;
- The exception mechanism is not disciplined and was developed without considering DbC;
- We cannot activate and deactivate contracts by class.

4 OO design techniques

- Finding Objects:
  - External objects (books, people, figures, etc.);
  - Existing classes;
  - Adaptation by inheritance;
  - Define abstract classes by sharing properties (from ADT).
- The first big mistake:
  promote a function to an object!
- Interface Techniques:
  - command query separation;
  - objects as state machines;
  - an interface, multiple implementations.
- The second big mistake:
  confuse customers with heirs or vice versa!
  - *client*: has/uses
  - *heir*: is