Programming Paradigms

(Lectures on High-performance Computing for Economists VII)

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Programming Approaches

Paradigms I

- A paradigm is the preferred approach to programming that a language supports.
- Main paradigms in scientific computation (many others for other fields):
  1. Imperative.
  2. Structured.
  3. Procedural.
  4. Object-Oriented.
  5. Functional.

Paradigms II

- Multi-paradigm languages: `C++`, introduction a few years go of λ-calculus features.
- Different problems are better suited to different paradigms.
- You can always "speak" with an accent.
- Idiomatic programming.

Imperative, structured, and procedural

Imperative

- Oldest approach.
- Closest to the actual mechanical behavior of a computer$\Rightarrow$ original imperative languages were abstractions of assembly language.
- A program is a list of instructions that change a memory state until desired end state is achieved.
- Useful for quite simple programs.
- Difficult to scale.
- Soon it led to spaghetti code.

Structured

- *Go To Statement Considered Harmful*, by Edsger Dijkstra in 1968.
- Structured program theorem (Böhm-Jacopini): sequencing, selection, and iteration are sufficient to express any computable function.
- Hence, structured: subroutines/functions, block structures, and loops, and tests.
- This is paradigm you are likely to be most familiar with.

Procedural

- Evolution of structured programming.
- Divide the code in procedures: routines, subroutines, modules methods, or functions.
- Advantages:
    1. Division of work.
    2. Debugging and testing.
    3. Maintenance.
    4. Reusability.

OOP

Object-oriented programming I

- Predecesors in the late 1950s and 1960s in the `LISP` and `Simula` communities.
- 1970s: `Smalltalk` from the Xerox PARC.
- Large impact on software industry.
- Complemented with other tools such as design patterns or UML.
- Partial support in several languages: structures in `C` (and structs in older versions of `Matlab`).
- Slower adoption in scientific and HPC.
- But now even `Fortran` has OO support.

Object-oriented programming II

- Object: a composition of nouns (numbers, strings, or variables) and verbs (functions).
- Class: a definition of an object.
- Analogy with functional analysis in math.
- Object receive messages, processes data, and sends messages to other objects.

Object-orientated programming: basic properties

- Encapsulation.
- Inheritance.
- Polymorphis.
- Overloading.
- Abstraction penalty.

Example in Matlab

- Class *household*.
- We create the file `household.m`.
- We run `Example_Use_Class.m`.
- Public, private, and protected properties and methods.

Functional Programming

Functional programming

- Nearly as old as imperative programming.
- Created by John McCarthy with `LISP` (list processing) in the late 1950s.
- Many important innovations that have been deeply influential.
- Always admired in academia but with little practical use (except in Artificial Intelligence).

Theoretical foundation

- Inspired by Alonzo Church's λ-calculus from the 1930s.
- Minimal construction of "abstractions" (functions) and substitutions (applications).
- Lambda Calculus is Turing Complete: we can write a solution to any problem that can be solved by a computer.
- John McCarthy is able to implement it in a practical way.
- Robin Milner creates ML in the early 1970' s.

Why functional programming?

- Recent revival of interest.
- Often functional programs are:
  1. Easier to read.
  2. Easier to debug and maintain.
  3. Easier to parallelize.
- Useful features:
  1. Hindley–Milner type system.
  2. Lazy evaluation.
  3. Closures.

Main idea

- All computations are implemented through functions: functions are first-class citizens.
- Main building blocks:
  1. Immutability: no variables gets changed (no side effects). In some sense, there are no variables.
  2. Recursions.
  3. Curried functions.
  4. Higher-order functions: compositions ($\simeq$operators in functional analysis).

Interactions

- How do we interact then?

  1. Pure functional languages (like `Haskell`): only limited side changes allowed (for example, I/O) and tightly enforced to prevent leakage.

  2. Impure functional languages (like `OCalm` or `F#`): side changes allowed at the discretion of the programmer.

- Loops get substituted by recursion.

- We can implement many insights from functional programming even in standard languages such as `C++` or `Matlab`.

Functional languages

- Main languages:

  1. `Mathematica`.
  2. `Common Lisp/Scheme/Clojure`.
  3. `Standard ML/Calm/OCalm/F#`.
  4. `Haskell`.
  5. `Erlang/Elixir`.
  6. `Scala`.