INF231:
Functional Algorithmic and Programming
Lecture 1: Introduction, simple expressions and simple types

Academic Year 2023 - 2024

The right vision about computer science

Computer science is NOT about:

- using a computer
- fix a computer
- using a software or the Internet (Facebook, Google, MsWord, . . .)

Among other things, computer science is about:

- understanding computers
- understanding computation
- designing (efficient) methods to compute

“Computer science is no more about computers
than astronomy is about telescopes.”

Edsger Wybe Dijkstra

About algorithms and algorithmic

A central and basic concept in computer science

Algorithmic consists in:

- Automating methods meant to solve a problem
- Study correctness, completeness, and efficiency of a solution
  $\Rightarrow$ This means: you need to “think hard about it”, not just code it.

Four styles (among others) can be used to express algorithms:

- imperative-style: a list of actions
- object-oriented: objects and their interactions are the central components
- logical languages: predicates are the central components
- functional-style: closer to mathematical concepts

Then we turn algorithms into programs using a programming language

Imperative vs functional algorithmic styles

On examples

Example (“Currying”)

Functions are the first class citizens

Imperative style (Python)

```
def area_rectangle
(width,length):
   return width*length
```

Functional style (OCaml)

```
let area_rectangle
(width:int) (length:int):int
   = width*length

let area_rectangle_of_width2
= area_rectangle 2
```

What is `area_rectangle` 2 ?

- for Python: an argument error!
- for OCaml: the function `length` $\mapsto$ 2 $\times$ `length`.

Imperative vs functional algorithmic styles

On examples

Example (Factorial of an integer)

Imperative style (Python)

```
def fact (n):
    if n==0:
        return 1
    else:
        res = 1
        for (i in range(n)):
            res = res *(i+1)

    return res
```

Functional style (OCaml)

```
let rec fact (n:int):int =
    if (n=0 || n=1) then 1
    else n * fact (n-1)
```

- code is shorter
- exactly the mathematical definition
- easier to understand

Imperative vs functional algorithmic styles

On examples

Example (GCD of two integers *a* and *b*)

Can be computed using the remainder of the Euclidean division of *a* by *b*

Imperative style (Python)

```
def gcd (a,b):
    r = a%b
    while (r!=0):
        a = b
        b = r

    return b
```

Functional style (OCaml)

```
let rec gcd (a:int) (b:int):int
    = let r = a mod b in
        if r = 0 then b
        else gcd b r
```

- code is shorter
- nothing is modified
- closer to the mathematical procedure

Imperative vs functional algorithmic styles

The killing example

Example (Creating affine functions)

Given two integers a and b, compute/return the function $x \mapsto a * x + b$

Imperative style (Python)	Functional style (OCaml)
	⋮

`a nightmare ...`
`(unless using`
`lambda-function)`
	`let affine (a:int) (b:int):int -> int`
	`  = fun x -> a*x+b`

	⋮

Le language [O]Caml

[O]Caml is a newly developed programming language that succeeds in being at the same time very powerful and yet simple to understand. Resulting from a long reflection on programming languages, [O]Caml is organized around a small number of basic notions, each of which is easy to understand, and whose combination proves to be extremely fertile. [O]Caml's simplicity and rigor have made its popularity grow in the teaching of computer science, particularly as the first language in introductory programming courses. Its expressiveness and power make it a language of choice in research laboratories [...]. In short, [O]Caml is an easy language with which to solve difficult problems.

translated from: "Le langage Caml" (Leroy, Weis)[1]

[1] [O]Caml est un langage de programmation de conception récente qui réussit à être à la fois très puissant et cependant simple à comprendre. Issu d'une longue réflexion sur les langages de programmation, [O]Caml s'organise autour d'un petit nombre de notions de base, chacune facile à comprendre, et dont la combinaison se révèle extrêmement féconde. La simplicité et la rigueur de [O]Caml lui valent une popularité grandissante dans l'enseignement de l'informatique, en particulier comme premier langage dans des cours d'initiation à la programmation. Son expressivité et sa puissance en font un langage de choix dans les laboratoires de recherche [. . .].
En bref, [O]Caml est un langage facile avec lequel on résout des problèmes difficiles.

Le language [O]Caml and Functional languages in general

in a nutshell

Result of the fruitful collaboration of mathematicians and computer scientists:

- they have the rigor of mathematics
- they rely on few but powerful concepts (λ-calculus)
- they are as expressive as other languages (Turing complete)
- they favor efficient, concise and effective algorithms
- they insist on typing

Example (OCaml in nature)

Unison
File Synchronizer

LexiFi

...

About OCaml and functional languages in general

Features and Advantages

Features:

Functional:
- functions are first-class values and citizens
- highly flexible with the use of functions: nesting, passed as argument, storing

strongly typed:
- everything is typed at compile time
- syntactic constraints on programs

type inference: "types automatically computed from the context"

polymorphic: "generic functions"

pattern-matching: "a super `if`"

Advantages:

Rigorous: closer to mathematical concepts

More concise: less mistakes

Typing is a central concept: better type-safe than sorry

Primitive types and basic expressions

`int`: the integers

The set of signed integers $\mathbb{Z}$, e.g., $-10, 2, 0, 3, 9 \ldots$

Several alternate forms:

ddd ...	an int literal specified in decimal
*0o*ooo ...	an int literal specified in octal
*0b*bbb...	an int literal specified in binary
*0x*hhh ...	an int literal specified in hexadecimal

where *d* (resp. *o*, *b*, *h*) denotes a decimal (resp. octal, binary, hexadecimal) digit

Usual operations:

`-i`	negation	`lnot`	bit-wise inverse
`i + j`	addition	`i lsl j`	logical shift left
`i - j`	substraction	`i lsr j`	logical-shift right
`i * j`	multiplication	`i land j`	bitwise-and
`i / j`	division	`i lor j`	bitwise-or
`i mod j`	remainder	`i lxor j`	bitwise exclusive-or

DEMO: integers

Primitive types and basic expressions

`float`: the real numbers

The set of real numbers $\mathbb{R}$ (an approximation actually): dynamically scaled floating point numbers
Requires at least either:

- a decimal point, or
- an exponent (base 10), prefixed by an *e* or *E*

Remark Not exact computation □

Example

0.2, 2`e7`, 1`E10`, 10.3`E2`, 33.23234`E`(−1.5), 2.

Usual operators:

`−.x`	floating-point negation
`x +. y`	floating-point addition
`x −. y`	floating-point subtraction
`x *. y`	float-point multiplication
`x /. y`	floating-point division
`int_of_float x`	float to int conversion
`float_of_int x`	int to float conversion

DEMO: float

Primitive types and basic expressions

`bool`: the Booleans

The set of truth-values $\mathbb{B} = \{\mathrm{tt}, \mathrm{ff}\}$

Some operators on Booleans:

`not`	logical negation
&&	logical conjunction
||	logical disjunction

DEMO: operators using Booleans

Primitive types and basic expressions

`bool`: the Booleans

Some operations returning a Boolean

`x = y`	x is *equal* to y
`x == y`	x is *identical* to y
`x != y`	x is not identical to y
`x <> y`	x is not equal to y
`x < y`	x is less than y
`x <= y`	x is not greater than y
`x >= y`	x is not lesser than y
`x > y`	x is greater than y

DEMO: operators returning Booleans

Remark Distinction between == and =:

- = is *structural* equality (compare the structure of arguments)
- == is *physical* equality (check whether the arguments occupy the same memory location)
- Returns the same results on basic types: int, bool, char

Hence `e1 == e2` implies `e1 = e2` □

DEMO: illustration of the difference between = and ==

Primitive types and basic expressions

`char`: the Characters

The set of characters *Char* $\subseteq \{'a', 'b', \ldots, 'z', 'A', \ldots, 'Z'\}$

Contains also several escape sequences:

`'\\'`	backslash character itself
`'\"'`	single-quote character
`'\t'`	tabulation character
`'\r'`	carriage return character
`'\n'`	new-line character
`'\b'`	backspace character

Conversion from int to char (and vice-versa): a char can be represented using its ASCII code:

- `Char.code`: returns the ASCII code of a character
- `Char.chr`: returns the character with the given ASCII code

From lower to upper-case and vice-versa:

- `Char.lowercase_ascii`
- `Char.uppercase_ascii`

DEMO: char

Primitive types and basic expressions

`unit`: the singleton type

Simplest type that contains one element ()

Used by side-effect functions (every function should return a value)

Remark Similar to type `void` in C □

Used to create additional outputs such as printing messages or operating without a return!, e.g.,

```
let a=(print_endline ''Hello''; 3+4);;
```

DEMO: type unit

More on operators

Operators have a type

Constraining the arguments and results:

- order
- number

$\hookrightarrow$ the "signature of the operator"

Operators are functions, i.e., values (hence they have a type).

Consider an operator `op`:

`arg1`	$type_1$
`arg2`	$type_2$
...	...
`argn`	$type_n$
`result`	$type_r$

$$\Rightarrow \quad \text{type}_1 \to \text{type}_2 \to \ldots \to \text{type}_n \to type_r$$

$$=$$

type of `op`

Example (Types of some operators)

`+` : `int` $\to$ `int` $\to$ `int`

`=` : `int` $\to$ `int` $\to$ `bool`

`<` : `int` $\to$ `int` $\to$ `bool`

...

DEMO: type of operators

More on operators

precedences and associativity

Remainder about associativity:

- right associativity: `a op b op c` means `a op` (`b op c`)
- left associativity: `a op b op c` means (`a op b`) `op c`

Precedences of operators on the basic types, in **increasing order**:

Operators								Associativity
||	&&							right
=	==	!=	<>	<	<=	>	>=	left
+	−	+.	−.					left
*	/	*.	/.	mod	land	lor	lxor	left
`lsl`	`lsr`	`asr`						right
`lnot`								left
;								right

DEMO: associativity

More on Typing

About OCaml type system

Typing is a mechanism/concept aiming at:

- avoiding errors
- favoring *abstraction*
- checking that expressions are sensible, e.g.
  - `1 + yes`
  - `true * 42`

Type checking in OCaml: OCaml is strictly and statically typed

- strict: no implicit conversion between types nor type coercion
- static: checking performed before execution

Type inference: for any expression *e*, OCaml (automatically and systematically) computes the type of *e*:

Example (Type system on integers and floats)

- Two sets of distinct operations:
  - integers (+,−,*)
  - floats (+.,−., *.)
- No implicit conversion between them, e.g., 1+ 0.42 yields an error

More on Typing

About OCaml type system (ctd)

OCaml is a safe programming language:

- Programs never go wrong at runtime
- Easier to write correct programs: many errors are detected

Remark Comparison with C, Python:

- C, Python are *weakly typed*: values can be coerced
- a lot of runtime errors, e.g., segmentation-fault, bus-error, etc. . .

□

"Better type-safe than sorry"

The language constructs

if . . . then . . . else . . .

An expression defined using an alternative (or a conditional) control structure

`if cond then expr1 else expr2`

- the result is a value
- `cond` should be a Boolean expression
- `expr1` and `expr2` should be of the same type

Remark The else branch cannot be omitted unless the whole `expr1` is of type unit (hence the whole expression is of type unit) □

DEMO: if. . . then. . . else. . .

Running your code

Compilation vs Interpretation

Two ways to interact/evaluate/execute your code: compilation and interactive interpretation

Compiling:

- Place your program in a `.ml` file
- Use one of the compilers:
  - `ocamlc`: compiles to byte-code
  - `ocamlopt`: compiles to native machine code

Interpretation:

- Type `ocaml`
- Directly type your expression

Remark

- Byte-code is compiled faster but runs slower
- Native machine code is compiled slower but runs faster

DEMO: compiling vs interpreting, compiler options

Summary and Assignment

Summary

- Basic types and operations:

type	operations	constants
Booleans	`not, &&, ||`	`true, false`
integers	`+,-,*,/,mod`	`..., -1, 0, 1, ...`
floats	`+.,-.,*.,/.`	`0.4, 12.3, 16. , 64.`

- `if...then...else` constcuct
- OCaml type system
- Compilation / Interpretation

Assignment 1

Play with the codes seen in class! Explore yourself, and enjoy :).