

OCaml Cheatsheet

CSCI 431, Fall 2024: Introduction to Functional Programming

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This document has two purposes: (a) to familiarize me with the peculiarities of OCaml syntax, and (b) to present *you*, the students of CSCI 431, with an operational overview of the OCaml language, and to be a one-stop guide to some selected issues relating to its syntax and semantics. Notably, this document is neither intended to be a pedagogical introduction, nor a comprehensive language reference. The official language reference may be accessed at <https://caml.inria.fr/pub/docs/manual-ocaml/>.

Note: This document will be updated as the semester progresses, and is expected to be perpetually incomplete. Please check back regularly.

1 Installation

We summarize the instructions listed [here](#).

1. Install Opam using the instructions listed [here](#). The commands for some popular operating systems are as follows:

a) On recent versions of Fedora, run

```
$ dnf install opam
```

b) On recent versions of Ubuntu, run

```
$ apt install build-essential mercurial darcs
$ add-apt-repository ppa:avsm/ppa
$ apt update
$ apt install opam
```

c) On computers running OSX with the Homebrew package manager, run

```
brew install opam
```

Prefix the sudo qualifier to the above commands as appropriate.

2. Initialize Opam and create a switch for this course:

```
$ opam init
$ eval $(opam env)
$ opam switch create fa2024-csci431 \
                    ocaml-base-compiler.5.2.0
$ eval $(opam env)
```

Confirm that the switch has been correctly initialized by running `opam switch`. Opam is a package manager for OCaml packages.

3. Install the appropriate packages within the switch:

```
$ opam install base core \
                menhir \
                utop ppx_deriving
```

Place the following toplevel directives in your `.ocamlinit` file:

```
#use "topfind";;
#thread;; (* Threads need to be enabled for Core to work *)
#require "core.top";;
#require "ppx_deriving.std";;
```

4. You may optionally install OCaml language support on your editor. See the instructions available [here](#). If you are using Visual Studio Code, this consists of the following two steps:

- a) Install the OCaml Language Server Protocol (LSP):

```
$ opam install ocaml-lsp-server
```

The Language Server Protocol is a recent standard developed by IDE vendors to provide language-specific features within the IDE which can be best implemented by support from the compiler, debugger, static analyzer, or other parts of the framework.

- b) Install the IDE extension to provide language support. Either run

```
$ code --install-extension ocaml-lsp-ocaml-platform
```

from the command line, or navigate to File > Preferences > Extensions, and install the extension named “OCaml Platform”. You can find a more detailed description of this extension [here](#).

2 Interactive Development Using the REPL and Utop

1. On Semicolons: ; and ;;. See <https://baturin.org/docs/ocaml-faq/>.
 - a) The expression `e1 ; e2` is equivalent to `let _ = e1 in e2`.
 - b) The double-semicolon, `stmt ; ;` is an end-of-input marker for the top-level interpreter. Instead write either `let _ = stmt`, or `let () = stmt` to require that `stmt` has unit type.
2. To help organize large programs, OCaml provides a module system. The module system provides the ability to encapsulate parts of the program, i.e., separate specifications from implementations, and to define *functors* which can transform modules to other modules. The keywords `open` and `include` are associated with the module system. We will study them later in the semester.
3. To build on libraries developed by other programmers, `opam` provides the ability to install *packages*. In order to use these packages, `utop` provides the `#use` and `#require` keywords. One may place standard incantations in the `.ocamlinit` file.

3 The Bytecode Compiler, Native Code Compiler, and Build System

Two versions of the OCaml compiler exist, which are guaranteed to be semantically equivalent: (a) the bytecode compiler, `ocamlc`, and (b) the native code compiler, `ocamlopt`. Both compilers produce an executable `a.out` file from a file containing OCaml source code. However, the executable produced by `ocamlopt` is an optimized native code binary (in ELF format, if running on Linux, or as a Mach-O file, if running on Mac):

```
$ ocamlopt test.ml; file a.out
a.out: Mach-O 64-bit executable arm64
$ ocamlc test.ml; file a.out
a.out: a ocamlrun script executable (binary data)
```

4 Basic Data Types and Built-In Operations

See <https://caml.inria.fr/pub/docs/manual-ocaml/expr.html#ss%3Aexpr-operators> for the list of infix operations initially defined in the system, and <https://caml.inria.fr/pub/docs/fpcl/fpcl-04.pdf> for additional background. There are six basic data types:

1. The type of machine integers, `int`, as in 0, 1, -4, etc. They are represented in 2-s complement form and support the following operations:
 - a) Infix arithmetic operations: addition, subtraction, multiplication, division, and integer modulus. Respectively, `(+)`, `(-)`, `(*)`, `(/)`, `(mod)` : `int -> int -> int`.
 - b) Infix bitwise operations, `(land)`, `(lor)`, `(lxor)`, `(lsl)`, `(lsr)`, `(asr)`: `int -> int -> int`. Prefix bitwise negation (i.e., 1-s complement), `lnot` : `int -> int`.
 - c) The representational limits, `max_int`, `min_int` : `int`

For example,

```
# 2 + 4;;
- : int = 6
# 8 mod 3;;
- : int = 2
# 3 land 5;;
- : int = 1
# max_int;;
- : int = 4611686018427387903
# min_int;;
- : int = -4611686018427387904
# lnot max_int = min_int;;
- : bool = true
```

2. The type of floating point numbers, `float`, as in 2.3, -5.8, and (2.). They are represented in accordance with the IEEE-754 standard. As with integers, they support the following operations:
 - a) Arithmetic: `(+.)`, `(-.)`, `(*.)`, `(/.)`, `(**)` : `float -> float -> float`. The expression `x ** y` performs floating point exponentiation, x^y .
 - b) Conversion to and from machine integers. Respectively, `int_of_float` : `float -> int` and `float_of_int` : `int -> float`.

For example,

```
# 2.3 +. 4.8;;
- : float = 7.1
# -2.3;;
- : float = -2.3
# -.2.3;;
- : float = -2.3
# 2. ** 3.2;;
```

```

- : float = 9.18958683997628
# max_float;;
- : float = 1.7976931348623157e+308
# min_float;;
- : float = 2.2250738585072014e-308
# float_of_int 2;;
- : float = 2.
# int_of_float 3.2;;
- : int = 3
# int_of_float (-3.2);;
- : int = -3

```

3. The Boolean type, `bool`, of values `true` and `false`.

- a) Boolean conjunctions and disjunctions, (`&&`), (`||`): `bool -> bool -> bool`. The responses to a StackOverflow question (<https://stackoverflow.com/q/23833221>) indicate that short-circuiting evaluation is followed. This may be confirmed by evaluating the expressions `true || raise (Failure "A")` and `false && raise (Failure "A")`. Two variants, (`&`), (`or`): `bool -> bool -> bool`, have been marked as deprecated.
- b) Negation, `not` : `bool -> bool`.
- c) Structural equality and inequality, (`=`), (`<>`): `'a -> 'a -> bool`. These are often the equality operators what you want.
- d) Physical equality and inequality, (`==`), (`!=`): `'a -> 'a -> bool`.
- e) Ordinal comparisons, (`<`), (`<=`), (`>`), (`>=`): `'a -> 'a -> bool`. Note the polymorphic comparison operators.

Unsurprisingly,

```

# 2 = 3;;
- : bool = false
# 2 = 2;
- : bool = true
# 2. < 2.3;
- : bool = true
# "abc" < "abcd";;
- : bool = true
# "abd" > "ac";;
- : bool = false
# true && false;;
- : bool = false
# not true;;
- : bool = false

```

Conditional expressions are constructed in the usual way:

```
# let x = "abcd" in
  let y = "abd" in
    String.length(if x < y then x else y);;
- : int = 4
```

4. The type of 8-bit characters, `char`, consisting of values such as `'a'`, `'E'`, `'\n'`. The `char_of_int : int -> char` and `int_of_char : char -> int` convert between the two using the ASCII mapping.
5. The type of strings of 8-characters, `string`. String constants are enclosed within double-quotation marks, as in `"Hello, World!"`. The following functions are defined:
 - a) Indexing the individual characters of a string, like `s.[i]`, which returns the *i*-th character of the string `s`.
 - b) The infix operator for string concatenation, `(^) : string -> string -> string`.
 - c) The function `String.length : string -> int` which returns the length of a string.
6. The type `unit` of the single value `()`.

```
# ();;
- : unit = ()
```

The following derived data types are also very useful:

1. The type of lists of elements with a common type `'a`: `'a list = [] | :: of 'a * 'a list`. They may be compactly represented using the list notation, as in `[1; 5; 8; 9]`. The following pre-defined functions are relevant:
 - a) The functions returning the head and tail of a list:
 - i. `List.hd : 'a list -> 'a`, and
 - ii. `List.tl : 'a list -> 'a list`.
 Both functions throw an exception when applied to the empty list.
 - b) The function returning the length of a list, `List.length : 'a list -> int`.
 - c) The infix operator to concatenate two lists, `(@) : 'a list -> 'a list -> 'a list`.
 - d) `List.map : ('a -> 'b)-> 'a list -> 'b list`.
 - e) `List.fold_left : ('a -> 'b -> 'a)-> 'a -> 'b list -> 'a`.
 - f) `List.fold_right : ('a -> 'b -> 'b)-> 'a list -> 'b -> 'b`.
 - g) `List.filter : ('a -> bool)-> 'a list -> 'a list`.
 - h) `List.find : ('a -> bool)-> 'a list -> 'a`.
 - i) `List.exists : ('a -> bool)-> 'a list -> bool`.
 - j) `List.for_all : ('a -> bool)-> 'a list -> bool`.

2. The type of n-way products, $'a_1 * 'a_2 * \dots * 'a_n$. These can be constructed as (e_1, e_2, \dots, e_n) . The `unit` type can be regarded as a degenerate 0-way product.
 - a) The functions returning the first and second elements of a pair, `fst : 'a * 'b -> 'a` and `snd : 'a * 'b -> 'b`, respectively.

5 Syntactic Trivia

1. Follow the OCaml programming guidelines, available at <https://ocaml.org/learn/tutorials/guidelines.html>.

2. Comments:

a) `(* This is a comment. *)`

b) `(* Comments can be nested. (*Like this. *)*)`

3. Two forms of `let` bindings exist:

a) Let declarations:

```
# let v = e;;  
# ...
```

Here, the variable `v` is bound to the result of evaluating `e` in the rest of the program. It works in both the REPL and in freestanding files. Redeclarations result in shadowing, without warning.

b) Let expressions:

```
let v = e1 in e2;;
```

Here, the variable `v` is bound to the result of evaluating `e1` while evaluating `e2`. Notably, `v` is not bound while evaluating the first sub-expression `e1`. Once again, nested redeclarations of `v` result in shadowing, without warnings.

For example,

```
# let v = 3;;  
val v : int = 3  
# let v = v + v;;  
val v : int = 6  
# v;;  
- : int = 6  
# let v = 3 in (let v = v + v in v + 2) + v  
- : int = 11
```

4. Functions can be:

a) Non-recursive, as in `let f x = e`. The previous value of `f`, if any, is used while evaluating `e`. For example,

```
# let f x = x + 3;;  
val f : int -> int = <fun>  
# let f x = (f x) + 3;;  
val f : int -> int = <fun>  
# f 3;;  
- : int = 9
```

b) Recursive, as in `let rec f x = e`. References to the variable `f` within `e` result in recursive calls.

c) Mutually recursive, as in:

```
# let rec even x = match x with 0 -> true | _ -> odd (x -
    1) and
    odd x = match x with 0 -> false | _ -> even (x
        - 1);;
val even : int -> bool = <fun>
val odd : int -> bool = <fun>
# even 0;;
- : bool = true
# even 5;;
- : bool = false
# odd 5;;
- : bool = true
```

d) Or of the anonymous non-recursive kind:

```
# let f = fun x -> x @ [ 4; 5 ];;
val f : int list -> int list = <fun>
```

5. Custom data types, as in:

```
type 'a tree = Leaf | Node of 'a * 'a tree * 'a tree;
```

Note that type names begin with a lower-case letter, while constructors begin with an upper-case letter. Constructors are not functions. See Xavier Leroy's [justification](#).

6. One can match against syntactic patterns, similar to the following piece of code:

```
# let l = [ 1; 2; 3 ];;
val l : int list = [1; 2; 3]
# match l with
| [] -> 0
| a :: b :: [] -> 5
| a :: b :: _ -> 7
| _ -> 2;;
- : int = 7
```

Partial matches are fine, as in the following, but the compiler will complain:

```
# let f x = match x with true -> false;;
Line 1, characters 10-36:
Warning 8: this pattern-matching is not exhaustive.
Here is an example of a case that is not matched:
false
val f : bool -> bool = <fun>
```

```
# f true;;
- : bool = false
# f false;;
Exception: "Match_failure //toplevel//:1:10"
Called from file "toplevel/toploop.ml", line 212, characters 17-27
```

The keyword `function` is similar to `fun`, but with built-in pattern-matching:

```
# let f = function [] -> 0 | hd :: tl -> hd;;
val f : int list -> int = <fun>
# f (3 :: []);;
- : int = 3
# let g = function [] -> 0;;
Line 1, characters 8-24:
Warning 8: this pattern-matching is not exhaustive.
Here is an example of a case that is not matched:
_::_
val g : 'a list -> int = <fun>
```