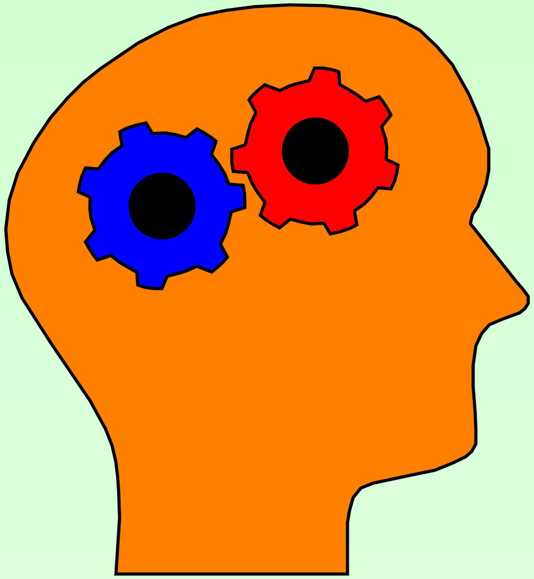
Lecture 10 : **OCaml Basics and Imperative Programming**



"Basics of OCaml and Imperative Programming

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Topics

- Basics of OCaml
- Mutable Reference & Records
- Input/Output Functions
- Iterators and Loops
- Arrays, String, Hash-Tables Modules
- Memoization

OCaml vs Haskell

OCaml	Haskell
strict (by default)	lazy (by default)
impure	pure
let & let rec	let (rec by default)
Impure IO	Monadic I/O
Modules/Functors	Type classes
OOP	Layout Rule
	Comprehension

Non-Recursive Let

- In OCaml, `let` binding is non-recursive.

```
let x = 1 in      // 1
 let x = x-3 in   // 1-3
```

- For (mutual) recursive, use `let rec` instead:

```
let rec f x = ..g x..
    and g x = ..f x..g x..
 in …
```

- Non-recursive let supports shadowing and allows reuse of names.

Post-fix Type Application

- Type variables are written as `` `a `` in OCaml
- In Haskell, prefix type application used

```
map :: (a->b) -> ([]) a -> ([]) b
```

- In OCaml, post-fix type application used

```
map :: (`a->`b) -> `a list -> `b list
```

Strict Evaluation

- let binding is strictly evaluated.

```
let x = e1 in      //  e1 is strictly evaluated
let y = e2 in      // e2 is strictly evaluated
..
```

- Arguments are strictly evaluated but the order of evaluation is not specified

```
f e1 e2 // {e1,e2} are strictly evaluated
```

- Use `let` if argument order is important.

```
let v1 = e1 in  // e1 is evaluated
let v2 = e2 in  // e2 is evaluated
f v1 v2         // call is invoked
```

Lazy Module

- Laziness in OCaml is captured through type

```
t Lazy.t
```

- Deferred computation is built using:

```
let (v:`a Lazy.t) = lazy (e:`a)
```

- It is strictly evaluated through:

```
force : 'a Lazy.t -> `a
… force v ..
```

- Can check if already evaluated using:

```
is_val : 'a Lazy.t -> bool
```

Pure versus Imperative

Pure versus Imperative

- Thus far, used mostly pure functions (without side-effects).

- Benefits of Pure Functions
  - Easier to reason/debug
  - Less error prone
  - Easily composable

When is Imperative Needed?

- Imperative feature also important
  - To model the real-world
  - For some high performance considerations (e.g. hash tables & mutable graphs)

- Compromise:
  - Use pure functions *where possible* (by default), and imperative features *where necessary*.

Mutable Reference and Fields

Mutable Reference

- Reference type supports pointer to a memory location that can be updated.

```
(* creates a mutable reference ptr *)
let ptr = ref 10;;

(* prints content of ptr *)
print_endline (string_of_int !ptr);;

(* update the content of ptr *)
ptr := !ptr + 1;;

print_endline (string_of_int !ptr);;
```

Creating Mutable Reference

- Command `ref` has type `'a → 'a ref`.

```
(* creates a mutable reference ptr *)
let ptr = ref 10;;

let ptr2 = ref "hello";;
```

- In above example:
  - `ptr` has `(int ref)` type.
  - `ptr2` has `(string ref)` type

Dereferencing Mutable Locations

- Command `!` has type `'a ref → 'a`.

```
(* returns content of a mutable reference *)
let v:int = !ptr;;

let s:string = !ptr2;;
```

- In follow-up example:
  - `v` has `int` type.
  - `s` has `string` type

Updating Mutable Reference

- Command `:=` has type `'a ref → 'a → unit`.

```
(* updating a mutable reference *)
let () = ptr := !ptr + 1;;

let () = ptr2 := !ptr2 ^ " there!";;
```

- In follow-up example:
  - `ptr` content will change to `11`.
  - `ptr2` will change to `"hello there!"`
- Assignment returns unit (or void) type.

Mutable Fields of Record

- Records are immutable by default, but we can selectively provide fields that are mutable.
- Example:

```
(* declaring a record type *)
type ('a, 'b) pair =
  { mutable first : 'a;
      second : 'b
   } ;;

(* constructing a record value *)
let p1 = {first = 1; second = "cs2104"};;
```

Retrieve Fields of Record

- We can retrieve mutable and immutable fields in the same way, namely `record.field`.

```
print_endline ("First: "^(string_of_int p1.first));;

print_endline ("Second: "^(p1.second));;
```

Updating Mutable Fields Only

- Only mutable fields can be updated.

```
(* update to mutable field *)
p1.first <- p1.first + 1;;


(* compile time error! *)
p1.second <- p1.second^" hello";;
```

➔ Error: The record field label second is not mutable

Implementation of Ref Type

- How are reference types related to mutable fields of records?

- Each ref type is implemented as a record with exactly one mutable field!

- Thus, mutable fields are the fundamental construct in OCaml.

Implementation of Ref Type

```
(* type declaration *)
type 'a ref = { mutable contents : 'a };;

(* construction *)
let ref v = { contents = v };;

(* retrieval *)
let (!) r = r.contents;;

(* update *)
let (:=) r v = r.contents <- v;
```

Weak Polymorphism

- Types of mutable fields must <u>not</u> be polymorphic. Following is invalid:

```
let (p4:('a list) ref) = ref [];;

p4 := 1::!p4;

p4 := "hello”::!p4;; (* error *)
```

- Mutable reference must have a <u>single</u> type, so that update and retrieval remains consistent.

Weak Polymorphism

- Immutable values can be polymorphic:

```
let id x = x;;
(* id: forall `a. `a -> `a *)
```

- Mutable reference can only be monomorphic.

```
let p_id = ref id;;
(* p_id : (`_a -> `_a) ref *)
```

weak polymorphism that must be bound to a monotype

➔Error: The type of this expression, ('_a -> '_a) ref, contains type variables that cannot be generalized

Weak Polymorphism

- Weakly polymorphic type must be instantiated to a monotype within the same module.

```
let p_id = ref id;;
(* p_id : ('_a -> '_a) ref *)

let v = !p_id 3;;
(* forces '_a be instantiated to int *)

let s = !p_id "hello";;
(* contradictory use cause type error *)
```

An Example

- Remembering first value.

```
let memo =
    let cache = ref None in
    (fun x ->
       match !cache with
       | Some y -> y
       | None -> cache := Some x; x);;
```

(* val memo : '_a -> '_a = <fun> *)

```
memo 3;; (* --> 3 *)
memo 4;; (* --> 3 *)
```

Wrongly Placed

- Cache is now local to each call !

  where a new cache is created for each call.

```
let memo =
    (fun x ->
     let cache = ref None in
       match !cache with
       | Some y -> y
       | None -> cache := Some x; x);;
```

```
memo 3;; (* --> 3 *)
memo 4;; (* --> 4 *)
```

Input/Output

Input/Output

- Apart from data mutation, I/O is the other major source of side-effects.
- I/O involves interactions with the real world.
- Many I/O libraries including Asynchronous I/O library.

Buffered I/O Library

- This allows buffering to optimize interaction with the Unix I/O library.

- Two types of channels:
  - in_channel (for reading)
  - out_channel (for writing)

Common I/O Channels

```
stdin   (*  standard input *)

stdout  (*  standard output*)

stderr  (*  standard error *)
```

Interact with Terminal

```
let test () =
     output_string stdout
          "What is your name?";
     flush stdout;
     let ans = input_line stdin in
          output_string stdout
               ("Hello "^ans^"\n");;
```

Output to a File

```
let file = open_out "test.out";;
(* creates an out_channel file *)

output_string file "Hello There!";;
  (* writes to file *)

close_out file;;
(* closes the file *)
```

Formatted Printing

- Formatted printing takes a format string to determine how printing is to be done.

```
let pr = Printf.printf
  ("%i is an integer, %F is a float”^^
   “\"%s\" is a string\n“);;
```

```
pr 3 4.5 "five";;
```

```
➔ 3 is an integer, 4.5 is a float, "five" is a string
```

Formatted Printing

- OCaml uses a type-safe solution:

```
let fmt = "%i is an integer, %F is a
    float"^^"\"%s\" is a string\n");;
```

```
(int -> float -> string -> 'c, 'b, 'c) fmt
```

```
let pr = Printf.printf fmt;;
```

```
pr : int -> float -> string -> ()
```

```
pr 3 4.5 "five";;
```

Loops and Iterators

Loop Iterators

- OCaml provides for/while loops to make it easier for imperative programming.

```
for i = 0 to 3 do
     printf "i = %d\n" i done;;
➔
i = 0
i = 1
i = 2
i = 3
- : unit = ()
```

Note that i itself is local and immutable

Loop Iterators

- A count-down for-loop.

```
for i = 3 downto 0 do
     printf "i = %d\n" i done;;
➔
i = 3
i = 2
i = 1
i = 0
- : unit = ()
```

Loop Iterators

- A while-loop.

```
let i = ref 3;;
while (!i>=0) do
 printf "i = %d\n" !i;
 i := !i-1
done;;
```

➔
```
     i = 3
     i = 2
     i = 1
     i = 0
     - : unit = ()
```

Loop Iterators

- Implementation of for_loop using higher-order

```
let for_loop init final stmt =
   let rec aux i =
    if i<=final
    then (stmt i; aux (i+1))
   in aux init
```

- Exercise : write recursive codes for while and for_downto loops.

List Iterator

- We also have iterators over data structures.

```
List.iter : ('a -> unit) -> 'a list -> unit
```

```
List.iter f [a1; ...; an]
```

applies function **`f`** in turn to **`[a1; ...; an]`**.

It is equivalent to

`begin f a1; f a2; ...; f an; () end`.

Sequences

Sequences

- Sequences of the form: `e1;e2;..;en` are executed for their effects.

- It is equivalent to:

```
let _ = e1 in
let _ = e2 in
…
en
```

Sequences

- Safer to use :

```
let () = e1 in
let () = e2 in
…
en
```

- All except `en` are of the unit type. Why?

Evaluation Order

- Evaluation-order of arguments are implementation-dependent!

- What is the outcome of below?

```
let eval x =
     printf "Elem %d\n" x; x ;;
[eval 1; eval 2]
```

➔

Elem 2

Elem 1

- : int list = [1; 2]

Evaluation Order

- Similarly:

```
let eval x =
      printf "Elem %d\n" x; x ;;
(eval 1, eval 2)
```

➔

Elem 2
Elem 1
- : int * int = (1, 2)

Mutable Modules

Mutable Modules

- Quite a number of modules have mutable data structures.
- Examples are : Arrays, Strings, Hash Tables.
- They could be used to support both imperative and functional-style programming.

Array

- Key operators.

```
val make : int -> 'a -> 'a array
  (* make n v returns a mutable array of
     size n, with initial value v *)
val length : 'a array -> int
  (* returns size of array *)

val get : 'a array -> int -> 'a
  (* get a n returns n-th elem of array a *)

val set: 'a array -> int -> 'a -> unit
  (* set a n v updates n-th elem of
     array a with new value v *)
```

Array

- Short-hands.

```
val get : 'a array -> int -> 'a
   (* Array.get a n = a(n)  *)

val set: 'a array -> int -> 'a -> unit
   (* Array.set a n v = a(n)<-v *)
```

Array

- Useful Higher-Order Functions.

```
val mapi : (int -> 'a -> 'b) ->
      'a array -> 'b array

val fold_left : ('a -> 'b -> 'a) ->
      'a -> 'b array -> 'a

val fold_right : ('b -> 'a -> 'a) ->
      'b array -> 'a -> 'a
```

String

- We have used only string in a functional way.

- String are not only compact (8 characters per memory word), it also supports mutation:

```
val set: string -> int -> char -> unit
  (* set s n c updates n-th elem of
     string s with value char c
     short-hand s.[n]<-c
  *)
```

Hash Table (Hashtbl)

- Hash tables implement generic dictionary.

```
module Hashtbl

type ('a, 'b) t

val create : ?random:bool -> int
                  -> ('a, 'b) t
```

optional labeled parameter

(* `Hashtbl.create n` will create a new hash table of initial size n, while `~random:true` allows a randomized seed to be used at creation *)

Hash Table

- Access operators.

```
val add : ('a, 'b) t -> 'a -> 'b -> unit
  (* (add tbl x y) to add (x,y) to tbl *)

find : ('a, 'b) t -> 'a -> 'b
  (* (find tbl x) returns current binding of x *)

remove : ('a, 'b) t -> 'a -> unit
  (* (remove tbl x) remove current binding of x *)
```

Memoization

Memoization

- Redundant calls can be eliminated by tabulation using dynamic programming.
- General Technique : Memoization.
- Can use hash table to store previously computed value for retrieval rather than re-computation.

Recursion

- Recall naïve fibonacci.

```
let rec fib n =
  if n<=1 then 1
  else fib (n-1) + fib(n-2);;
```

- Contains many redundant fib calls when computed with moderately sized inputs.

Using Memo-Functions

- This stores previously computed values in say a hash table. Example:

```
let fib_hash = Hashtbl.create 10;;

let rec fib_memo n =
  if n<=1 then 1
  else try
         Hashtbl.find fib_hash n
  with _ ->
      let r = fib_memo (n-1) + fib_memo (n-2) in
      let _ = Hashtbl.add fib_hash n r  in
      r
```

- Trade off memory space for time.

Pure Memo-Function

- Localize the effect of memo-table:

```
let fib_memo2 n =
  let tbl = Hashtbl.create 10 in
  let rec aux n =
    if n<=1 then 1
    else try
          Hashtbl.find tbl n
    with _ ->
        let r = aux (n-1) + aux (n-2) in
        let _ = Hashtbl.add tbl n r  in
        r
  in aux n
```

- Pure function when viewed from outside. Tradeoffs?