



Modules

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The OCaml Module System

Abstract and concrete data types

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Introduction

Modules are used to realize data type (ADT and implementation) and collecting functions.

Modules are composed of two parts:

- a (optional) public interface exposing the types and operations defined in the module (**sig ... end**);
- the module implementation (**struct ... end**).

Modules can abstract data and hide implementation details

```
module A :
sig
...
end =
struct
...
end ;;
```

Modules are useful for organizing large implementations in smaller self-contained pieces of code.



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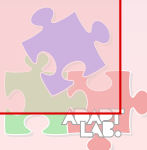
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Structure (Struct ... End)

```
module PriorityQueue =
struct
  type priority = int
  type char_queue = Empty | Node of priority * char * char_queue * char_queue
  exception QueueIsEmpty
  let empty = Empty
  let rec insert queue prio elt =
    match queue with
    | Empty -> Node(prio, elt, Empty, Empty)
    | Node(p, e, left, right) ->
        if prio <= p
        then Node(prio, elt, insert right p e, left)
        else Node(p, e, insert right prio elt, left)
  let rec remove_top = function
    | Empty -> raise QueueIsEmpty
    | Node(prio, elt, left, right) ->
        if prio <= prio
        then Node(prio, elt, remove_top left, right)
        else Node(prio, elt, remove_top right, right)
  let extract = function
    | Empty -> raise QueueIsEmpty
    | Node(prio, elt, _, _) as queue -> (prio, elt, remove_top queue)
end;;
```



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Structure Evaluation

```
#use "char_pqueue.ml" ;;
module PriorityQueue :
sig
  type priority = int
  type char_queue =
    Empty
    | Node of priority * char * char_queue * char_queue
  exception QueueIsEmpty
  val empty : char_queue
  val insert : char_queue -> priority -> char -> char_queue
  val remove_top : char_queue -> char_queue
  val extract : char_queue -> priority * char * char_queue
end
# let pq = empty ;;
val pq : PriorityQueue.char_queue = Empty
# let pq = insert pq 0 'a' ;;
val pq : PriorityQueue.char_queue = Node (0, 'a', Empty, Empty)
# let pq = insert (insert pq 3 'c') (-7) 'w';;
val pq : PriorityQueue.char_queue =
  Node (-7, 'w', Node (0, 'a', Empty, Empty), Node (3, 'c', Empty, Empty))
# let pq = extract pq;;
val pq : priority * char * PriorityQueue.char_queue =
  (-7, 'w', Node (0, 'a', Empty, Node (3, 'c', Empty, Empty)))
```



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The OCaml Module System

Signature (Sig ...End)

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```
module type CharQueueAbs =
  sig
    type priority = int          (* still concrete *)
    type char_queue             (* now abstract *)
    val empty : char_queue
    val insert : char_queue -> int -> char -> char_queue
    val extract : char_queue -> int * char * char_queue
    exception QueueIsEmpty
  end;;
```

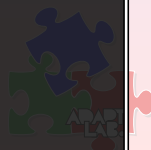
WRT the previous implementation this:

- opacifies the type `char_pqueue` and hides the `remove_top` operation

```
# #use "CharPQueueAbs.mli" ;;
module type CharPQueueAbs =
  sig
    type priority = int
    type char_queue
    val empty : char_queue
    val insert : char_queue -> int -> char -> char_queue
    val extract : char_queue -> int * char * char_queue
    exception QueueIsEmpty
  end

# module AbstractPrioQueue = (PrioQueue: CharPQueueAbs);
module AbstractPrioQueue : CharPQueueAbs

# AbstractPrioQueue.remove_top;;
Error: Unbound value AbstractPrioQueue.remove_top
# AbstractPrioQueue.insert AbstractPrioQueue.empty 1 'a' ;;
- : AbstractPrioQueue.char_queue = <abstr>
```



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The OCaml Module System

Separate Compilation

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Modules and their interface can be separately compiled.

```
[17:11]cazzola@surtur:~/lp/ml/mod-01>ls
CharPQueueAbs.mli CharPQueue.ml main.ml
[17:11]cazzola@surtur:~/lp/ml/mod-01>ocamlc -c CharPQueueAbs.mli
[17:12]cazzola@surtur:~/lp/ml/mod-01>ocamlc -c CharPQueue.ml
[17:16]cazzola@surtur:~/lp/ml/mod-01>ocamlc -o main CharPQueue.cmo main.ml
[17:19]cazzola@surtur:~/lp/ml/mod-01>ls
CharPQueueAbs.cmi CharPQueueAbs.mli CharPQueue.cmi CharPQueue.cmo CharPQueue.ml
main* main.cmi main.cmo main.ml
```

```
open CharPQueue.AbstractPrioQueue;;
let x = insert empty 1 'a' ;;
```

In this case the file names for the module implementation and interface must be different (and start with a capital letter).



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The OCaml Module System

Separate Compilation (Cont'd)

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The implementation and interface of the module can share the same file name (apart of the suffix)

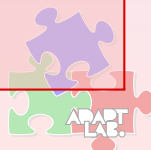
- module, sig and struct keywords are dropped

The module name comes after the module file name.

```
[17:39]cazzola@surtur:~/lp/ml/mod-02>ls
CharPQueue.mli CharPQueue.ml main.ml
[17:39]cazzola@surtur:~/lp/ml/mod-02>ocamlc -c CharPQueue.mli
[17:39]cazzola@surtur:~/lp/ml/mod-02>ocamlc -c CharPQueue.ml
[17:39]cazzola@surtur:~/lp/ml/mod-02>ocamlc -o main CharPQueue.cmo main.ml
[17:39]cazzola@surtur:~/lp/ml/mod-02>ls
CharPQueue.cmi CharPQueue.cmo CharPQueue.ml CharPQueue.mli main* main.cmi
main.cmo main.ml
```

This is how the signature looks:

```
type priority = int          (* still concrete *)
type char_queue             (* now abstract *)
val empty : char_queue
val insert : char_queue -> int -> char -> char_queue
val extract : char_queue -> int * char * char_queue
exception QueueIsEmpty
```



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The OCaml Module System

Functors.

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Functors are “functions” from structures to structures.

This means

- fixed the signatures of the input and output structures; then
- the implementation details can change without affecting any of the modules that use it.

Functors allow to

- avoid duplication and
- increase orthogonality

in a type safe package.



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The OCaml Module System

Functors: an Example.

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`is_balanced()` checks that a string uses Balanced parenthesis.

```
let is_balanced str =
  let s = Stack.empty in try
    String.iter
      (fun c -> match c with
        | '(' -> Stack.push s c
        | ')' -> Stack.pop s
        | _ -> ()) str;
    Stack.is_empty s
  with Stack.EmptyStackException -> false
```

The idea is to iterate on the string and

- to push any open parenthesis on a stack; and
- to pop it when a close parenthesis is encountered

If the algorithm ends with an empty stack the string is Balanced otherwise it is unbalanced.



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The OCaml Module System

Functors: an Example.

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`is_balanced()` checks that a string uses Balanced parenthesis.

```
module Matcher (Stack : StackADT.StackADT) =
  struct
    let is_balanced str =
      let s = Stack.empty in try
        String.iter
          (fun c -> match c with
            | '(' -> Stack.push s c
            | ')' -> Stack.pop s
            | _ -> ()) str;
        Stack.is_empty s
      with Stack.EmptyStackException -> false
  end
```

Matcher is a functor that binds our algorithm to a Stack abstract data type.

```
[17:09]cazzola@surtur:~/lp/ml>ocaml
module Matcher :
  functor (Stack : StackADT.StackADT) -> sig val is_balanced : string -> bool end
```

Instantiation make concrete the algorithm.



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The OCaml Module System

Functors: an Example (Cont'd).

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Functors **must** be instantiated.

```
module UnboundedStack = struct
  type char_stack = {
    mutable c : char list
  }
  exception EmptyStackException
  let empty = { c = [] }
  let push s x = s.c <- x :: s.c
  let pop s =
    match s.c with
    | hd::tl -> s.c <- tl
    | [] -> raise EmptyStackException
  let top s =
    match s.c with
    | hd::_ -> hd
    | [] -> raise EmptyStackException
  let is_empty s = (s.c = [])
end;;
```

```
module BoundedStack = struct
  type char_stack = {
    mutable c : char array;
    mutable top : int
  }
  exception EmptyStackException
  let empty = {top=0; c=Array.make 10 ' '}
  let push s x =
    s.c.(s.top) <- x; s.top <- s.top+1
  let pop s =
    match s.top with
    | 0 -> raise EmptyStackException
    | _ -> s.top <- s.top - 1
  let top s =
    match s.top with
    | 0 -> raise EmptyStackException
    | _ -> s.c.(s.top)
  let is_empty s = (s.top = 0)
end;;
```

Both implementations adhere to the StackADT interface.



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The OCaml Module System

Functors: an Example (Cont'd).

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```
[18:15]cazzola@surtur:~/lp/ml>ocaml
# module M0 = Matcher(BoundedStack);;
module M0 : sig val is_balanced : string -> bool end
# module M1 = Matcher(UnboundedStack);;
module M1 : sig val is_balanced : string -> bool end
# M0.is_balanced "a(b)+c(a+d(e-f))";;
- : bool = true
# M0.is_balanced "a(b)+c(a+d(e-f))";;
- : bool = false
# M1.is_balanced "a(b)+c(a+d(e-f))";;
- : bool = true
# M1.is_balanced "a(b)+c(a+d(e-f))";;
- : bool = false
```



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References

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