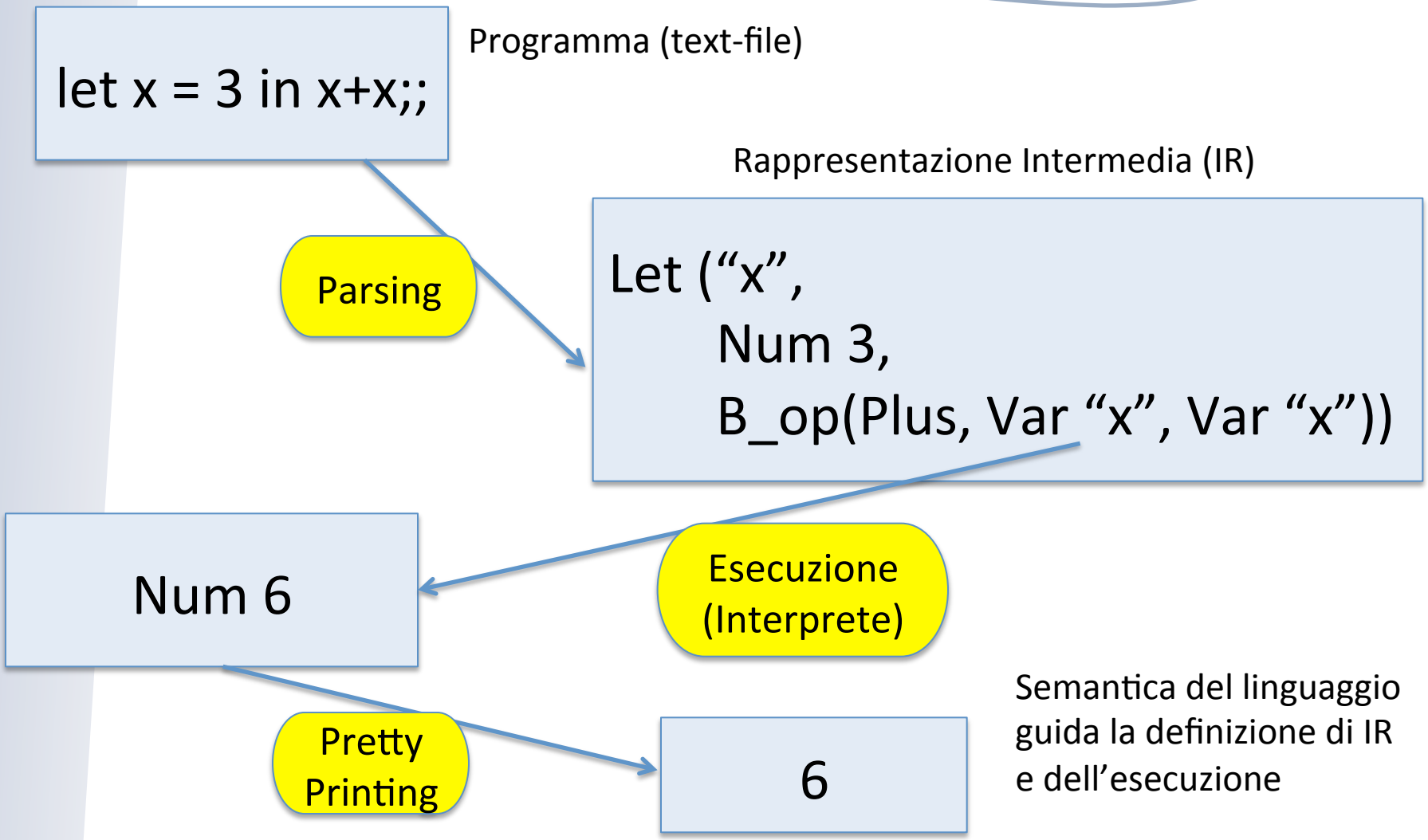
AA 2016-2017

17. Realizzare un interprete in OCaml

La struttura



La struttura nel dettaglio

OCAML Type per descrivere la rappresentazione intermedia

```
type variable = string

type op = Plus | Minus | Times | …

type exp =
      | Int_e of int
      | Op_e of exp * op * exp
      | Var_e of variable
      | Let_e of variable * exp * exp

type value = exp
```

La struttura nel dettaglio


```
type variable = string

type op = Plus | Minus | Times | …

type exp =
        | Int_e of int
        | Op_e of exp * op * exp
        | Var_e of variable
        | Let_e of variable * exp * exp

type value = exp
```

Rappresentazione di "3 + 17"

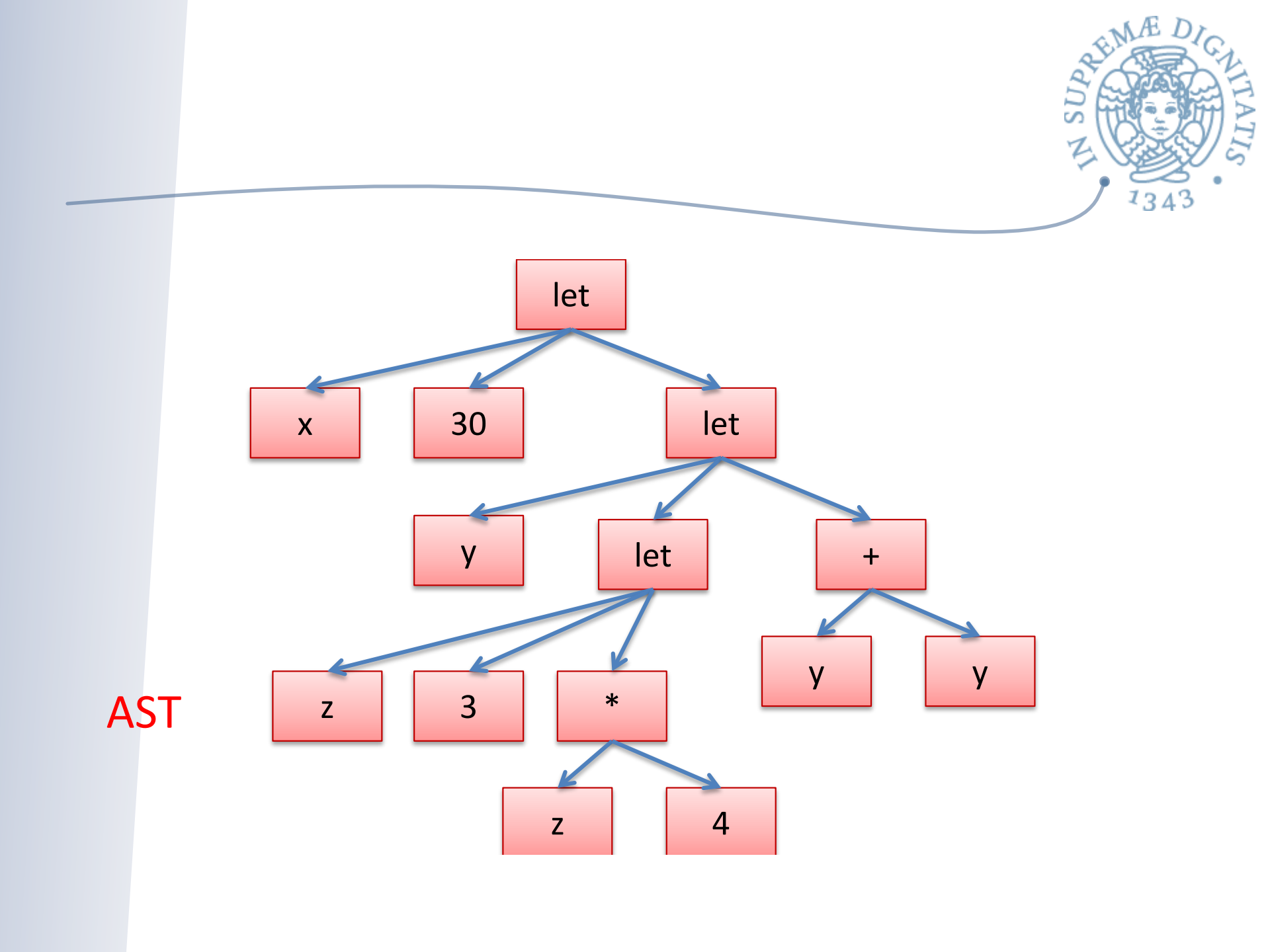
```
let e1 = Int_e 3
let e2 = Int_e 17
let e3 = Op_e (e1, Plus, e2)
```


```
let x = 30 in
  let y =
   (let z = 3 in
        z*4) in
    y+y;;
```

Programma OCaml

Exp

```
Let_e("x", Int_e 30,
   Let_e("y",
      Let_e("z", Int_e 3,
               Op_e(Var_e "z", Times, Int_e 4)),
      Op_e(Var_e "y", Plus, Var_e "y")
```


AST
let
x
30
let
y
let
+
z
3
*
y
y
z
4

Variabili: dichiarazione e uso


```
type variable = string

type exp =
      | Int_e of int
      | Op_e of exp * op * exp
      | Var_e of variable
      | Let_e of variable * exp * exp
```

Run time: operazione di supporto


```
let is_value (e : exp) : bool =
      match e with
            | Int_e _ -> true
            | ( Op_e _
            | Let_e _
            | Var_e _ ) -> false;;

eval_op : value -> op -> value -> value

substitute : value -> variable -> exp -> exp
```

Variabili: dichiarazione e uso


```
Type variable = string

type exp =
      | Int_e of int
      | Op_e of exp * op * exp
      | Var_e of variable
      | Let_e of variable * exp * exp
```

Uso di una variabile

Variabili: dichiarazione e uso


```
Type variable = string

type exp =
      | Int_e of int
      | Op_e of exp * op * exp
      | Var_e of variable
      | Let_e of variable * exp * exp
```

Uso di una variabile

Dichiarazione di variable

L'interprete

RTS

```
is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp

let rec eval (e : exp) : exp =
      match e with
      | Int_e i ->
      | Op_e(e1,op,e2) ->
      | Let_e(x,e1,e2) ->
```

L'interprete

RTS

```
is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp

let rec eval (e : exp) : exp =
      match e with
      | Int_e i -> Int_e i
      | Op_e(e1,op,e2) ->
      | Let_e(x,e1,e2) ->
```

L'interprete

RTS

```
is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp

let rec eval (e : exp) : exp =
      match e with
      | Int_e i -> Int_e i
      | Op_e(e1,op,e2) -> let v1 = eval e1 in
                                  let v2 = eval e2 in
                                    eval_op v1 op v2
      | Let_e(x,e1,e2) ->
```

L'interprete

RTS

```
is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp

let rec eval (e : exp) : exp =
      match e with
      | Int_e i -> Int_e i
      | Op_e(e1,op,e2) -> let v1 = eval e1 in
                                  let v2 = eval e2 in
                                    eval_op v1 op v2
      | Let_e(x,e1,e2) -> let v1 = eval e1 in
                                  let e2' = substitute v1 x e2 in
                                   eval e2'
```

L'interprete

RTS

```
is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp

let rec eval (e : exp) : exp =
      match e with
      | Int_e i -> Int_e i
      | Op_e(e1,op,e2) -> eval_op eval e1 op eval e2
      | Let_e(x,e1,e2) -> let v1 = eval e1 in
                                  let e2' = substitute v1 x e2 in
                                   eval e2'
```

L'interprete

RTS

```
is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp

let rec eval (e : exp) : exp =
      match e with
      | Int_e i -> Int_e i
      | Op_e(e1,op,e2) -> eval_op eval e1 op eval e2
      | Let_e(x,e1,e2) -> let v1 = eval e1 in
                          let e2' = substitute v1 x e2 in
                           eval e2'
```

Come avviene la valutazione?

Usare **let** per definirne l'ordine

L'interprete

RTS

is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp

```
let rec eval (e : exp) : exp =
      match e with
      | Int_e i -> Int_e i
      | Op_e(e1,op,e2) -> eval_op eval e1 op eval e2
      | Let_e(x,e1,e2) -> let v1 = eval e1 in
                          let e2' = substitute v1 x e2 in
                           eval e2'

      | Var_e x -> ???
```

Non dovremmo incontrare una variabile – l'avremmo già dovuta sostituire con un valore!!

Questo è un **errore di tipo**

L'interprete

RTS

```
is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp

let rec eval (e : exp) : exp option =
      match e with
      | Int_e i -> Some(Int_e i)
      | Op_e(e1,op,e2) -> eval_op eval e1 op eval e2
      | Let_e(x,e1,e2) -> let v1 = eval e1 in
                                  let e2' = substitute v1 x e2 in
                                   eval e2'
      | Var_e x -> None
```

Questo complica l'interprete: matching sui risultati delle chiamate ricorsive di eval

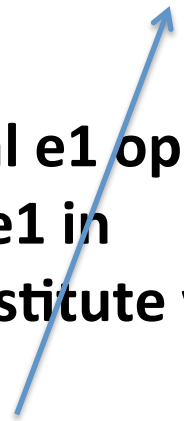
L'interprete

RTS

```
is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp
```

```
let rec eval (e : exp) : exp =
      match e with
      | Int_e i -> Int_e i
      | Op_e(e1,op,e2) -> eval_op eval e1 op eval e2
      | Let_e(x,e1,e2) -> let v1 = eval e1 in
                                  let e2' = substitute v1 x e2 in
                                   eval e2'
      | Var_e x -> raise (UnboundVariable x)
```

Tali eccezioni fanno parte del RTS



RTS: eval_op


```
let eval_op (v1:exp) (op:operand) (v2:exp) : exp =
    match v1, op, v2 with
        | Int_e i, Plus, Int_e j -> Int_e (i + j)
        | Int_e i, Minus, Int_e j -> Int_e (i - j)
        | Int_e i, Times, Int_e j -> Int_e (i * j)
        | _ , (Plus | Minus | Times), _ ->
          if is_value v1 && is_value v2
                        then raise TypeError
                        else raise NotValue
```

RTS: substitution


```
let substitute (v:value) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
        match e with
          | Int_e _ ->
          | Op_e(e1,op,e2) ->
          | Var_e y -> ... use x ...
          | Let_e (y,e1,e2) -> ... use x ...


    in subst e
```

RTS: substitution


```
let substitute (v:value) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
        match e with
          | Int_e _ -> e
          | Op_e(e1,op,e2) ->
          | Var_e y -> ... use x ...
          | Let_e (y,e1,e2) -> ... use x ...


    in subst e
```

RTS: substitution


```
let substitute (v:value) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
        match e with
          | Int_e _ -> e
          | Op_e(e1,op,e2) -> Op_e(subst e1,op,subst e2)
          | Var_e y -> ... use x ...
          | Let_e (y,e1,e2) -> ... use x ...


    in subst e
```

x, v impliciti

RTS: substitution


```
let substitute (v:value) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
        match e with
          | Int_e _ -> e
          | Op_e(e1,op,e2) -> Op_e(subst e1,op,subst e2)
          | Var_e y -> if x = y then v else e
          | Let_e (y,e1,e2) -> ... use x ...


    in subst e
```

RTS: substitution


```
let substitute (v:value) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
        match e with
          | Int_e _ -> e
          | Op_e(e1,op,e2) -> Op_e(subst e1,op,subst e2)
          | Var_e y -> if x = y then v else e
          | Let_e (y,e1,e2) -> Let_e (y,subst e1,subst e2)


    in subst e
```

RTS: substitution


```
let substitute (v:value) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
        match e with
          | Int_e _ -> e
          | Op_e(e1,op,e2) -> Op_e(subst e1,op,subst e2)
          | Var_e y -> if x = y then v else e
          | Let_e (y,e1,e2) -> Let_e (y,subst e1,subst e2)


    in subst e
```

ERRORE

RTS: substitution


```
let substitute (v:value) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
        match e with
          | Int_e _ -> e
          | Op_e(e1,op,e2) -> Op_e(subst e1,op,subst e2)
          | Var_e y -> if x = y then v else e
          | Let_e (y,e1,e2) -> Let_e (y,subst e1,
                                  if x = y then e2 else subst e2)

    in subst e
```

If x = y …
shadow scope!!

Funzioni

Sintassi


```
type exp = Int_e of int | Op_e of exp * op * exp
    | Var_e of variable | Let_e of variable * exp * exp
    | Fun_e of variable * exp | FunCall_e of exp * exp
```

Sintassi


```
type exp = Int_e of int | Op_e of exp * op * exp
    | Var_e of variable | Let_e of variable * exp * exp
    | Fun_e of variable * exp | FunCall_e of exp * exp
```

La sintassi OCaml **fun x e** viene rappresentata come **Fun_e(x, e)**

La chiamata **fact 3** viene rappresentata come
FunCall_e (Var_e “fact”, Int_e 3)

Estendiamo il RTS


```
let is_value (e : exp) : bool =
    match e with
        | Int_e _ -> true
        | Fun_e (_,_) -> true
        | ( Op_e (_,_,_)
            | Let_e (_,_,_)
            | Var_e _
            | FunCall_e (_,_) ) -> false
```

Le funzioni sono valori!!

Interprete ++


```
is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp

let rec eval (e : exp) : exp =
      match e with
      | :
      | Var_e x -> raise (UnboundVariable x)
      | Fun_e (x, e) -> Fun_e (x, e)
      | FunCall_e (e1, e2) ->
            match eval e1, eval e2 with
            | Fun_e (x, e), v2 -> eval (substitute v2 x e)
            | _ -> raise (TypeError)
```

Funzioni ricorsive


```
type exp = Int_e of int | Op_e of exp * op * exp
    | Var_e of variable | Let_e of variable * exp * exp
    | Fun_e of variable * exp | FunCall_e of exp * exp
    | Rec_e of variable * variable * exp
```

let g = rec f x -> f (x + 1) in g 3

```
Let_e ("g",
        Rec_e ("f", "x",
                FunCall_e (Var_e "f", Op_e (Var_e "x", Plus, Int_e 1))
               ),
        FunCall (Var_e "g", Int_e 3)
         )
```

Le funzioni ricorsive sono valori


```
let is_value (e : exp) : bool =
    match e with
        | Int_e _ -> true
        | Fun_e (_,_) -> true
        | Rec_e of (_,_,_) -> true
        | ( Op_e (_,_,_)
            | Let_e (_,_,_)
            | Var_e _
            | FunCall_e (_,_) ) -> false
```

La nozione di sostituzione

- Sostituire il valore v al posto della variabile x nella espressione e: e [v / x]
- (x + y) [7/y] diventa (x + 7)
- (let x = 30 in let y = 40 in x + y) [7/y] diventa (let x = 30 in let y = 40 in x + y)
- (let y = y in let y = y in y + y) [7/y] diventa (let y = 7 in let y = y in y + y)

Come valutare le funzioni ricorsive

IDEA

(rec f x = body) arg --> body [arg/x] [rec f x = body/f]

Passaggio parametri

JIT compilation del body


```
let g = rec f x ->
      if x <= 0 then x
                  else x + f (x - 1)
in g 3
```

La dichiarazione

```
g 3 [rec f x ->
          if x <= 0 then x
               else x + f (x-1) / g]
```

La sostituzione

```
(rec f x ->
      if x <= 0 then x else x + f (x - 1))
3
```

Risultato finale


```
(if x <= 0 then x else x + f (x - 1))
      [ 3 / x ]
      [ rec f x ->
            if x <= 0 then x
            else x + f (x - 1) / f ]
```

```
(if 3 <= 0 then 3 else 3 +
      (rec f x ->
            if x <= 0 then x
            else x + f (x - 1)) (3 - 1))
```

Interprete

is_value : exp -> bool
eval_op : value -> op -> value -> value
substitute : value -> variable -> exp -> exp

```
let rec eval (e : exp) : exp =
    match e with
    | :
    | FunCall_e (e1, e2) ->
        match eval e1 with
          | Fun_e (x, e) -> let v = eval e2 in substitute e x v
          | (Rec_e (f, x, e)) as g -> let v = eval e2 in
                                      substitute (substitute e x v) f g
```

Cosa abbiamo imparato?

- OCaml può essere usato come linguaggio per la simulazione della semantica operazionale di un linguaggio (incluso se stesso!)
- Vantaggio: simulazione dell'implementazione
- Svantaggio: complicato per le operazioni da effettuare con i tipi di Ocaml
  - Op_e(e1, Plus, e2) rispetto a "e1 + e2"