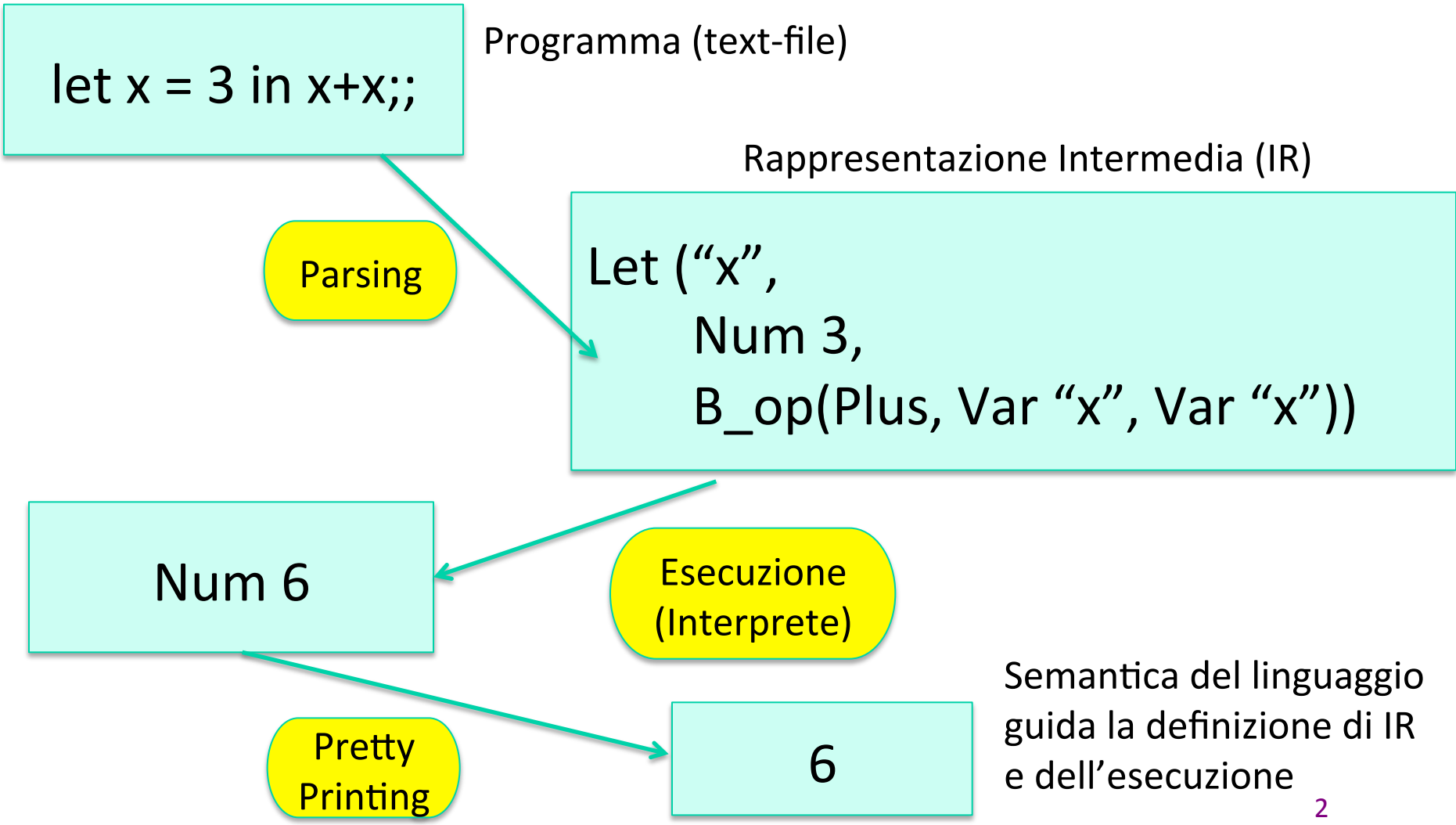
PROGRAMMAZIONE 2
16. Realizzare un interprete in OCaML

La struttura



La struttura nel dettaglio

OCaML Type per descrivere la rappresentazione intermedia

```
type variable = string

type operand = 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
```

La struttura nel dettaglio

```
type variable = string

type operand = Plus | Minus | Times | …

type exp =
            | Int_e of int
            | Op_e of exp * op * exp
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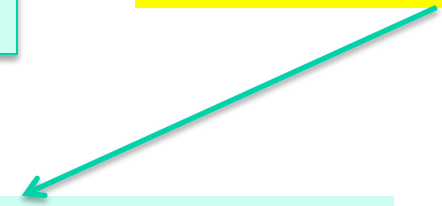
```

Rappresentazione di "3 + 17"



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

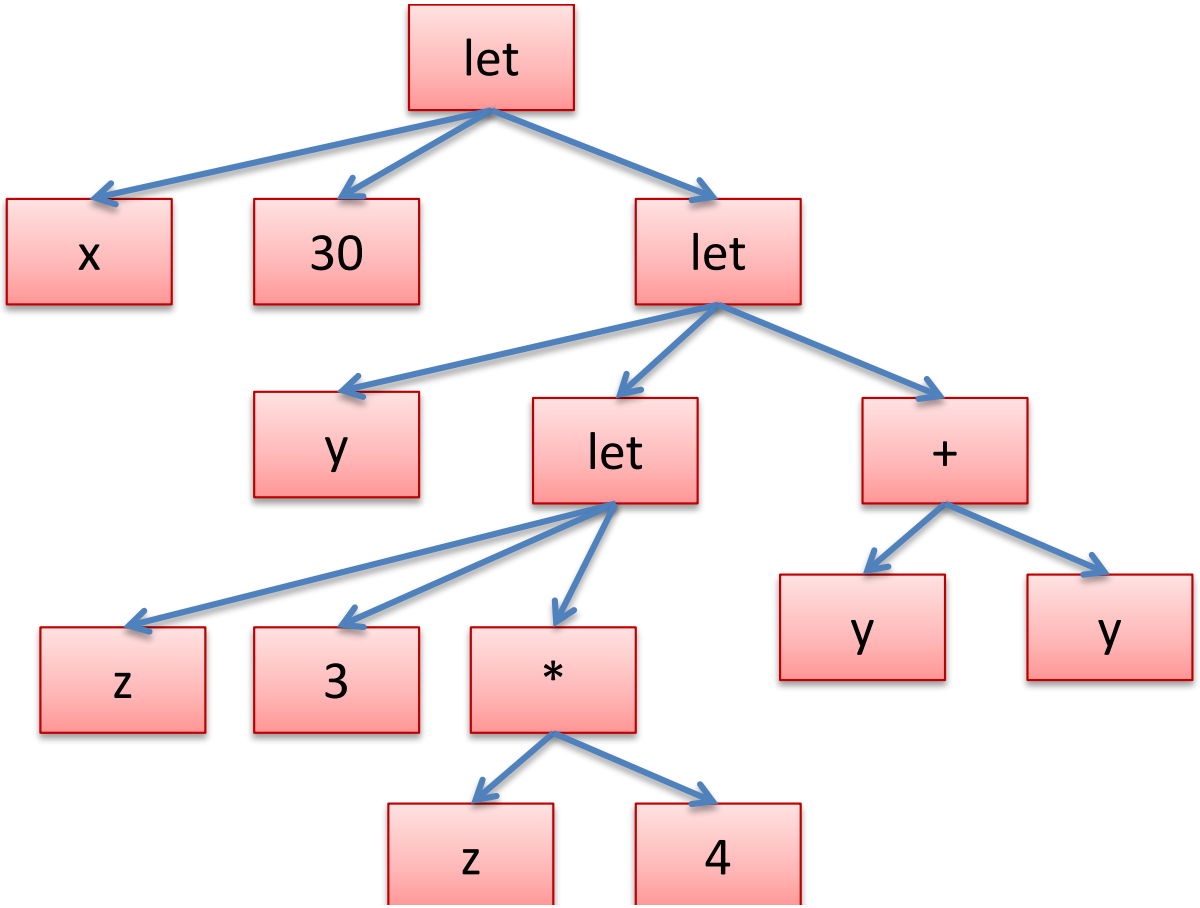
```
let x = 30 in
  let y =
    (let z = 3 in z*4) in
          y+y;;
```

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



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
```

Runtime: operazione di supporto

eval_op : exp -> op -> exp -> exp

substitute : exp -> variable -> exp -> exp

Variabili: dichiarazione e uso

```
type variable = string

type exp =
          Int_e of int
        | Op_e of exp * op * exp
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Uso di una variabile

Variabili: dichiarazione e uso

```
type variable = string

type exp =
          Int_e of int
        | Op_e of exp * op * exp
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```

Uso di una variabile

Dichiarazione di variable

L’interprete

RTS

```
eval_op : exp -> op -> exp -> exp
substitute : exp -> variable -> exp -> exp

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

L'interprete

RTS

```
eval_op : exp -> op -> exp -> exp
substitute : exp -> variable -> exp -> exp

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

L'interprete

RTS

```
eval_op : exp -> op -> exp -> exp
substitute : exp -> variable -> exp -> exp

let rec eval (e : exp) : exp =
    match e with
        Int_e _ -> e
      | 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

```
eval_op : exp -> op -> exp -> exp
substitute : exp -> variable -> exp -> exp

let rec eval (e : exp) : exp =
    match e with
        Int_e _ -> e
      | 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

```
eval_op : exp -> op -> exp -> exp
substitute : exp -> variable -> exp -> exp

let rec eval (e : exp) : exp =
    match e with
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L'interprete

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      | Let_e(x,e1,e2) -> let v1 = eval e1 in
                          let e2' = substitute v1 x e2 in
                            eval e2'
```

Come avviene la valutazione?

Si usa **let** per definirne l'ordine

L'interprete

RTS

eval_op : exp -> op -> exp -> exp
substitute : exp -> variable -> exp -> exp

```
let rec eval (e : exp) : exp =
    match e with
        Int_e _ -> e
      | 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 _ -> ???
```

Non dovremmo incontrare una variabile – avremmo già dovuta sostituirla con un valore!!

Questo è un **errore di tipo**

L'interprete

RTS

```
eval_op : exp -> op -> exp -> exp
substitute : exp -> variable -> exp -> exp

let rec eval (e : exp) : exp =
    match e with
        Int_e _ -> e
      | 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 _ -> Null
```

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

L'interprete

RTS

```
eval_op : exp -> op -> exp -> exp
substitute : exp -> variable -> exp -> exp

let rec eval (e : exp) : exp =
    match e with
          Int_e _ -> e
        | 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 _ -> 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)
        | _, _, _ -> raise (BadOp (v1,op,v2))
```

RTS: substitution

```
let substitute (v:exp) (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:exp) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
        match e with
            Int_e _ -> e
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          | Var_e y -> ... use x ...
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    in subst e
```

RTS: substitution

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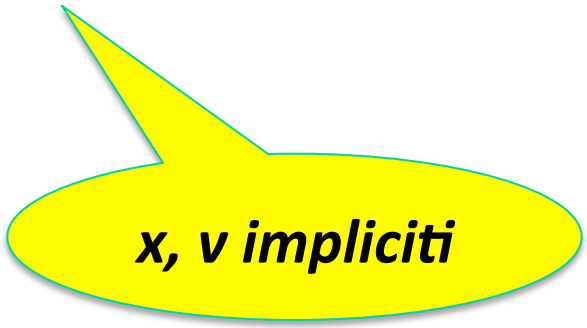
let substitute (v:exp) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
        match e with
            Int_e _ -> e
          | Op_e(e1,op,e2) -> Op_e(subst e1,op,subst e2)
          | Var_e y -> ... use x ...
          | Let_e (y,e1,e2) -> ... use x ...
    in subst e
```



RTS: substitution

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let substitute (v:exp) (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:exp) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
        match e with
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          | 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

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let substitute (v:exp) (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

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let substitute (v:exp) (x:variable) (e:exp) : exp =
    let rec subst (e:exp) : exp =
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            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
```

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)

Esempio (e va cambiato il RTS)

```
let f = fun x -> x + 1 in f 3
```

```
Let_e (“f”,
        Fun_e (“x”, Op_e (Var_e “x”, Plus, Int_e 1)),
        FunCall (Var_e “f”, Int_e 3)
       )
```

L'interprete+

RTS

```
eval_op : exp -> op -> exp -> exp
substitute : exp -> variable -> exp -> exp

let rec eval (e : exp) : exp =
    match e with
        :
      | Var_e _ -> raise (UnboundVariable x)
      | Fun_e _ -> e
      | FunCall_e (e1,e2) ->
            match eval e1, eval e2 with
                Fun_e (x,e3), v2 -> eval (substitute v2 x e3)
              | _ -> raise (TypeError)
```

Ricorsione

```
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
         | Letrec_e of variable * exp * exp
```

```
                                        let rec f = fun x -> f (x + 1) in f 3
Letrec_e (“f”,
          Fun_e (“x”,
                 FunCall_e (Var_e “f”, Op_e (Var_e “x”, Plus, Int_e 1))
                 ),
          FunCall (Var_e “f”, Int_e 3)
         )
```

L'interprete++

RTS

```
eval_op : exp -> op -> exp -> exp
substitute : exp -> variable -> exp -> exp

let rec eval (e : exp) : exp =
    match e with
          :
        | Letrec_e (x,e1,e2) ->
            let e1_unwind =
                substitute (Letrec_e (x,e1,Var_e x)) x e1 in
                  eval (Let_e (x,e1_unwind,e2))
```

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"