SOTTOPROGRAMMI IN LINGUAGGI IMPERATIVI

Caratteristiche del linguaggio imperativo

- include totalmente il linguaggio funzionale
  - inclusi i costrutti `Fun`, `Apply` e `Rec`
- le espressioni includono un nuovo costrutto `Proc` da usare soltanto nelle dichiarazioni di sottoprogrammi nei blocchi
  - il costrutto permette di specificare sottoprogrammi che hanno come corpo un comando
  - la loro invocazione non provoca la restituzione di un valore ma la modifica dello store

- i comandi includono un nuovo costrutto `Call` per la chiamata di sottoprogrammi
- i blocchi (oltre alla lista di comandi) hanno
  - dichiarazioni di costanti e variabili (già viste)
  - dichiarazioni di funzioni e procedure (usare rec per la ricorsione)

3

Espressioni

```
type ide = string
type exp =  Eint of int
        | Ebool of bool
        | Den of ide
        | Prod of exp * exp
        | Sum of exp * exp
        | Diff of exp * exp
        | Eq of exp * exp
        | Minus of exp
        | Iszero of exp
        | Or of exp * exp
        | And of exp * exp
        | Not of exp
        | Ifthenelse of exp * exp * exp
        | Let of ide * exp * exp
        | Newloc of exp
        | Fun of ide list * exp
        | Appl of exp * exp list
        | Rec of ide * exp
        | Proc of ide list * decl * com list
```

4

Dichiarazioni e comandi

```
and decl = (ide * exp) list * (ide * exp) list

and com =
      | Assign of exp * exp
      | Cifthenelse of exp * com list * com
                                              list
      | While of exp * com list
      | Block of decl * com list
      | Call of exp * exp list
```


Commenti

```
type exp =  ...
         | Proc of ide list * decl * com list
and com = ...
         | Call of exp * exp list
```

- Le procedure hanno
  - una lista di parametri
    - ✓identificatori nel costrutto di astrazione procedurale (formali)
    - ✓espressioni nel costrutto di chiamata (attuali)
- come nel caso delle funzioni, assumiamo la modalità standard di passaggio dei parametri (ovvero il passaggio per valore)
  - le espressioni parametro attuale sono valutate (`dval`) ed i valori ottenuti sono legati nell'ambiente al corrispondente parametro formale
- un linguaggio imperativo reale ha in più i tipi, le eccezioni ed eventuali meccanismi come i puntatori che vedremo nella estensione orientata ad oggetti

Semantica delle procedure

```
type exp =  ...
      | Proc of ide list * decl * com list
and com = ...
        | Call of exp * exp list
```

- A differenza delle funzioni, i valori `proc` con cui interpretiamo le procedure siano soltanto denotabili
- le procedure possono
  - essere dichiarate
  - essere passate come parametri
  - essere utilizzate nel comando `Call`
- le procedure non possono essere restituite come valore di una espressione

7

```
type eval =
       | Int of int | Bool of bool | Novalue
       | Funval of efun
and dval =
       | Dint of int | Dbool of bool | Unbound
       | Dloc of loc
       | Dfunval of efun
       | Dprocval of proc
and  mval =
       | Mint of int
       | Mbool of bool
       | Undefined

and efun = (dval list) * (mval store) -> eval

and proc = (dval list) * (mval store) -> mval store
```

8

Soliti meccanismi di conversione

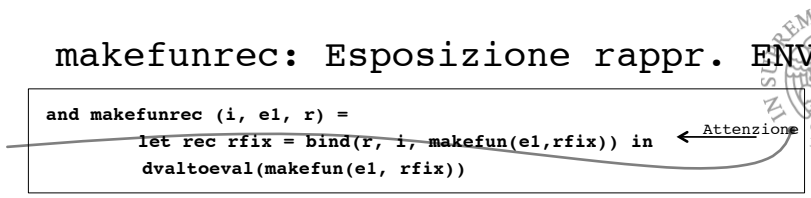
```
exception Nonstorable
exception Nonexpressible
let evaltomval e = match e with
        | Int n -> Mint n
        | Bool n -> Mbool n
        | _ -> raise Nonstorable
let mvaltoeval m = match m with
        | Mint n -> Int n
        | Mbool n -> Bool n
        | _ -> Novalue
let evaltodval e = match e with
        | Int n -> Dint n
        | Bool n -> Dbool n
        | Novalue -> Unbound
        | Funval n -> Dfunval n
let dvaltoeval e = match e with
        | Dint n -> Int n
        | Dbool n -> Bool n
        | Dloc n -> raise Nonexpressible
        | Dfunval n -> Funval n
        | Dprocval n -> raise Nonexpressible
        | Unbound -> Novalue
```

9

```
type efun = expr * dval env
type proc = expr * dval env
let rec makefun ((a:exp),(x:dval env)) = match a with
   | Fun(ii,aa) -> Dfunval(a,x)
   | _ -> failwith ("Non-functional object")
and makefunrec (i, Fun(ii, aa), r) =
    let functional (rr: dval env) =  bind(r, i, makefun(e1,rr)) in
        let rec rfix =  function x -> functional rfix x  in
                                                    dvaltoeval(makefun(e1,
    rfix))
and makeproc((a:exp),(x:dval env)) = match a with
   | Proc(ii,b) -> Dprocval(a, x)
   | _ -> failwith ("Non-functional object")
and applyfun ((ev1:dval),(ev2:dval list), s) = match ev1 with
   | Dfunval(Fun(ii,aa), x) -> sem(aa, bindlist(x, ii, ev2), s)
   | _ -> failwith ("attempt to apply a non-functional object")
and applyproc ((ev1:dval),(ev2:dval list), s) = match ev1 with
   | Dprocval(Proc(ii,b), x) -> semb(b, bindlist(x, ii, ev2), s)
   | _ -> failwith ("attempt to apply a non-functional object")
```

10

makefunrec: Esposizione rappr. ENV



```
and makefunrec (i, e1, r) =
        let rec rfix = bind(r, i, makefun(e1,rfix)) in
        dvaltoeval(makefun(e1, rfix))
```

Attenzione

Soluzione:
Introduciamo nell'ambiente un operatore ausiliario bindfun:
bindfun(i,e,r,mk) = let rec rfix = bind(r,i,mk(e,rfix)) in rfix
ridefiniamo (fuori dall'ambiente) makefunrec:
makefunrec(i,e,r) = dvaltoeval(makefun(e,bindfun(i,e,r,makefun)))

- volendo distinguere funzioni da procedure avremmo potuto usare il costruttore makeproc invece di makefun

Per liste di procedure e funzioni mutuamente ricorsive, occorre anche:

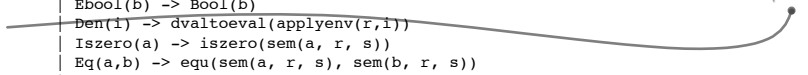
- un analogo di bind per coppie di liste

```
let rec bindlist(r,is,es) = match (is,es) with
      |([],[]) -> r
      |(i::is1, e::es1) -> bindlist(bind(r,i,e),is1,es1)
      |_ -> raise ....
```

- un analogo di bindfunlist per fix su più coppie:

```
bindfunlist(is,es,r,mk) =
      let rec rfix = bindlist(r,is,map(function x -> mk(x,rfix))es)
          in rfix
```


Semantica operazionale espressioni 1



```
let rec sem ((e:exp), (r:dval env), (s: mval store)) = match e with
      | Eint(n) -> Int(n)
      | Ebool(b) -> Bool(b)
      | Den(i) -> dvaltoeval(applyenv(r,i))
      | Iszero(a) -> iszero(sem(a, r, s))
      | Eq(a,b) -> equ(sem(a, r, s), sem(b, r, s))
      | Prod(a,b) ->  mult (sem(a, r, s), sem(b, r, s))
      | Sum(a,b) ->  plus (sem(a, r, s), sem(b, r, s))
      | Diff(a,b)  ->  diff (sem(a, r, s), sem(b, r, s))
      | Minus(a) ->  minus(sem(a, r, s))
      | And(a,b) ->  et (sem(a, r, s), sem(b, r, s))
      | Or(a,b) ->  vel (sem(a, r, s), sem(b, r, s))
      | Not(a) -> non(sem(a, r, s))
      | Ifthenelse(a,b,c) ->
           let g = sem(a, r, s) in
           if typecheck("bool",g) then
              (if g = Bool(true)
              then sem(b, r, s)
              else sem(c, r, s))
           else failwith ("nonboolean guard")
     | Let(i,e1,e2) -> let (v, s1) = semden(e1, r, s) in sem(e2, bind (r ,i, v), s1)
     | Fun(i,a) ->  dvaltoeval(makefun(Fun(i,a), r))
     | Appl(a, b) -> let (v1, s1) = semlist(b,r,s) in
        applyfun(evaltodval(sem(a,r,s)), v1, s1)
     | Rec(i, e) -> makefunrec(i, e, r)
     | Val(e) -> let (v, s1) = semden(e, r, s) in (match v with
        | Dloc n -> mvaltoeval(applystore(s1, n))
        | _ -> failwith("not a variable"))
     | _ -> failwith("nonlegal expression for sem")
```

Semantica operazionale espressioni 2

```
and semden ((e:exp), (r:dval env), (s: mval store)) =  match e with
        | Den(i) -> (applyenv(r,i), s)
        | Fun(i,e1) -> (makefun(e,r), s)
        | Proc(il,b) -> (makeproc(e,r), s)
        | Newloc(e) -> let m = evaltomval(sem(e, r, s)) in
              let (l, s1) = allocate(s, m) in (Dloc l, s1)
        | _ -> (evaltodval(sem(e, r, s)), s)
and semlist(el, r, s) = match el with
            | [] -> ([], s)
            | e::el1 -> let (v1, s1) = semden(e, r, s) in
              let (v2, s2) = semlist(el1, r, s1) in (v1 :: v2, s2)

val sem : exp * dval env * mval store -> eval = <fun>
val semden : exp * dval env * mval store ->
    dval * mval store = <fun>
val semlist : exp list * dval env * mval store ->
    dval list * mval store = <fun>
```


Semantica operazionale comandi

```
let rec semc((c: com), (r:dval env), (s: mval store)) = match c with
        | Assign(e1, e2) -> let (v1, s1) = semden(e1, r, s) in
          (match v1 with
          | Dloc(n) -> update(s1, n, evaltomval(sem(e2, r, s1)))
          | _ -> failwith ("wrong location in assignment"))
        | Cifthenelse(e, cl1, cl2) -> let g = sem(e, r, s) in
              if typecheck("bool",g) then
               (if g = Bool(true) then semcl(cl1, r, s) else semcl (cl2, r, s))
              else failwith ("nonboolean guard")
        | While(e, cl) -> let g = sem(e, r, s) in
            if typecheck("bool",g) then
               (if g = Bool(true) then semcl((cl @ [While(e, cl)]), r, s)
                        else s)
            else failwith ("nonboolean guard")
        | Block(b) -> semb(b, r, s)
        | Call(e1, e2) -> let (p, s1) = semden(e1, r, s)  in
             let (v, s2) = semlist(e2, r, s1) in applyproc(p, v, s2)

and semcl(cl, r, s) = match cl with
        | [] -> s
        | c::cl1 -> semcl(cl1, r, semc(c, r, s))

val semc :  com * dval env * mval store -> mval store = <fun>
val semcl :  com list * dval env * mval store -> mval store =  <fun>
```

Semantica operazionale dichiarazioni

```
and semb ((dl, rdl, cl), r, s) =
      let (r1, s1) = semdl((dl, rdl), r, s) in semcl(cl, r1, s1)

and semdv(dl, r, s) = match dl with
       | [] -> (r,s)
       | (i,e)::dl1 -> let (v, s1) = semden(e, r, s) in
            semdv(dl1, bind(r, i, v), s1)
and semdl ((dl, rl), r, s) =  let (r1, s1) = semdv(dl, r, s) in
            semdr(rl, r1, s1)
and semdr(rl, r, s) =
    let functional ((r1: dval env)) = (match rl with
         | [] -> r
         | (i,e) :: rl1 -> let (v, s2) = semden(e, r1, s) in
             let (r2, s3) = semdr(rl1. bind(r, i, v), s) in r2) in
     let rec rfix = function x -> functional rfix  x in (rfix, s)

val semb :  (decl * com list) * dval env * mval store -> mval store =  <fun>
val semdl :  decl *  dval env *  mval store -> dval env * mval store = <fun>
val semdv :  (ide * expr) list *  dval env *  mval store ->
     dval env * mval store = <fun>
val semdr :  (ide * expr) list *  dval env *  mval store ->
     dval env * mval store = <fun>
```


Mutua ricorsione (implicita)

```
let(mdiccom: block) =
  ([("y", Newloc (Eint 0))],
  [("impfact", Proc(["x"],
           ([("z", Newloc(Den "x")) ;("w", Newloc(Eint 1))],
            [],
            [While(Not(Eq(Val(Den "z"), Eint 0)),
                [Assign(Den "w", Prod(Val(Den "w"),Val(Den "z")));
                 Assign(Den "z", Diff(Val(Den "z"), Eint 1))]);
           Cifthenelse
             (Eq (Val (Den "w"), Appl (Den "fact", [Den "x"])),
              [Assign (Den "y", Val (Den "w"))],
               [Assign (Den "y", Eint 0)])]   )));
    ("fact", Fun(["x"],
       Ifthenelse (Eq (Den "x", Eint 0), Eint 1,
         Prod (Den "x", Appl (Den "fact", [Diff (Den "x", Eint 1)])))) )],
  [ Call(Den "impfact", [Eint 4])])  ;;

# let itestore1 = semb(mdiccom, (emptyenv Unbound), (emptystore Undefined);;
# applystore(itestore1, 0);;
- : mval = Mint 24
```

Interprete iterativo

- non servono strutture dati diverse da quelle già introdotte per gestire i blocchi
  - la chiamata di procedura crea un nuovo frame invece di fare una chiamata ricorsiva a `semb`
- pila dei records di attivazione realizzata attraverso sei pile gestite in modo "parallelo"
  - `envstack` pila di ambienti
  - `cstack` pila di pile di costrutti sintattici etichettati
  - `tempvalstack` pila di pile di eval
  - `tempdvalstack` pila di pile di dval
  - `storestack` pila di memorie
  - `labelstack` pila di costrutti sintattici etichettati
- usiamo le due operazioni introdotte nel linguaggio funzionale per
  - inserire nella pila sintattica una lista di espressioni etichettate (argomenti da valutare nell'applicazione)
  - prelevare dalla pila dei temporanei una lista di eval (argomenti valutati nell'applicazione)

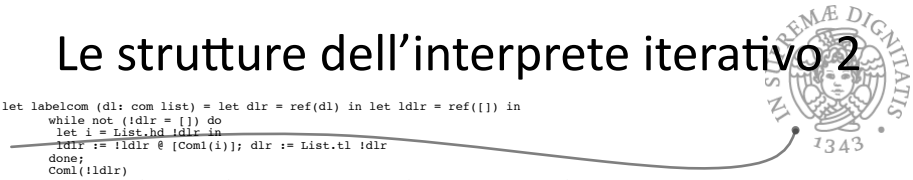
17

Le strutture dell'interprete iterativo 1

```
let cframesize(e) = 20
let tframesize(e) = 20
let tdframesize(e) = 20
let stacksize = 100
type labeledconstruct =
   | Expr1 of exp
   | Expr2 of exp
   | Exprd1 of exp
   | Exprd2 of exp
   | Com1 of com
   | Com2 of com
   | Coml of labeledconstruct list
   | Dec1 of ide * exp
   | Dec2 of ide * exp
   | Rec1 of (ide * exp) list
   | Decl of labeledconstruct list
let (cstack: labeledconstruct stack stack) = emptystack(stacksize,emptystack(1,Expr1(Eint(0))))

let (tempvalstack: eval stack stack) = emptystack(stacksize,emptystack(1,Novalue))

let (tempdvalstack: dval stack stack) = emptystack(stacksize,emptystack(1,Unbound))

let envstack = emptystack(stacksize,(emptyenv Unbound))

let storestack = emptystack(stacksize,(emptystore Undefined))

let (labelstack: labeledconstruct stack) =  emptystack(stacksize,Expr1(Eint(0)))
```

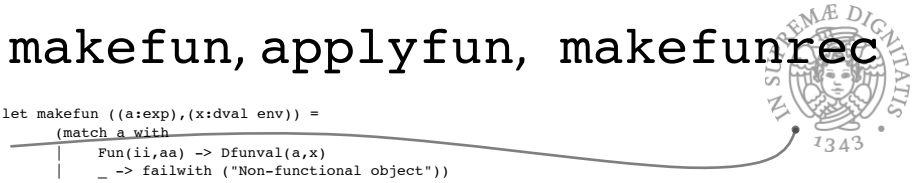
18

Le strutture dell'interprete iterativo 2



```
let labelcom (dl: com list) = let dlr = ref(dl) in let ldlr = ref([]) in
      while not (!dlr = []) do
       let i = List.hd !dlr in
       ldlr := !ldlr @ [Com1(i)]; dlr := List.tl !dlr
      done;
      Coml(!ldlr)
let labeldec (dl: (ide * exp) list) = let dlr = ref(dl) in let ldlr = ref([]) in
      while not (!dlr = []) do
       let i = List.hd !dlr in
       ldlr := !ldlr @ [Dec1(i)]; dlr := List.tl !dlr
      done;
      Decl(!ldlr)
let pushenv(r) = push(r,envstack)
let topenv() = top(envstack)
let popenv () = pop(envstack)
let svuotaenv() = svuota(envstack)
let pushstore(s) = push(s,storestack)
let popstore () = pop(storestack)
let svuotastore () = svuota(storestack)
let topstore() = top(storestack)
let pushargs ((b: exp list),(continuation: labeledconstruct stack)) =
     let br = ref(b) in
      while not(!br = []) do
          push(Exprdl(List.hd !br),continuation); br := List.tl !br
        done
let getargs ((b: exp list),(tempstack: dval stack)) =
      let br = ref(b) in let er = ref([]) in
      while not(!br = []) do
          let arg=top(tempstack) in
            pop(tempstack); er := !er @ [arg]; br := List.tl !br
        done;
        !er
```


makefun, applyfun, makefunrec



```
let makefun ((a:exp),(x:dval env)) =
      (match a with
       |    Fun(ii,aa) -> Dfunval(a,x)
       |    _ -> failwith ("Non-functional object"))
let applyfun ((ev1:dval),(ev2:dval list), s) =
      ( match ev1 with
      | Dfunval(Fun(ii,aa),r) -> newframes(Expr1(aa),bindlist(r, ii, ev2), s)
      | _ -> failwith ("attempt to apply a non-functional object"))
let makefunrec (i, e1, (r:dval env)) =
    let functional (rr: dval env) =
          bind(r, i, makefun(e1,rr)) in
          let rec rfix =  function x -> functional rfix x

                in dvaltoeval(makefun(e1, rfix))
let makeproc((a:exp),(x:dval env)) = match a with
   | Proc(ii,b) -> Dprocval(a, x)
   | _ -> failwith ("Non-functional object")
let applyproc ((ev1:dval),(ev2:dval list), s) = match ev1 with
   | Dprocval(Proc(ii,(l1, l2, l3)), x) ->
          newframes(labelcom(l3), bindlist(x, ii, ev2), s);
          push(Rdecl(l2), top(cstack));
          push(labeldec(l1),top(cstack))
   | _ -> failwith ("attempt to apply a non-functional object")
```

L'interprete iterativo 0

- la creazione di un nuovo record di attivazione (frame): invariata!

```
let newframes(ss, rho, sigma) =
    pushenv(rho);
    pushstore(sigma);
    let cframe = emptystack(cframesize(ss),Expr1(Eint 0)) in
    let tframe = emptystack(tframesize(ss),Novalue) in
    let dframe = emptystack(tdframesize(ss),Unbound) in
   push(ss, cframe);
    push(ss, labelstack);
    push(cframe,cstack);
    push(dframe,tempdvalstack);
    push(tframe,tempvalstack)
val newframes :  labeledconstruct * dval env *
    mval store -> unit = <fun>
```

21

L'interprete iterativo 1

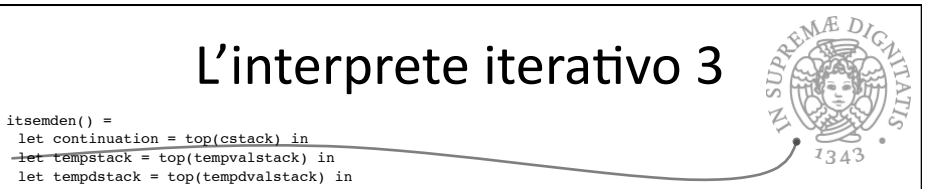
```
let itsem() =
     let continuation = top(cstack) in
     let tempstack = top(tempvalstack) in
    let tempdstack = top(tempdvalstack) in
    let rho = topenv() in
    let sigma = topstore() in
     (match top(continuation) with
       |Expr1(x) ->
      (pop(continuation); push(Expr2(x),continuation);
      (match x with
          | Iszero(a) -> push(Expr1(a),continuation)
          | Eq(a,b) -> push(Expr1(a),continuation); push(Expr1(b),continuation)
          | Prod(a,b) ->  push(Expr1(a),continuation); push(Expr1(b),continuation)
          | Sum(a,b) -> push(Expr1(a),continuation); push(Expr1(b),continuation)
          | Diff(a,b) ->  push(Expr1(a),continuation); push(Expr1(b),continuation)
          | Minus(a) ->  push(Expr1(a),continuation)
          | And(a,b) ->  push(Expr1(a),continuation); push(Expr1(b),continuation)
          | Or(a,b) ->  push(Expr1(a),continuation); push(Expr1(b),continuation)
          | Not(a) -> push(Expr1(a),continuation)
          | Ifthenelse(a,b,c) -> push(Expr1(a),continuation)
          | Val(a) -> push(Exprd1(a),continuation)
        | Newloc(e) -> failwith ("nonlegal expression for sem")
         | Let(i,e1,e2) ->  push(Exprd1(e1),continuation)
        | Appl(a,b) ->  push(Expr1(a),continuation);
            pushargs(b,continuation)
         | Proc(i,b) -> failwith ("nonlegal expression for sem")
         | _ -> ()))
```

22

L'interprete iterativo 2

```
      |Expr2(x) ->
       (pop(continuation); (match x with
              | Eint(n) ->  push(Int(n),tempstack)
              | Ebool(b) -> push(Bool(b),tempstack)
              | Den(i) ->   push(dvaltoeval(applyenv(rho,i)),tempstack)
              | Iszero(a) -> let arg=top(tempstack) in pop(tempstack); push(iszero(arg),tempstack)
              | Eq(a,b) -> let firstarg=top(tempstack) in pop(tempstack);
             let sndarg=top(tempstack) in pop(tempstack); push(equ(firstarg,sndarg),tempstack)
             | Prod(a,b) -> let firstarg=top(tempstack) in pop(tempstack);
             let sndarg=top(tempstack) in pop(tempstack); push(mult(firstarg,sndarg),tempstack)
             | Sum(a,b) -> let firstarg=top(tempstack) in pop(tempstack);
             let sndarg=top(tempstack) in pop(tempstack); push(plus(firstarg,sndarg),tempstack)
             | Diff(a,b)  -> let firstarg=top(tempstack) in pop(tempstack);
             let sndarg=top(tempstack) in pop(tempstack); push(diff(firstarg,sndarg),tempstack)
             | Minus(a) -> let arg=top(tempstack) in pop(tempstack); push(minus(arg),tempstack)
             | And(a,b) -> let firstarg=top(tempstack) in pop(tempstack);
             let sndarg=top(tempstack) in pop(tempstack); push(et(firstarg,sndarg),tempstack)
             | Or(a,b) -> let firstarg=top(tempstack) in pop(tempstack);
             let sndarg=top(tempstack) in pop(tempstack); push(vel(firstarg,sndarg),tempstack)
             | Not(a) -> let arg=top(tempstack) in pop(tempstack); push(non(arg),tempstack)
             | Ifthenelse(a,b,c) -> let arg=top(tempstack) in pop(tempstack); if typecheck("bool",arg) then
                                (if arg = Bool(true) then push(Expr1(b),continuation) else push(Expr1(c),continuation))
             else failwith ("type error"))
             | Val(e) -> let v = top(tempdstack) in pop(tempdstack); (match v with
                                | Dloc n -> push(mvaltoeval(applystore(sigma, n)), tempstack)
                                | _ -> failwith("not a variable"))
             | Fun(i,a) ->  push(dvaltoeval(makefun(Fun(i,a),rho)),tempstack)
             | Rec(f,e) -> push(makefunrec(f,e,rho),tempstack)
             | Let(i,e1,e2) -> let arg= top(tempdstack) in
             pop(tempdstack); newframes(Expr1(e2), bind(rho, i, arg), sigma)
             | Appl(a,b) -> let firstarg=evaltodval(top(tempstack)) in
             pop(tempstack);  let sndarg=getargs(b,tempdstack) in applyfun(firstarg, sndarg, sigma)
             | _ -> failwith("no more cases for itsem")))
     | _ -> failwith("no more cases for itsem"))

val itsem : unit -> unit = <fun>
```


L'interprete iterativo 3



```
let itsemden() =
     let continuation = top(cstack) in
     let tempstack = top(tempvalstack) in
     let tempdstack = top(tempdvalstack) in
     let rho = topenv() in
     let sigma = topstore() in
     (match top(continuation) with
     |Exprd1(x) -> (pop(continuation); push(Exprd2(x),continuation);
       match x with
            | Den i -> ()
            | Fun(i, e) -> ()
            | Proc(i, b) -> ()
            | Newloc(e)  ->  push(Expr1( e), continuation)
            | _ -> push(Expr2(x), continuation))
     |Exprd2(x) -> (pop(continuation); match x with
            | Den i -> push(applyenv(rho,i), tempdstack)
            | Fun(i, e) -> push(makefun(x, rho), tempdstack)
            | Proc(i, b) -> push(makeproc(x, rho), tempdstack)
            | Newloc(e)  -> let m=evaltomval(top(tempstack)) in pop(tempstack);
                       let (l, s1) = allocate(sigma, m) in push(Dloc l, tempdstack);
                       popstore(); pushstore(s1)
            | _ -> let arg = top(tempstack) in pop(tempstack);
           push(evaltodval(arg), tempdstack))
     | _ -> failwith("No more cases for semden")    )
val itsemden : unit -> unit = <fun>
```

L'interprete iterativo 4

```
let itsemcl () =
      let continuation = top(cstack) in
      let tempstack = top(tempvalstack) in
      let tempdstack = top(tempdvalstack) in
      let rho = topenv() in
      let sigma = topstore() in
      let cl = (match top(continuation) with
      | Coml(dl1) -> dl1
      | _ -> failwith("impossible in semdecl")) in
      if cl = [] then pop(continuation) else
      (let currc = List.hd cl in let newcl = List.tl cl in pop(continuation); push(Coml(newcl),continuation);
      (match currc with
         | Com1(Assign(e1, e2)) ->  pop(continuation); push(Coml(Com2(Assign(e1, e2))::newcl),continuation);
           push(Exprd1(e1), continuation); push(Expr1(e2), continuation)
         | Com2(Assign(e1, e2)) -> let arg2 = evaltomval(top(tempstack)) in pop(tempstack);
           let arg1 = top(tempdstack) in pop(tempdstack); (match arg1 with
                    | Dloc(n) -> popstore(); pushstore(update(sigma, n, arg2))
                    | _ -> failwith ("wrong location in assignment"))
         | Com1(While(e, cl)) -> pop(continuation); push(Coml(Com2(While(e, cl))::newcl),continuation);
           push(Expr1(e), continuation)
         | Com2(While(e, cl)) -> let g = top(tempstack) in pop(tempstack);
              if typecheck("bool",g) then (if g = Bool(true) then (let old = newcl in let newl =
                (match labelcom cl with
                    | Coml newl1 -> newl1
                    | _ -> failwith("impossible in while")) in
               let nuovo = Coml(newl @ [Coml(While(e, cl))] @ old) in pop(continuation); push(nuovo,continuation))
            else ()) else failwith ("nonboolean guard")
```


L'interprete iterativo 5

```
       | Com1(Cifthenelse(e, cl1, cl2)) -> pop(continuation);
         push(Coml(Com2(Cifthenelse(e, cl1, cl2))::newcl),continuation);
         push(Expr1(e), continuation)
       | Com2(Cifthenelse(e, cl1, cl2)) -> let g = top(tempstack) in pop(tempstack);
           if typecheck("bool",g) then (let temp = if g = Bool(true) then
            labelcom (cl1) else labelcom (cl2) in let newl = (match temp with
                  | Coml newl1 -> newl1
                  | _ -> failwith("impossible in cifthenelse")) in
            let nuovo = Coml(newl @ newcl) in  pop(continuation); push(nuovo,continuation))
              else failwith ("nonboolean guard")
       | Com1(Call(e, el)) ->  pop(continuation);
         push(Coml(Com2(Call(e, el))::newcl),continuation);
         push(Exprd1( e), continuation); pushargs(el, continuation)
       | Com2(Call(e, el)) ->
          let p = top(tempdstack) in pop(tempdstack);

          let args = getargs(el,tempdstack) in applyproc(p, args, sigma)

       | Com1(Block((l1, l2,l3))) -> newframes(labelcom(l3), rho, sigma);
                  push(Rdecl(l2),top(cstack));
                  push(labeldec(l1),top(cstack))
       | _ -> failwith("no more sensible cases in commands") ))
val itsemcl : unit -> unit = <fun>
```

L'interprete iterativo 6 (invariata!)

```
let itsemdecl () =
    let tempstack = top(tempvalstack) in
    let continuation = top(cstack) in
    let tempdstack = top(tempdvalstack) in
    let rho = topenv() in
    let sigma = topstore() in
    let dl = (match top(continuation) with
      | Decl(dl1) -> dl1
      | _ -> failwith("impossible in semdecl")) in
    if dl = [] then pop(continuation) else
    (let currd = List.hd dl in
    let newdl = List.tl dl in pop(continuation); push(Decl(newdl),continuation);
    (match currd with

      | Decl( (i,e)) ->
         pop(continuation);
         push(Decl(Dec2((i, e))::newdl),continuation);
         push(Exprdl(e), continuation)

      | Dec2((i,e)) ->
         let arg = top(tempdstack) in
         pop(tempdstack);
         popenv(); pushenv(bind(rho, i, arg))

      | _ -> failwith("no more sensible cases for semdecl")))

val itsemdecl : unit -> unit = <fun>
```


L'interprete iterativo 7

```
let itsemrdecl() =
         let tempstack = top(tempvalstack) in
         let continuation = top(cstack) in
         let tempdstack = top(tempdvalstack) in
         let rho = topenv() in
         let sigma = topstore() in
         let rl = (match top(continuation) with
            | Rdecl(rl1) -> rl1
            | _ -> failwith("impossible in semrdecl")) in
         pop(continuation);
         let functional (rr: dval env) =
            let pr = ref(rho) in
            let prl = ref(rl) in
            while not(!prl = []) do
             let currd = List.hd !prl in
             prl := List.tl !prl;
             let (i, den) =
             (match currd with
              |(j,  Proc(il,b)) -> (j, makeproc(Proc(il,b),rr))
              |(j,  Fun(il,b)) -> (j, makefun(Fun(il,b),rr))
              | _ -> failwith("no more sensible cases in recursive declaration")) in
             pr := bind(!pr, i, den)
            done;
            !pr  in
          let rec rfix = function x -> functional rfix  x in
            popenv();
            pushenv(rfix)
val itsemdecl : unit -> unit = <fun>
```

L'interprete iterativo 8

```
let initstate() = svuota(continuation); svuota(tempstack); svuota(tempdvalstack);
    svuotaenv(); svuotastore(); svuota(labelstack)
val initstate : unit -> unit = <fun>

let loop () =
  while not(empty(cstack)) do
    while not(empty(top(cstack))) do
     let currconstr = top(top(cstack)) in
     (match currconstr with
           | Expr1(e) -> itsem()
           | Expr2(e) -> itsem()
           | Exprd1(e) -> itsemden()
           | Exprd2(e) -> itsemden()
           | Coml(cl) -> itsemcl()
           | Rdecl(l) -> itsemrdecl()
           | Decl(l) -> itsemdecl()
           | _ -> failwith("non legal construct in loop"))
    done;
    (match top(labelstack) with
         | Expr1(_) -> let valore = top(top(tempvalstack)) in
             pop(top(tempvalstack)); pop(tempvalstack); push(valore,top(tempvalstack));
              popenv(); popstore(); pop(tempdvalstack)
         | Exprd1(_) -> let valore = top(top(tempdvalstack)) in
             pop(top(tempdvalstack)); pop(tempdvalstack); push(valore,top(tempdvalstack));
              popenv(); popstore(); pop(tempvalstack)
         | Decl(_) -> pop(tempvalstack); pop(tempdvalstack)
         | Rdecl(_) -> pop(tempvalstack); pop(tempdvalstack)
         | Coml(_) -> let st = topstore() in popenv(); popstore(); popstore(); pushstore(st);
               pop(tempvalstack); pop(tempdvalstack)
         | _ -> failwith("non legal label in loop"));
      pop(cstack); pop(labelstack)
  done
val loop : unit -> unit = <fun>
```


L'interprete iterativo 9 (invariato!)

```
let sem (e,(r: dval env), (s: mval store)) = initstate();
   push(emptystack(tframesize(e),Novalue),tempvalstack);
   newframes(Expr1(e), r, s);
   loop();
   let valore= top(top(tempvalstack)) in
   pop(tempvalstack); valore
val sem : exp * dval env * mval store -> eval = <fun>

let semden (e,(r: dval env), (s: mval store)) = initstate();
   push(emptystack(tdframesize(e),Unbound),tempdvalstack);
   newframes(Exprd1(e), r, s);
   loop();
   let valore= top(top(tempdvalstack)) in
   pop(tempdvalstack);
   valore
val semden : exp * dval env * mval store -> dval = <fun>

let semcl (cl,(r: dval env), (s: mval store)) = initstate();
   pushstore(emptystore(Undefined));
   newframes(labelcom(cl), r, s);
   loop();
   let st = topstore() in popstore();
   st
val semcl :  com list * dval env * mval store -> mval store =  <fun>
```

L'interprete iterativo 10 (invariato!)


```
let semdv(dl, r, s) =  initstate();
   newframes(labeldec(dl), r, s);
   loop();
   let st = topstore() in popstore();
   let rt = topenv() in popenv();
   (rt, st)
val semdv : (ide * exp) list * dval env * mval store ->
  dval env * mval store = <fun>

let semc((c: com), (r:dval env), (s: mval store)) = initstate();
   pushstore(emptystore(Undefined));
   newframes(labelcom([c]), r, s);
   loop();
   let st = topstore() in popstore();
   st
val semc : com * dval env * mval store -> mval store = <fun>
```


L'interprete iterativo 11


```
let semdr(dl, r, s) =  initstate();
   newframes(Rdecl(dl), r, s);
   loop();
   let st = topstore() in popstore();
   let rt = topenv() in popenv();
   (rt, st)
val semdr : (ide * exp) list * dval env * mval store ->
  dval env * mval store = <fun>

let semdl((dl, rl), r, s) =  initstate();
   newframes(Rdecl(rl), r, s);
   push(labeldec(dl), top(cstack));
   loop();
   let st = topstore() in popstore();
   let rt = topenv() in popenv();
   (rt, st)
val semdl : decl * dval env * mval store ->
  dval env * mval store = <fun>

let semb ((dl, rl, cl), r, s) = initstate();
   pushstore(emptystore(Undefined));
   newframes(labelcom(cl), r, s);
   push(Rdecl(rl), top(cstack));
   push(labeldec(dl), top(cstack));
   loop();
   let st = topstore() in popstore();
   st
val semb : (decl * com list) * dval env * mval store ->
  mval store = <fun>
```

Cosa abbiamo realizzato?

- come per il linguaggio funzionale, manca l'implementazione vera del dominio ambiente e quella del dominio store!
- nella implementazione attuale abbiamo una pila di ambienti ed una pila di memorie relativi alle varie attivazioni
  - ognuno degli ambienti è l'ambiente complessivo
    - ✓rappresentato attraverso una funzione
  - ognuna delle memorie è la memoria complessiva
    - ✓rappresentata attraverso una funzione
- in una implementazione reale ogni attivazione dovrebbe avere
  - l'ambiente locale (ed un modo per reperire il resto dell'ambiente visibile)
  - la memoria locale
  - l'ambiente e la memoria locali dovrebbero essere "implementati" al prim'ordine (con strutture dati)
- vedremo tali implementazioni tra un po' di tempo

33

scoping dinamico

- tutto come nel linguaggio funzionale
  - in particolare per quanto riguarda ricorsione, verifiche statiche ed ottimizzazioni
- vediamo soltanto i domini di funzioni e procedure in semantica operazionale
  - quelli della semantica iterativa sono ovviamente gli stessi
  - le funzioni di creazione e applicazione (per funzioni e procedure) sono lasciate come esercizio
- l' implementazione al prim'ordine dell'ambiente in presenza di scoping dinamico verrà vista quando parleremo di implementazione dello stato

34

Funzioni e procedure con scoping dinamico

scoping statico

```
type efun = exp * (dval env)
type proc = exp * (dval env)
```

scoping dinamico

```
type efun = exp
type proc = exp
```

35