Scope, Function Calls and Storage Management

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capitolo 7 del
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Introduzione

- Quando dichiariamo una variabile, il computer dove la memorizza?
- Quali sono le regole per accedere ad una variabile?
- Come vengono passate ai sottoprogrammi i dati?
- Due principali feature:
  - Divisione di un programma in sottoprogrammi
    - Non come il BASIC
    - Non si sanno tutte le variabili prima dell'esecuzione e l'allocazione della memoria avviene dinamicament
  - Uso della ricorsione

Topics

- Block-structured languages and stack storage
- In-line Blocks
  - activation records
  - storage for local, global variables
- First-order functions
  - parameter passing
  - tail recursion and iteration
- NO - Higher-order functions
  - deviations from stack discipline
  - language expressiveness => implementation complexity

Block-Structured Languages

- Nested blocks, local variables
  - Example

```
{ int x = 2;
    { int y = 3;
      x = y+2;
    }
}
```

new variables declared in nested blocks

local variable

global variable

outer block

inner block

  - Storage management
    - Enter block: allocate space for variables
    - Exits block: some or all space may be deallocated

Examples

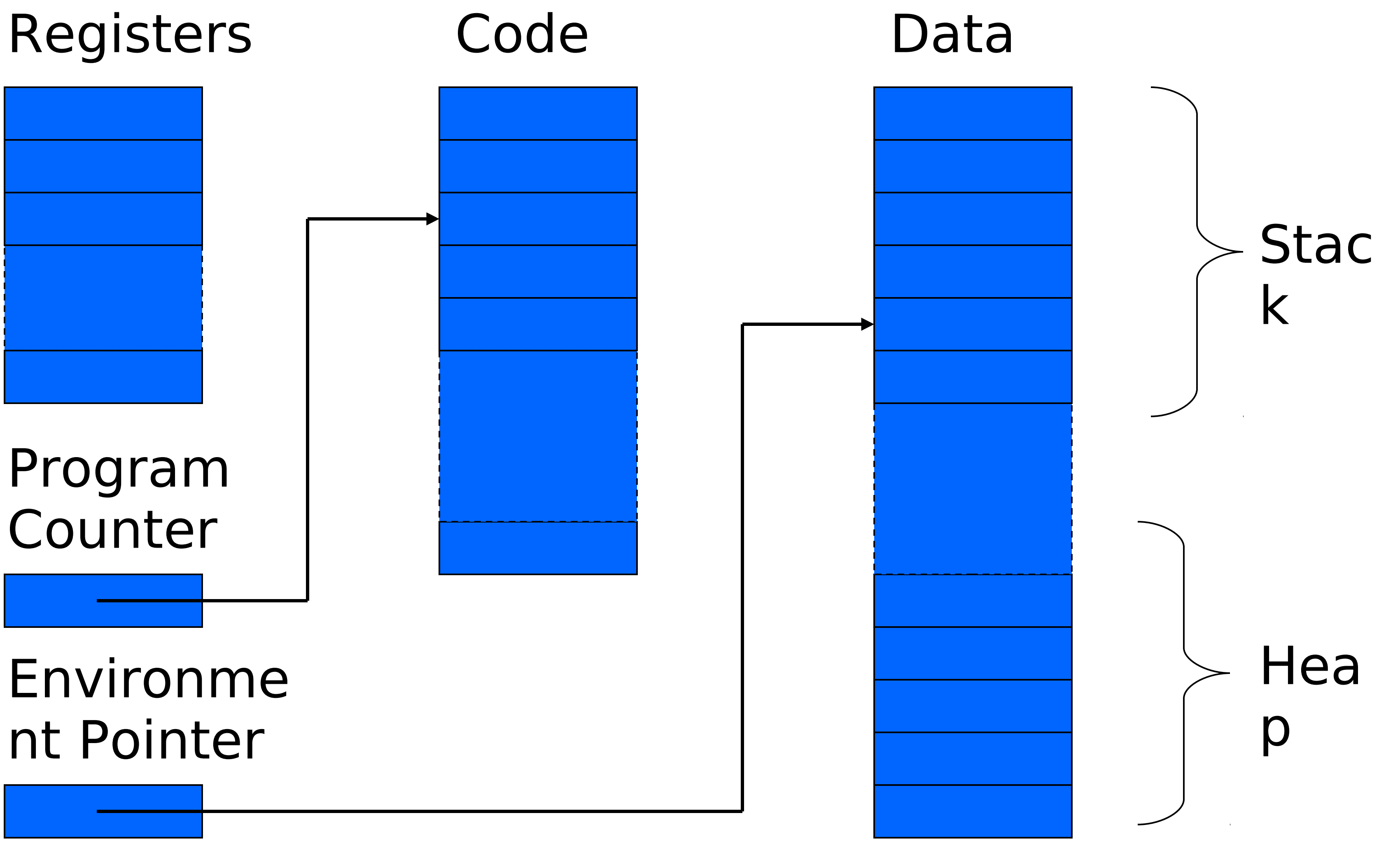
- Blocks in common languages
  - C/c++/Java { … }
  - Algol begin … end
  - ML let … in … end
- Two forms of blocks
  - In-line blocks
    - Blocks for control structure like if, for and so on.. similar to block inline
  - Blocks associated with functions or procedures

- Topic: block-based memory management, access to *local variables*, *parameters*,*global vars*
- It allows **recursive functions**

Alcune note

- Alcuni linguaggi (come Fortran) allocavano in modo fisso le variabili
  - Svantaggi …
- Block-structured languages:
  - New variables may be declared at various points in a program
  - Each declaration is visible within a block
  - When a program begins executing the instructions contained in a block, the memory is allocated
  - When a program exits, the memory id freed
  - An identifier that is not declared in the current block is considered global to the block

Simplified Machine Model



Interested in Memory Mgmt Only

- Registers, Code segment, Program counter
  - Ignore registers
  - Details of instruction set will not matter
- Data Segment
  - Stack contains data related to block entry/exit
  - Heap contains data of varying lifetime
  - **Environment pointer** points to current stack position
    - Block entry: add new activation record to stack
    - Block exit: remove most recent activation record

Some basic concepts

- Scope
  - Region of program text where declaration is visible
- Lifetime
  - Period of time when location is allocated to program

```
{ int x = ... ;
    {  int y = ... ;
        {  int x = ... ;
          ....
         };
    };
};
```

- Inner declaration of x hides outer one.
- Called “hole in scope”
- Lifetime of outer x includes time when inner block is executed
- Lifetime $\neq$ scope
- Lines indicate “contour model” of scope.

In-line Blocks

- Activation record
  - Data structure stored on run-time stack
  - Contains space for local variables
- Example

```
{ int x=0;
  int y=x+1;
      {  int z=(x+y)*(x-y);
      };
};
```

Push record with space for x, y

Set values of x, y

Push record for inner block

Set value of z

Pop record for inner block

Pop record for outer block

Intermediate results on the stack

May need space for variables and intermediate results like (x+y), (x-y)

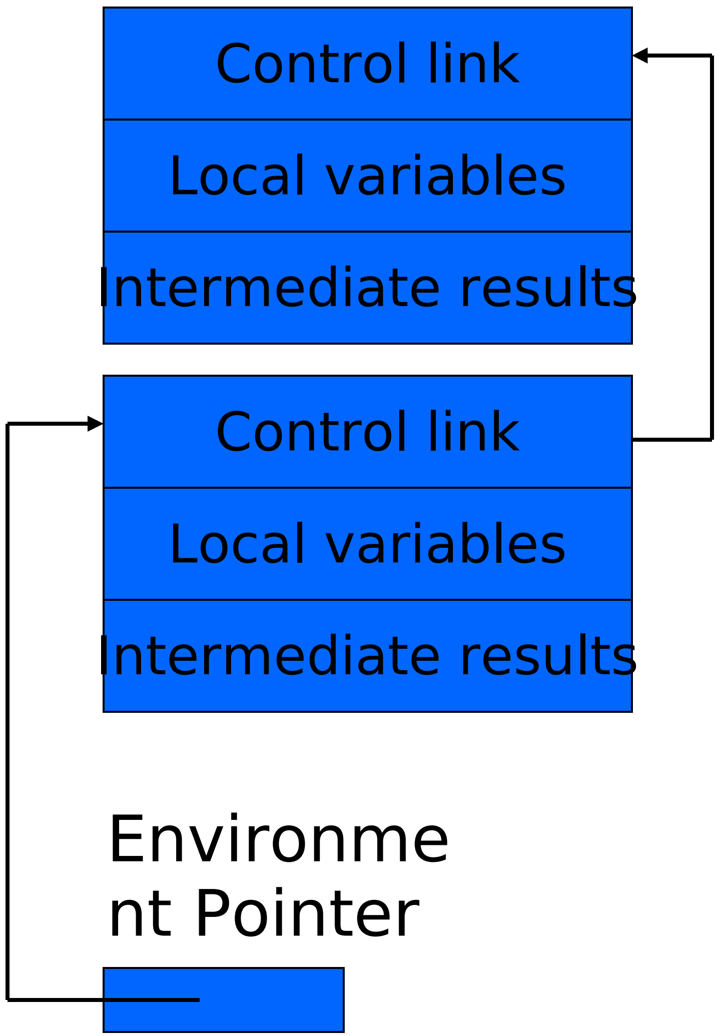
Example:

Int z = (x+y) *(x-y)

Control Link

- EP punta alla cima del record di attivazione corrente
- Record di attivazione ha dimensione variabile
- Come faccio a ripristinare EP quando faccio il pop del record di attivazione che non serve più?
- Uso il control link:
  - Puntatore alla cima del record di attivazione precedente
  - Viene salvato quando creo il record di attivazione
  - Viene ripristinato quando faccio il pop

Activation record for in-line block

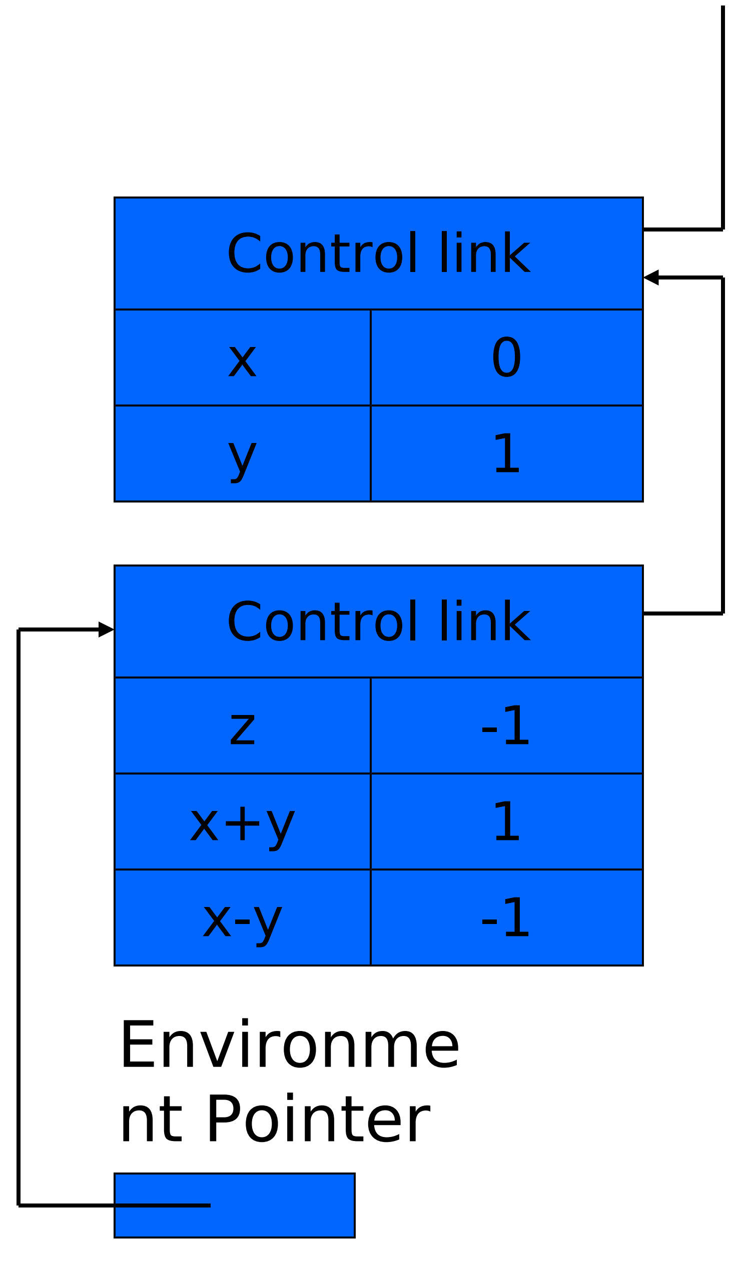


- Control link
  - pointer to previous record on stack
- Push record on stack:
  - Set new control link to point to old env ptr
  - Set env ptr to new record
- Pop record off stack
  - Follow control link of current record to reset environment pointer

Example

```
{ int x=0;
  int y=x+1;
     { int z=(x+y)*(x-y);
     };
};
```

- Push record with space for x, y (set control link = old env pointer, set env pointer)
- Set values of x, y
  - Push record for inner block
  - Set value of z
  - Pop record for inner block (set env pointer to control link)
- Pop record for outer block



Scoping rules

- Global and local variables
  - x, y are local to outer block
  - z is local to inner bock
  - x, y are global to inner block

```
{ int x=0;
  int y=x+1;
    {  int z=(x+y)*(x-y);
    };
};
```

- Static scope
  - global refers to declaration in closest enclosing block
- Dynamic scope
  - global refers to most recent activation record

These are same until we consider function calls.

Esercizio 7.1

Functions and procedures

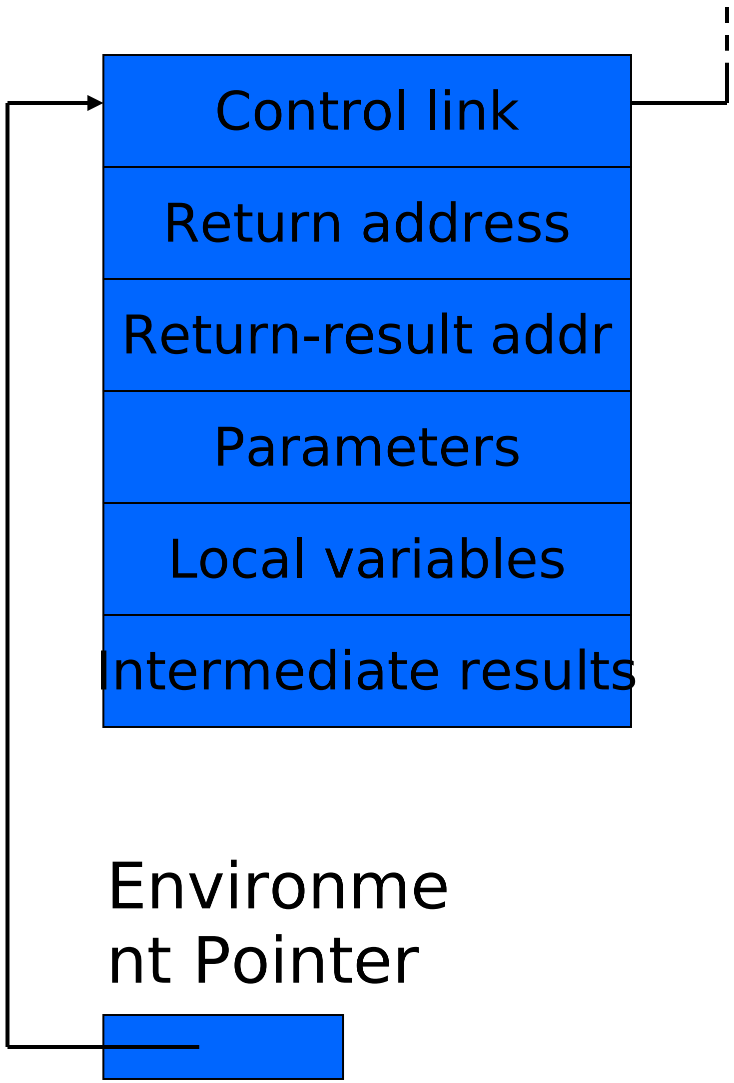
- Syntax of procedures (Algol) and functions (C)

```
procedure P (<pars>)
    begin
        <local vars>
        <proc body>
    end;
```

```
<type> function f(<pars>)
    {
        <local vars>
        <function body>
    };
```

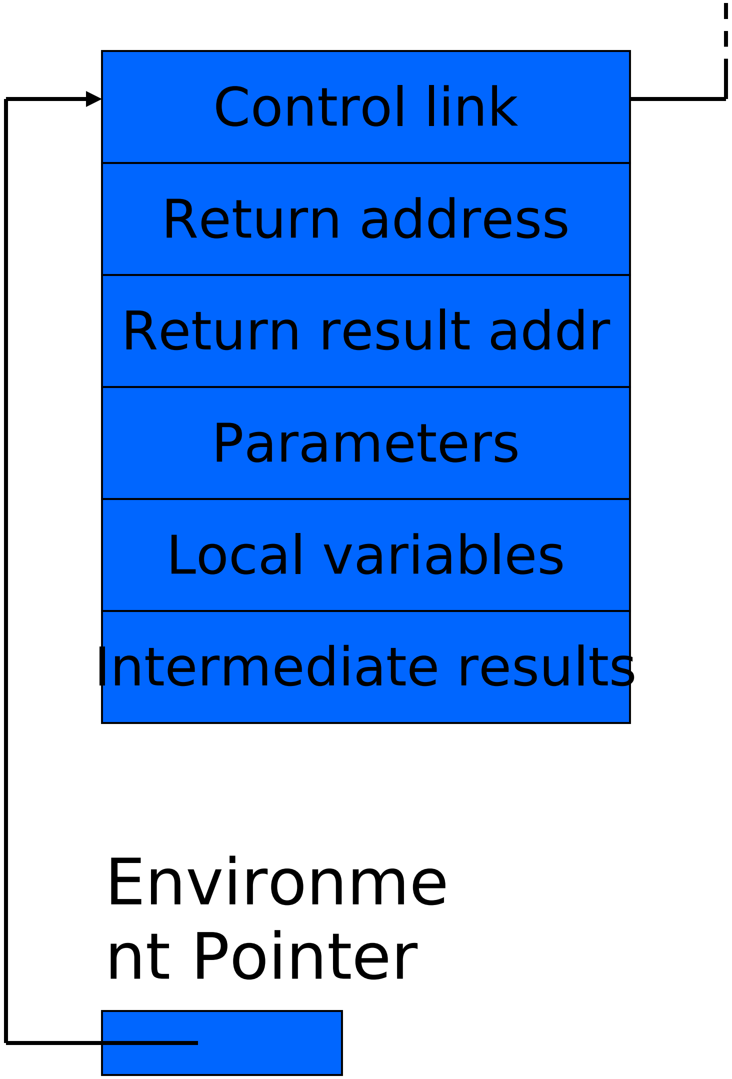
- Activation record must include space for
  - parameters
  - return address
  - Local variables
    (and intermediate result)
  - location to put return value on function exit

Activation record for function



- Return address
  - Location of code to execute on function return
- Return-result address
  - Address in activation record of calling block to receive return address
- Parameters
  - Locations to contain data from calling block

Example



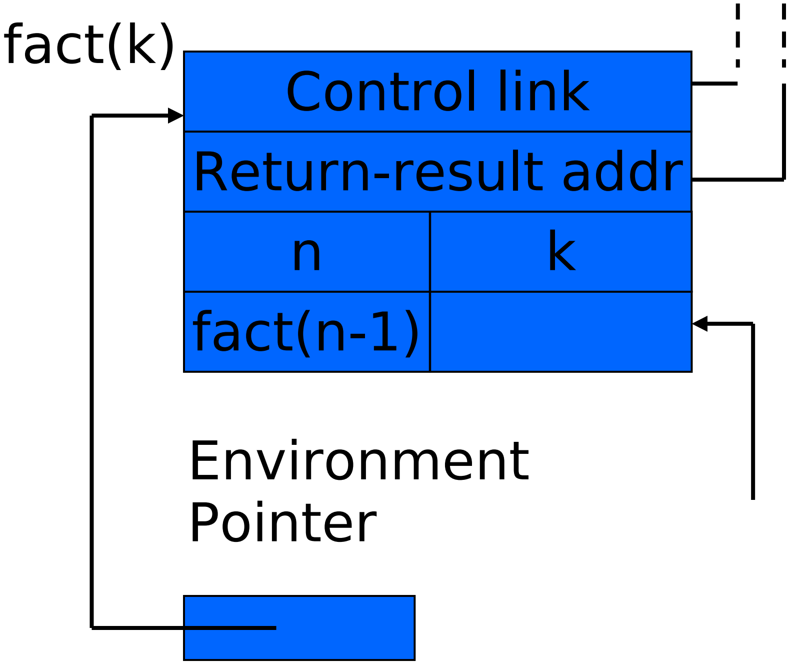
- Function

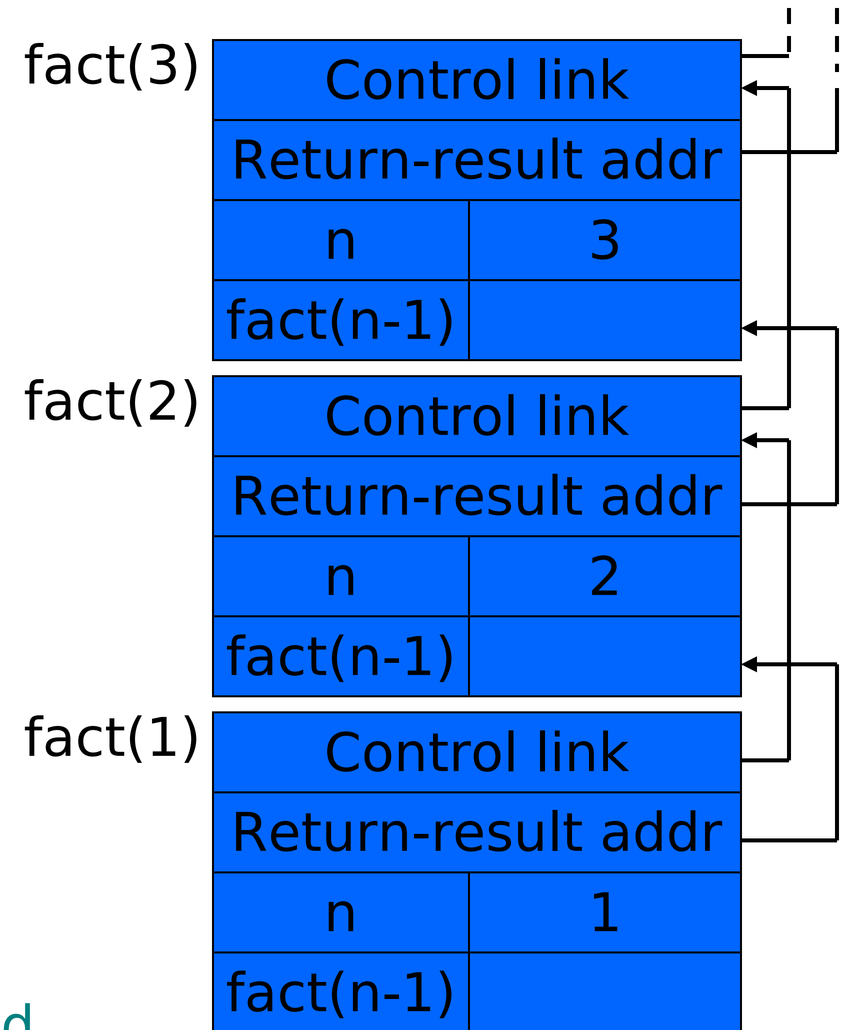
  fact(n) = if n<= 1 then 1

  else n * fact(n-1)

- Return result address
  - location to put fact(n)
- Parameter
  - set to value of n by calling sequence
- Intermediate result
  - locations to contain value of fact(n-1)

Function call



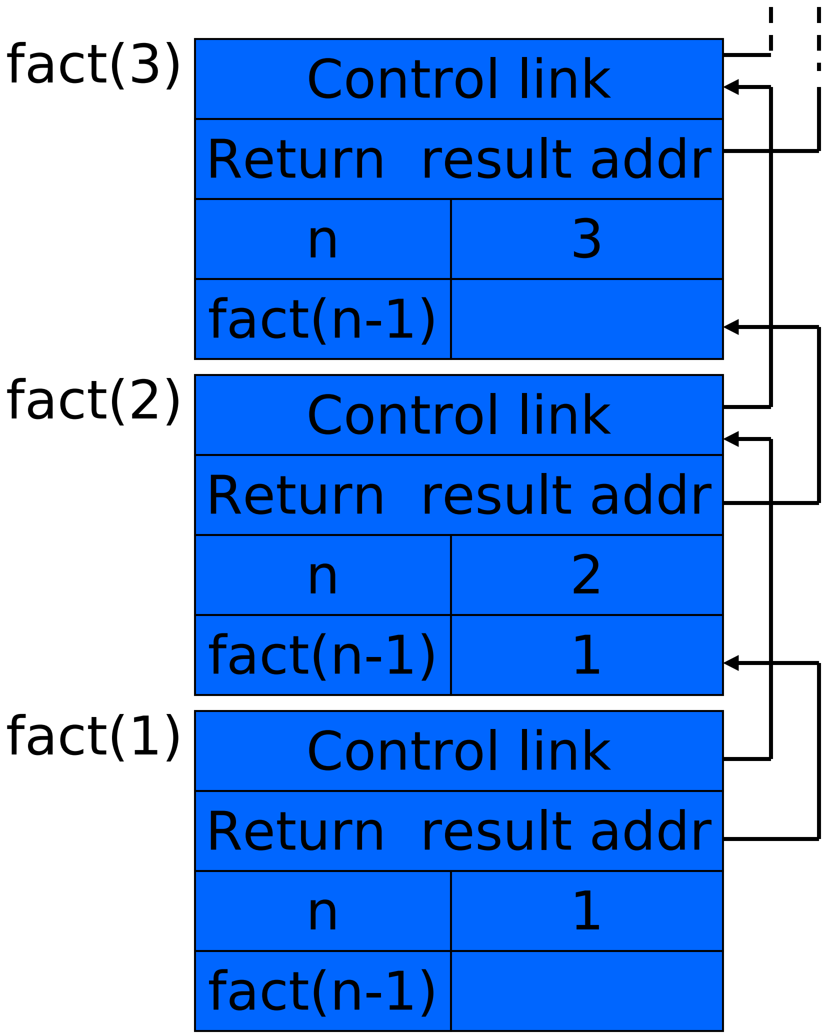


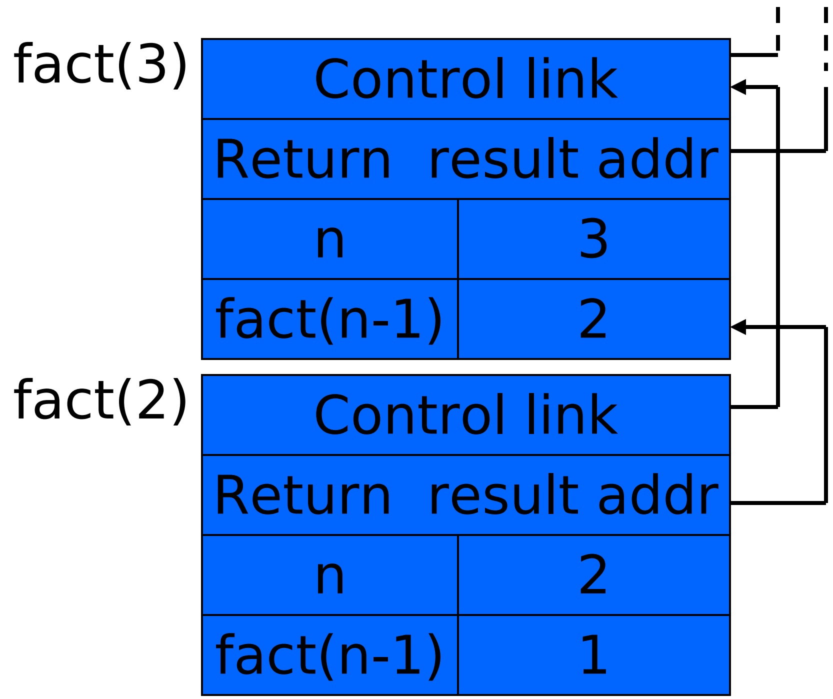
fact(n) = if n<= 1
then 1
else n * fact(n-1)

Return address omitted; would be ptr into code segment

Function return next slide →

Function return





fact(n) = if n<= 1
then 1
else n * fact(n-
1)

Topics for first-order functions

- Parameter passing
  - use ML reference cells to describe pass-by-value, pass-by-reference
- Access to global variables
  - global variables are contained in an activation record higher “up” the stack
- Tail recursion
  - an optimization for certain recursive functions

See this yourself: write factorial and run under debugger

ML imperative features (review)

- General terminology: L-values and R-values
  - Assignment y := x+3
    - Identifier on left refers to location, called its L-value
    - Identifier on right refers to contents, called R-value
- ML reference cells and assignment (anche in C++)
  - Different types for location and contents

    x : int non-assignable integer value

    y : int ref location whose contents must be integer

    !y the contents

    ref x expression creating new cell initialized to x
  - ML form of assignment

    y := x+3 place value of x+3 in location (cell) y

    y := !y + 3 add 3 to contents of y and store in location y

(in C++)

- Anche in C++ esistono i riferimenti:

- int y;

  int& x = y;

- Nota:

  References cannot be uninitialized. Because it is impossible to reinitialize a reference, they must be initialized as soon as they are created. In particular, local and global variables must be initialized where they are defined...
- Vedremo più avanti

Parameter passing

- Pass-by-reference
  - Caller places L-value (address) of actual parameter in activation record
  - Function can assign to variable that is passed
  - In some language is also call by variable
    - PASCAL:
      `procedure Name(a,b : integer;VAR c,d: integer);`
    - a and b are passed by value, c and d by reference
- Pass-by-value
  - Caller places R-value (contents) of actual parameter in activation record
  - Function cannot change value of caller’s variable
  - Reduces aliasing (alias: two names refer to same loc)

Example

pseudo-code

```
function f (x) =
    { x := x+1; return x
    };
var y : int = 0;
print f(y)+y;
```

Standard ML

pass-by-ref

```
fun  f (x : int ref) =
    ( x := !x+1;  !x  );
y = ref 0 : int ref;
f(y) + !y;
```

pass-by-value

```
fun f (z : int) =
    let x = ref z in
        x := !x+1; !x
    end;
y = ref 0 : int ref;
f(!y) + !y;
```

Example

pseudo-code

```
function f (x) =
    { x := x+1; return x
    };
var y : int = 0;
print f(y)+y;
```

pass-by-ref

pass-by-value

C++

```
int   f (int & x) {
      x = x+1;
      return x;
}
int y = 0;
cout<< f(y) + y;
```

```
int   f (int x) {
      x = x+1;
     return x;
}

int y = 0;
cout<< f(y) + y;
```

Passaggio di puntatori

- Il passaggio di puntatori è un passaggio per valore, ma si usa (in C) per ottenere lo stesso effetto del passaggio per riferimento.
- Es.:

```
int   f (int*  x) {
      *x = *x+1;
     return *x;
}

int y = 0;
printf(f(&y) + y;)
```

Se si vuole, si può evitare la modifica del parametro attuale mediante copia:

```
int   f (int*  x) {
     int z =  *x
     return z+1;
}

int y = 0;
printf(f(&y) + y;)
```

Passaggio degli array in C

- Come si passano gli array in C
- Si possono passare come array:
  - void foo(int arr[5])
  - When an array is passed as a parameter, only the memory address of the array is passed (not all the values). An array as a parameter is declared similarly to an array as a variable, but no bounds are specified. The function doesn't know how much space is allocated for an array. See the example below.
  - Ma arr è semplicemente un puntatore di interi, non c'è alcuna informazione sulla dimensione dell'array !!!
  - Attenzione quindi all'uso di **sizeof**
  - Vedi esempio !!!

Passaggio stringhe

- Esercizio

Passaggio di puntatori a puntatori

- Esercizio di passaggio di puntatore a puntatore
- Uso più frequente per modificare un puntatore.

PUNTATORE

```
int y = 10;

void styp(int* p) {
        p = &y;
}

int main(void) {
        int m = 0;
        int * q = &m;
        styp(q);
        printf("%d", *q);
        return EXIT_SUCCESS;
}
>> 0
```

– q punta ancora ad m

PUNTATORE a PUNTATORE

```
int y = 10;

void stypp(int** p) {
        *p = &y;
}

int main(void) {
        int m = 0;
        int * q = &m;
        stypp(&q);
        printf("%d", *q);
        return EXIT_SUCCESS;
}
>> 10
```

– q punta a y

Parameter passing & activation record

- pass by value: the value of the actual parameter is copied in the activation record as value of the formal parameter
  - Pass by pointer is a particular case
- pass by ref: the address of the actual parameter is copied in the activation record

Osservazioni

- Il passaggio per riferimento ha alcuni vantaggi
  - Meno memoria (pensa ad un oggetto)
- però alcuni svantaggi:
  - Indirezione ulteriore sullo stack
  - Side effect non desiderati – vedi esercio sul libro
  - Vedi es 7.4
  - Come passare le costanti??
  - Solo L-values, non posso passare Rvalue
  - Posso modificare il dato passato
- Passaggio per nome: il nome del par. Formale viene sostituito con il par. Attuale
  - Vedi esercizio 5.2
- Fate esercizi 7.3, 7.5, 7.6. 7.7 7.8

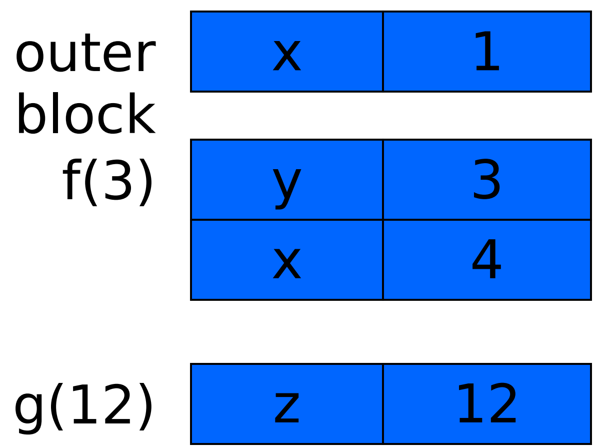
Passing parameters in Java

- Pass by value for primitive types
- Pass by reference for reference types (Objects, arrays, ...)
- NOT possible by value for Objects as in C++

Access to global variables

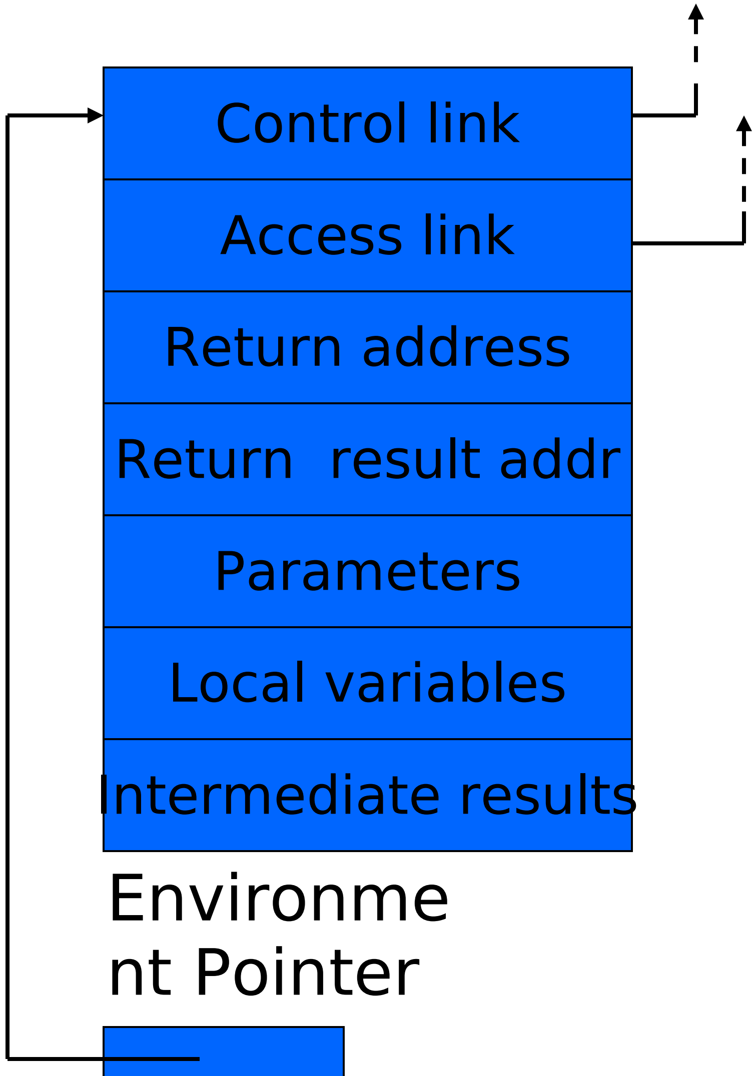
- Two possible scoping conventions
  - Static scope: refer to closest enclosing block
  - Dynamic scope: most recent activation record on stack
- Example

```
int x=1;
function g(z) = x+z;
function f(y) =
    { int x = y+1;
      return g(y*x) };
f(3);
```



Which x is used for expression x+z ?

Activation record for static scope



- Control (dynamic) link
  - Link to activation record of previous (calling) block
- Access (static) link
  - Link to activation record of closest enclosing block in program text
- Difference
  - Control link depends on dynamic behavior of prog
  - Access link depends on static form of program text

Ricorsione

- Una funzione matematica è definita ricorsivamente quando nella sua definizione compare un riferimento (chiamata) a se stessa.
- Esempio: Funzione fattoriale su interi non negativi:

  f(n) = n!

  definita ricorsivamente come segue:

  1 se n=0

  f(n)= n*f(n-1) se n>0

Esempi di problemi ricorsivi:

1) Somma dei primi n numeri naturali:

- somma(n)= 0 se n=0
- n+somma(n-1) altrimenti

2) Ricerca di un elemento el in una sequenza di interi:

- falso se sequenza terminata, altrimenti
- ricerca(el,sequenza)=vero se el=primo(sequenza), altrimenti
- ricerca(el,resto(sequenza))=

Programmi ricorsivi

- Molti linguaggi di programmazione offrono la possibilità di definire funzioni/procedure ricorsive.
- Calcolo del fattoriale di un numero:

```
int fattoriale(unsigned int n){
if (n<=1) return 1;
else return n*fattoriale(n-1);
}
```

Esempi (2)

- Alcune volte è necessario “complicare” la segnatura del metodo per renderelo ricorsivo:
- Ricerca di un elemento in un array (Java)

```
// cerca x in array a a partire dalla posizione pos
boolean search(int x, int[] a, int pos){
  if(pos >= a.length) return false;
  if(a[pos] == x) return true;
  // non trovato nella posizione pos vai alla prossima
  return search(x,a,pos+1);
}
```

Esempi (2 in C)

- In C spesso si passa anche la dimensione dell'array
- Ricerca di un elemento in un array (C)
- Array passato come puntatore

```
// cerca x in array a con lunghezza n
int search(int x, int* a, int n){
  if(n == 0) return 0;
  if(a[0] == x) return 1;
  // non trovato nella posizione a[0] vai alla prossima
  return search(x,a+1,n-1);
}
```

Tail recursion (first-order case)

- Function g makes a *tail call* to function f if
  - Return value of function f is return value of g
- Example

tail call　　　　　　　　　　　　not a tail call

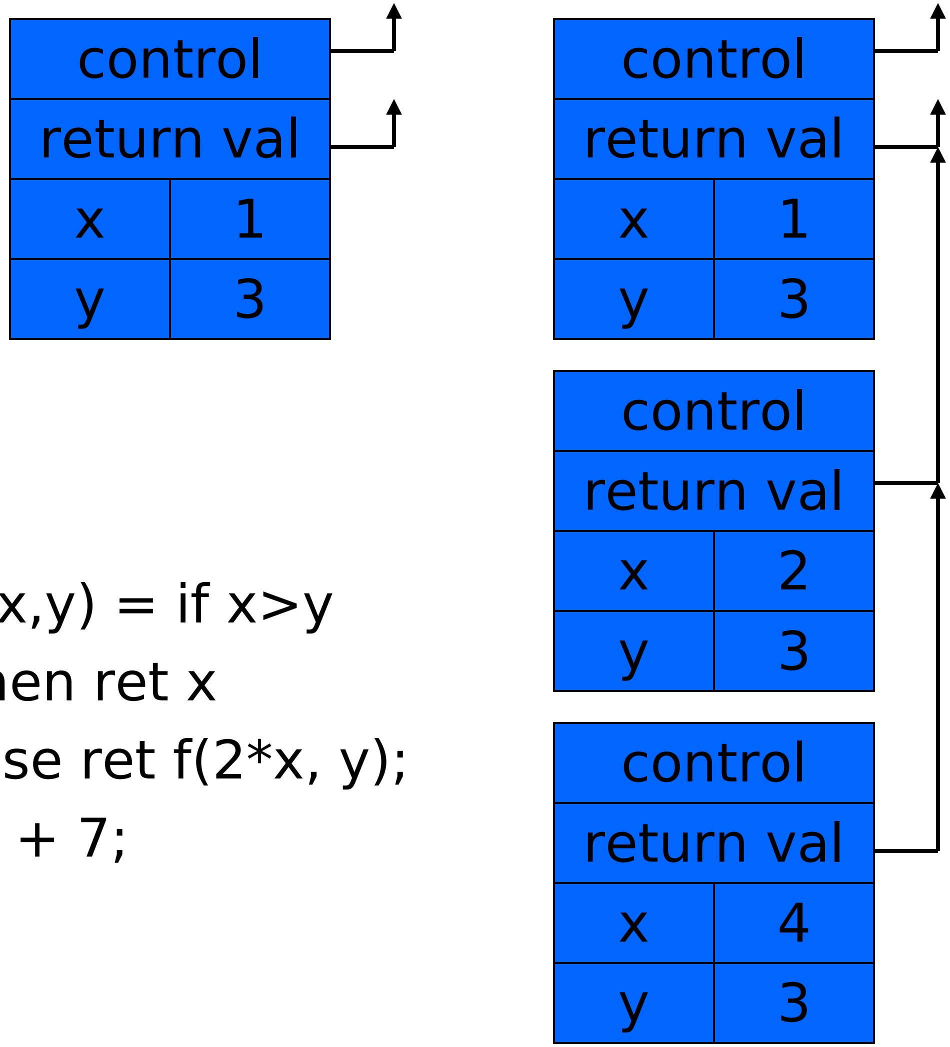
```
fun g(x) = if x>0 then return f(x) else return f(x)*2
```

- Optimization
  - Can pop activation record on a tail call
  - Especially useful for recursive tail call
    - next activation record has exactly same form

Example

Calculate least power of 2 greater than y

f(1,3)




```
fun f(x,y) = if x>y
        then ret x
        else ret f(2*x, y);
f(1,3) + 7;
```

Optimization

- Set return value address to that of caller

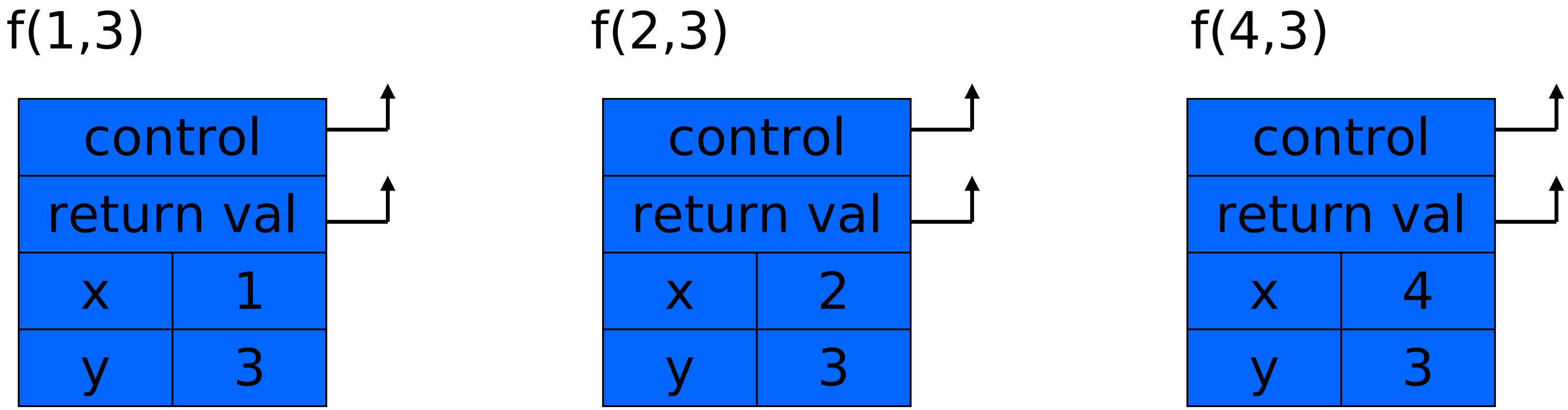
Question

- Can we do the same with control link?

Optimization

- avoid return to caller

Tail recursion elimination




```
fun f(x,y) = if x>y
      then x
      else f(2*x, y);
f(1,3);
```

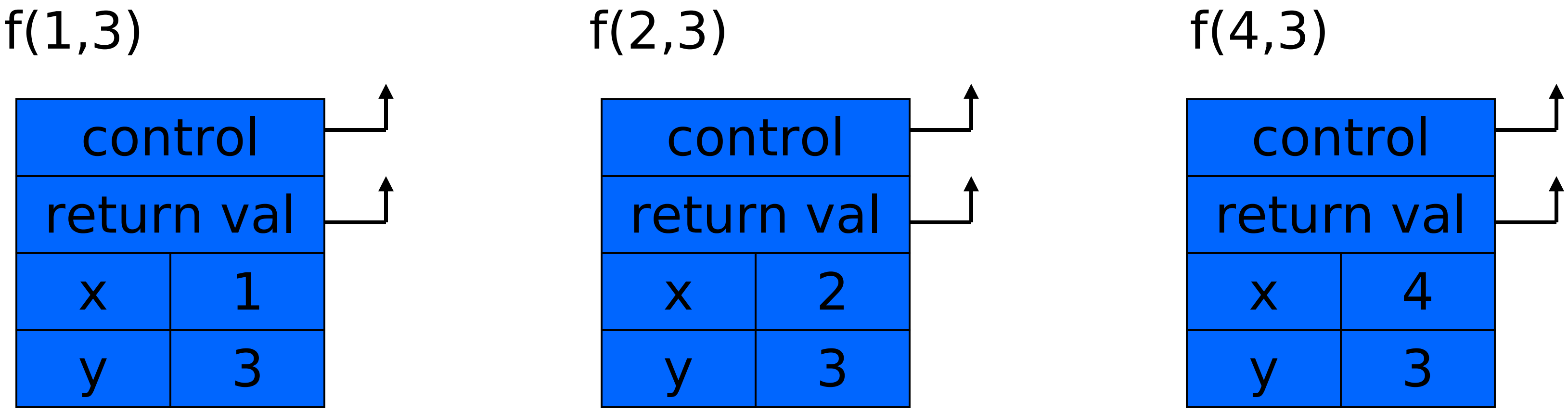
Optimization

- pop followed by push = reuse activation record in place

Conclusion

- Tail recursive function equiv to iterative loop

Tail recursion and iteration




```
fun f(x,y) = if x>y
      then x
      else f(2*x, y);
f(1,y);
```

```
fun g(y)  = {
    x := 1;
    while not(x>y) do
        x := 2*x;
    return x;
};
```

test

loop body

initial value

Higher-Order Functions

- Language features
  - Functions passed as arguments
  - Functions that return functions from nested blocks
  - Need to maintain environment of function
- Simpler case
  - Function passed as argument
  - Need pointer to activation record “higher up” in stack
- More complicated second case
  - Function returned as result of function call
  - Need to keep activation record of returning function

Summary of scope issues

- Block-structured lang uses stack of activ records
  - Activation records contain parameters, local vars, …
  - Also pointers to enclosing scope
- Several different parameter passing mechanisms
- Tail calls may be optimized
- Function parameters/results require closures
  - Closure environment pointer used on function call
  - Stack deallocation may fail if function returned from call
  - Closures *not* needed if functions not in nested blocks