Scope, Function Calls and Storage Management

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capitolo 7 del
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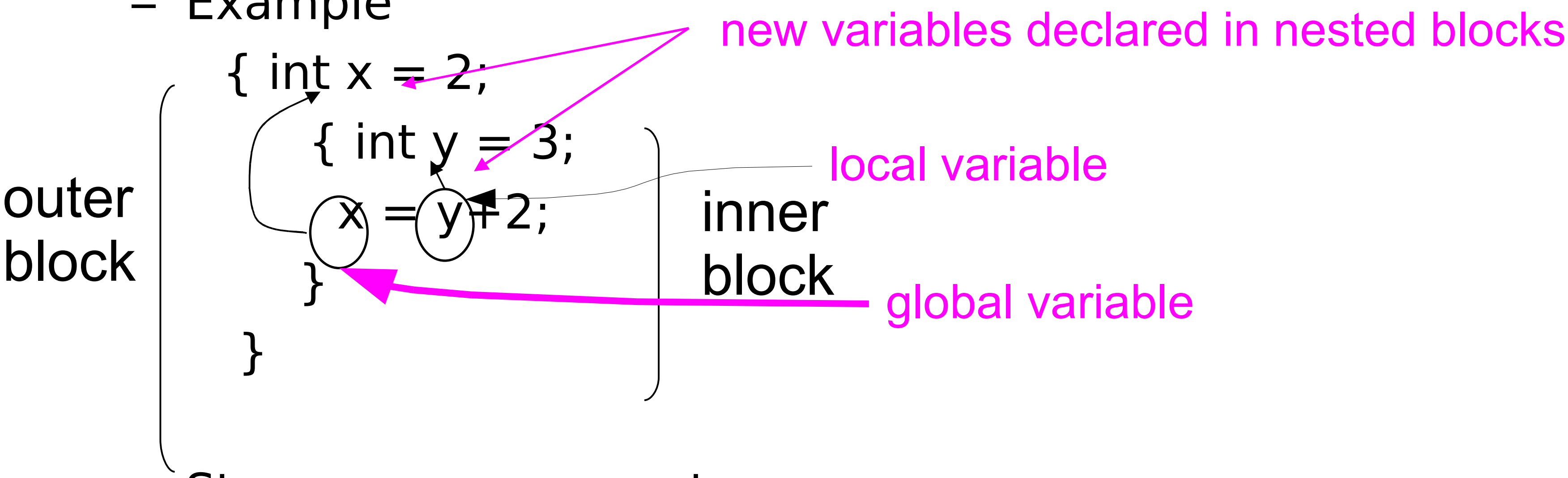
Topics

- 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
- Higher-order functions
  - deviations from stack discipline
  - language expressiveness => implementation complexity

Block-Structured Languages

- Nested blocks, local variables
  - Example

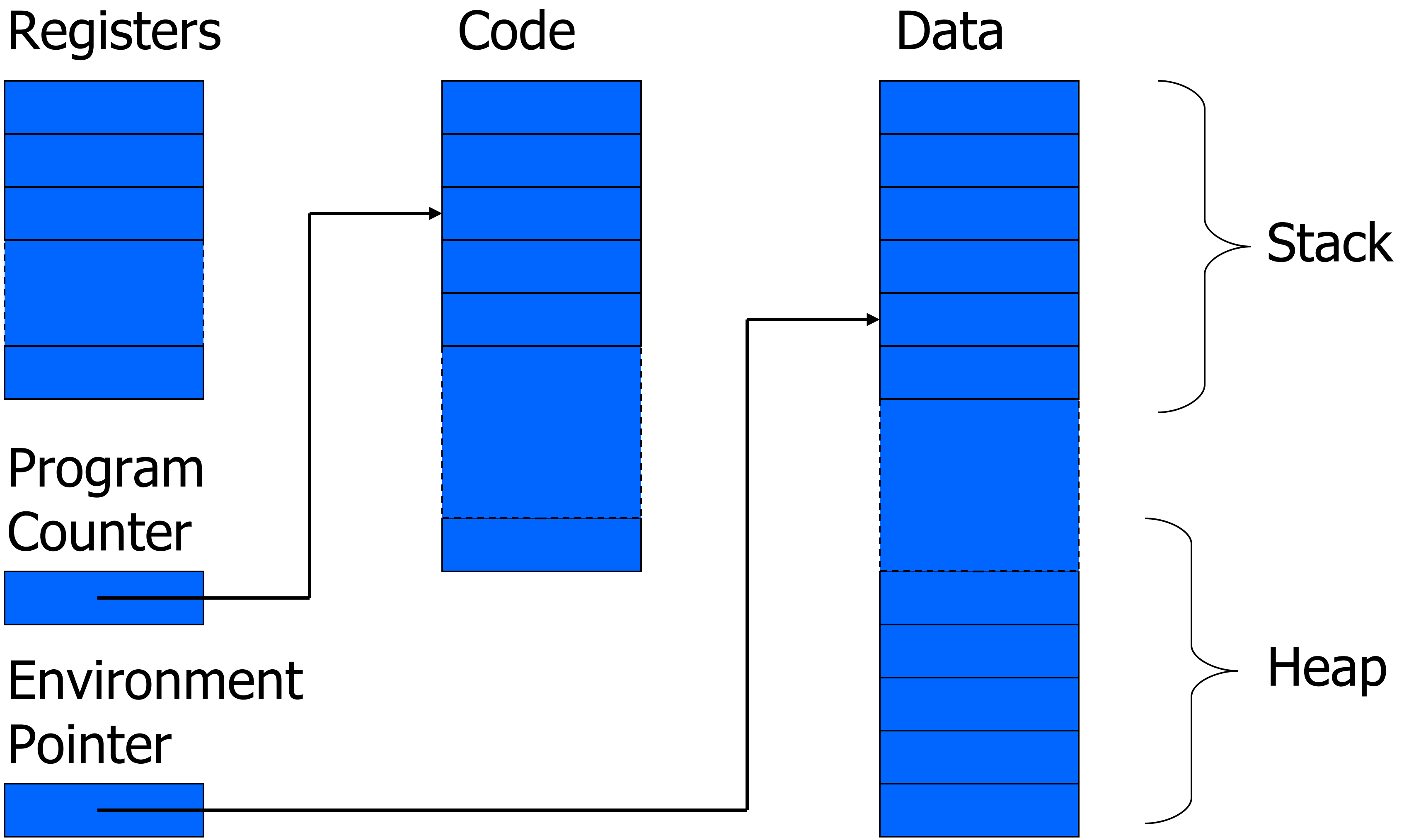


  - Storage management
    - Enter block: allocate space for variables
    - Exits block: some or all space may be deallocated

Examples

- Blocks in common languages
  - C/c++/Java { … }
  - Algol begin … end
  - ML let … in … end
- Two forms of blocks
  - In-line blocks
  - Blocks associated with functions or procedures
- Topic: block-based memory management, access to *local variables*, *parameters*,*global vars*
- It allows **recursive functions**

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 ≠ scope
- Lines indicate “contour model” of scope.

In-line Blocks

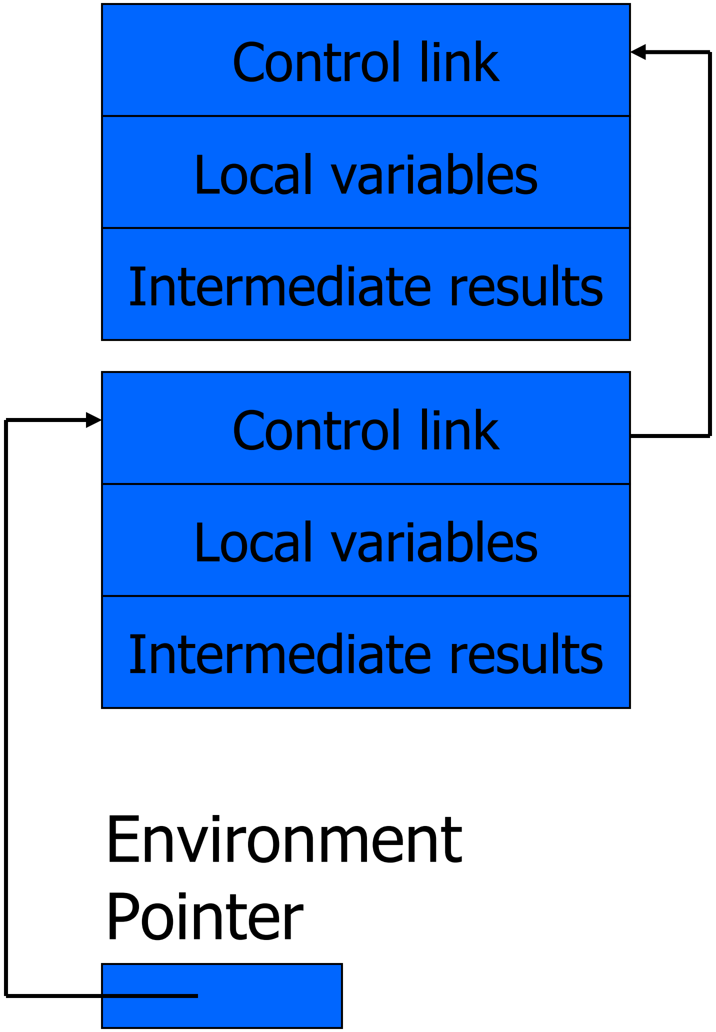
- Activation record
  - Data structure stored on run-time stack
  - Contains space for local variables
- Example

```
{ 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

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

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)

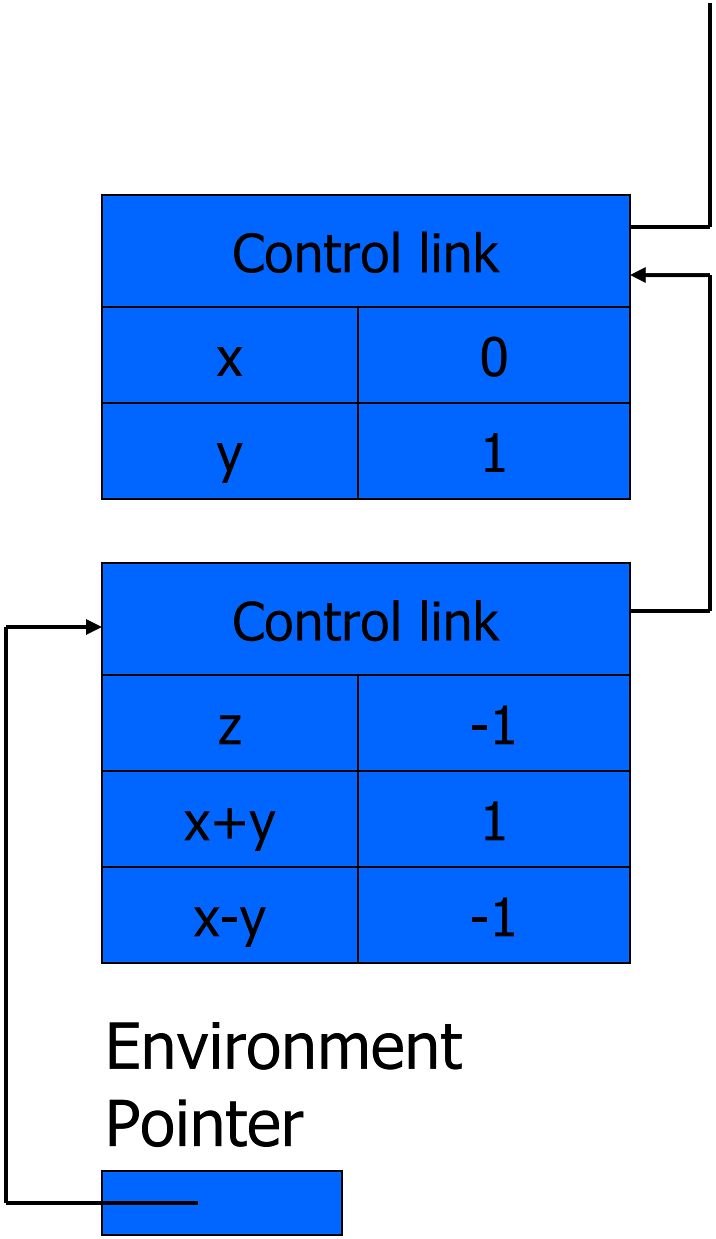
Set values of x, y

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

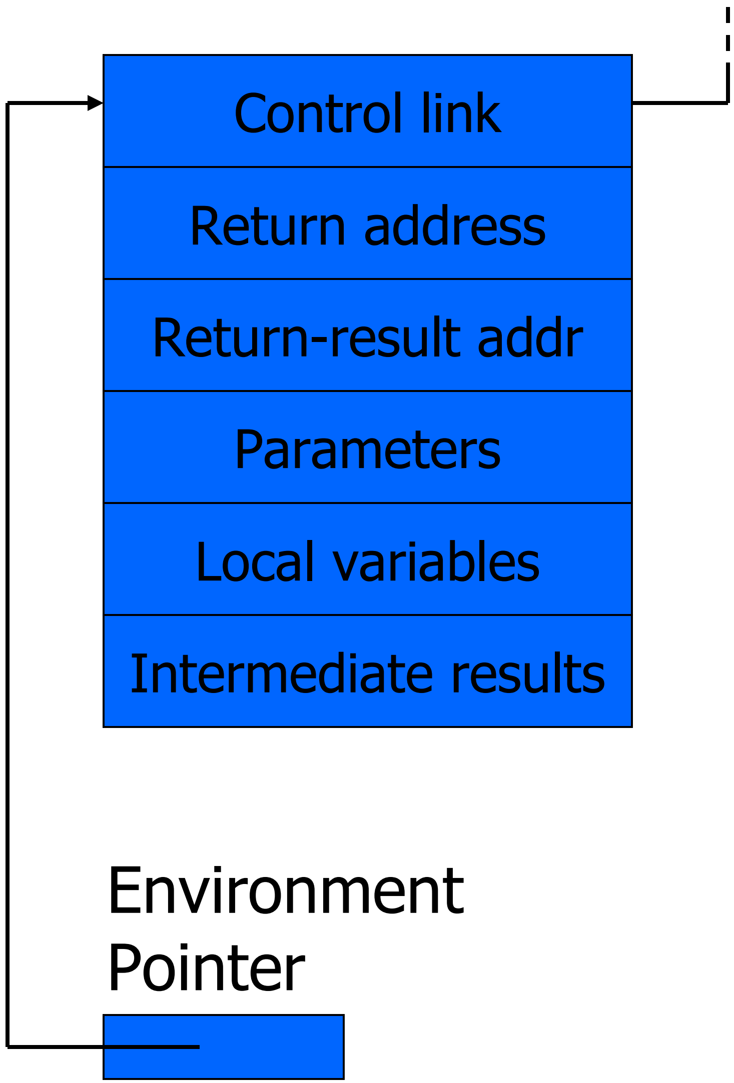
Functions and procedures

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

```
procedure P (<pars>)              <type> function f(<pars>)
    begin                            {
        <local vars>                     <local vars>
        <proc body>                      <function body>
    end;                           };
```

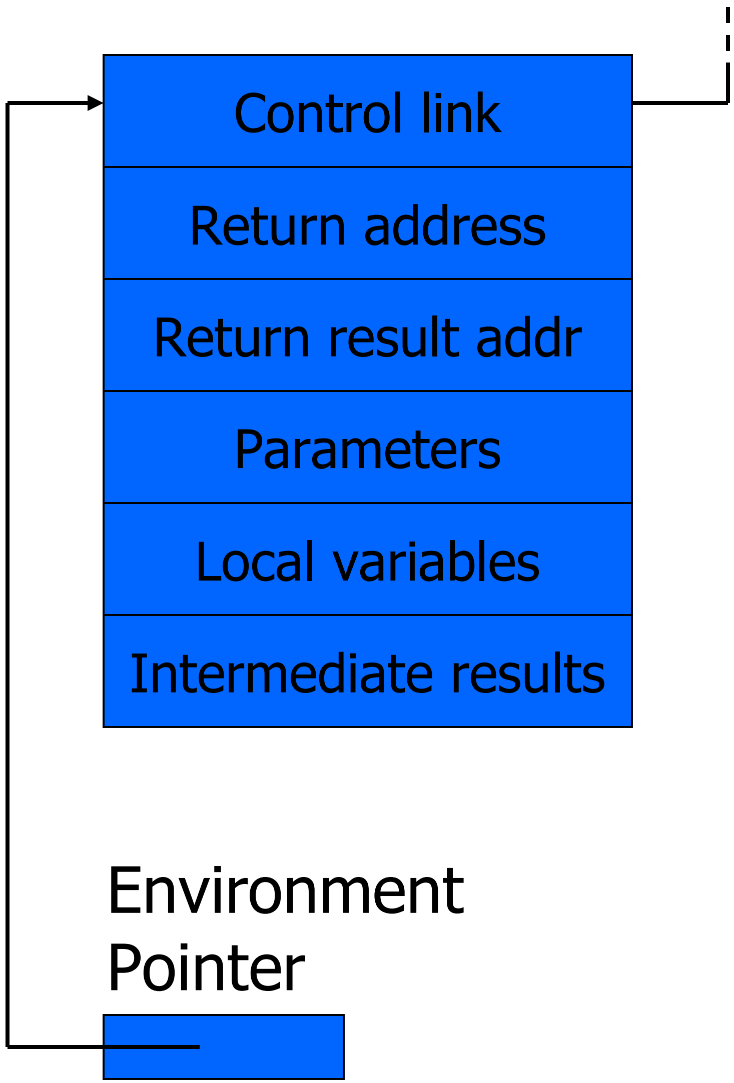
- Activation record must include space for
  - parameters
  - return address
  - return value
    (and intermediate result)
  - location to put return value on function exit

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

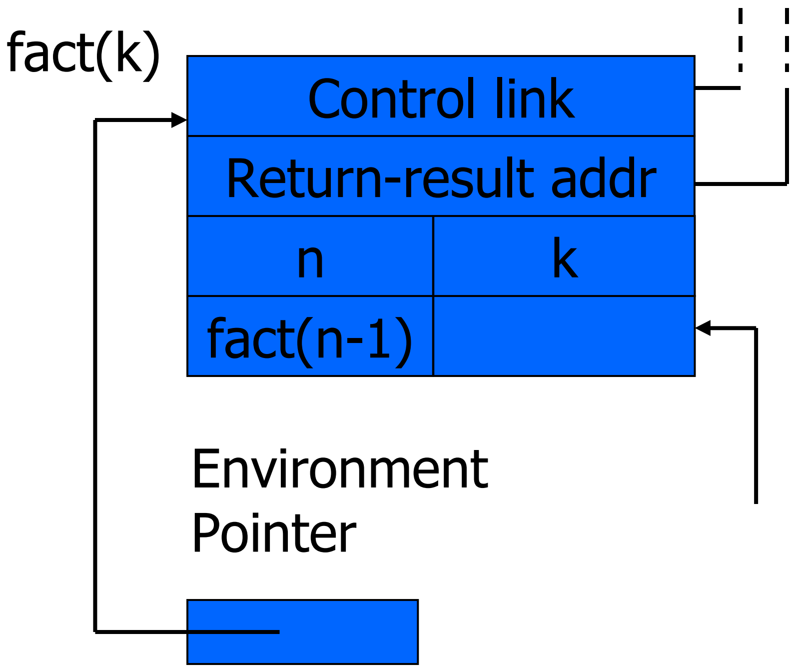


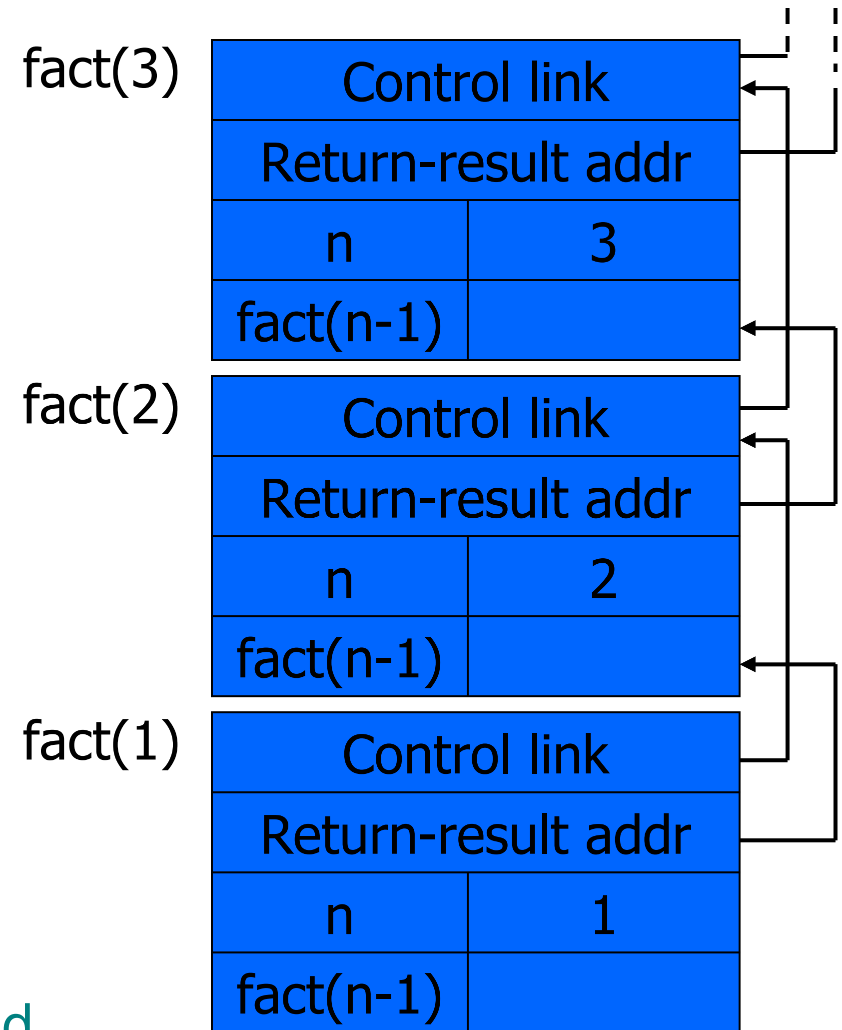
- Function

  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



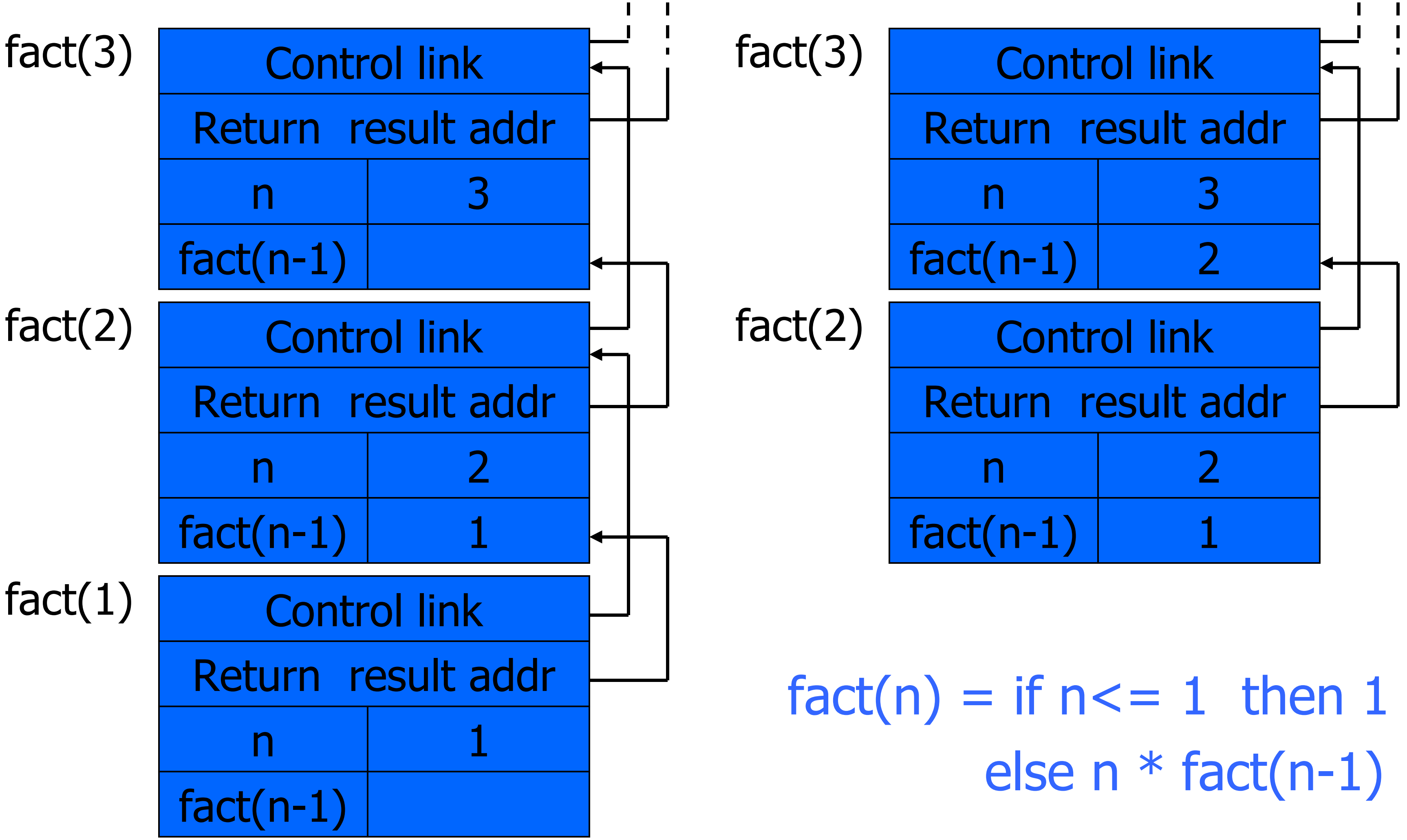


fact(n) = if n<= 1 then 1
else n * fact(n-1)

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

Parameter passing

- Pass-by-reference
  - Caller places L-value (address) of actual parameter in activation record
  - Function can assign to variable that is passed
- 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;
```

pass-by-ref

Standard ML

```
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;)
```

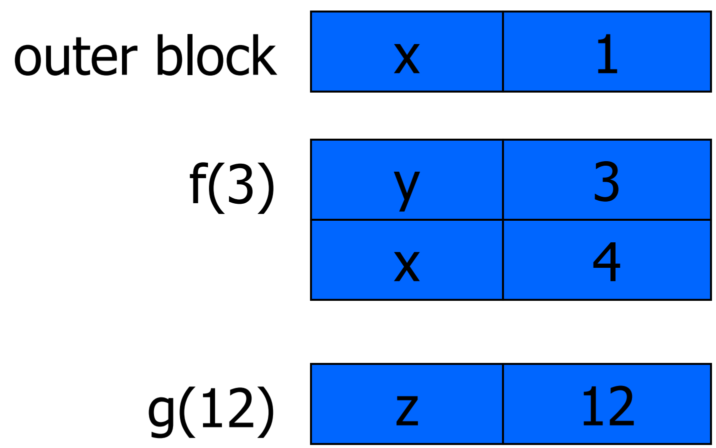
Parameter passing & activation record

- pass by value: the value of the actual parameter is copied in the activation record as value of the formal parameter
- pass by ref: the address of the actual parameter is copied in the activation record

Access to global variables

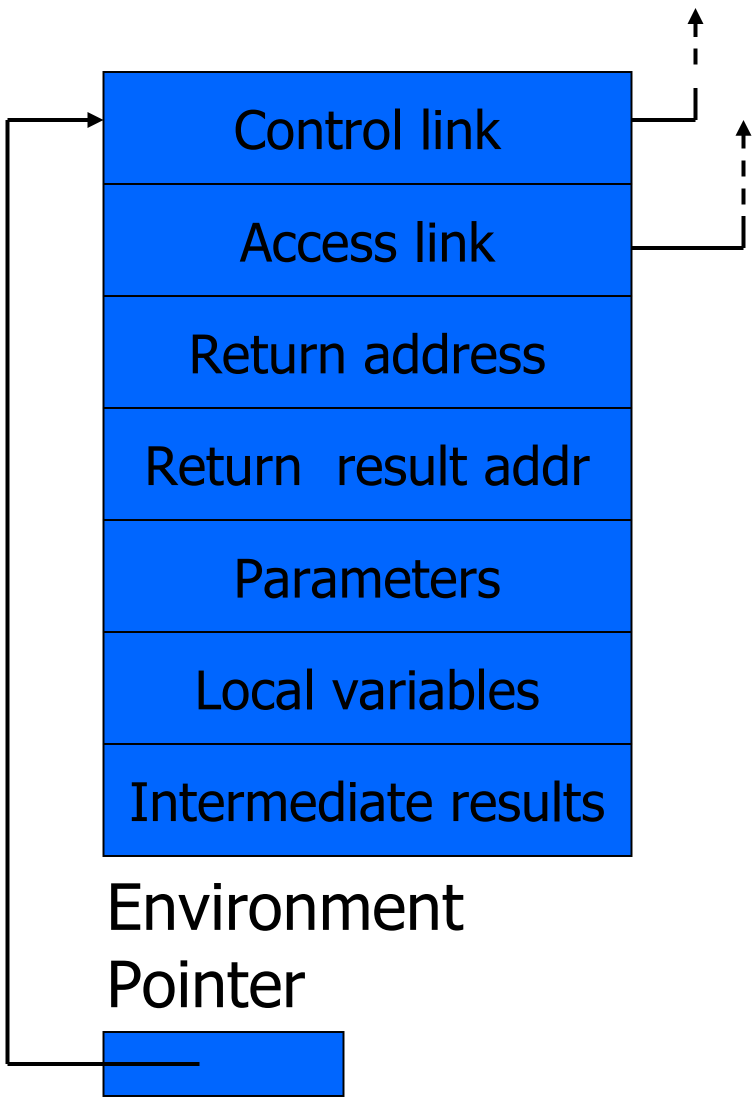
- Two possible scoping conventions
  - Static scope: refer to closest enclosing block
  - Dynamic scope: most recent activation record on stack
- Example

```
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

Complex nesting structure

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

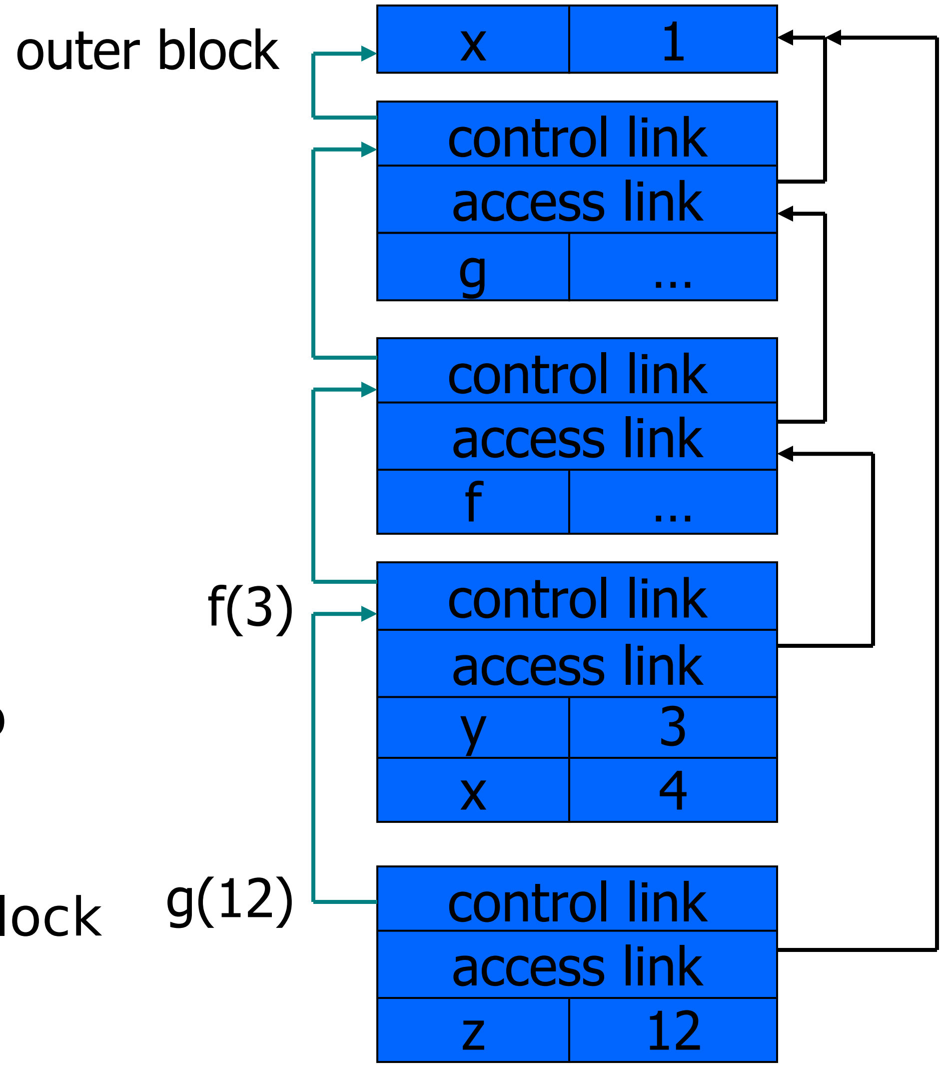
Simplify to

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

Simplified code has same block nesting, if we follow convention that each declaration begins a new block.

Static scope with access links

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



Use access link to find global variable:

- Access link is always set to frame of closest enclosing lexical block
- For function body, this is block that contains function declaration

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

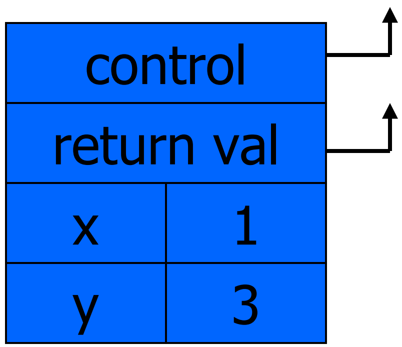
```
fun g(x) = if x>0 then return f(x) else return f(x)*2
```

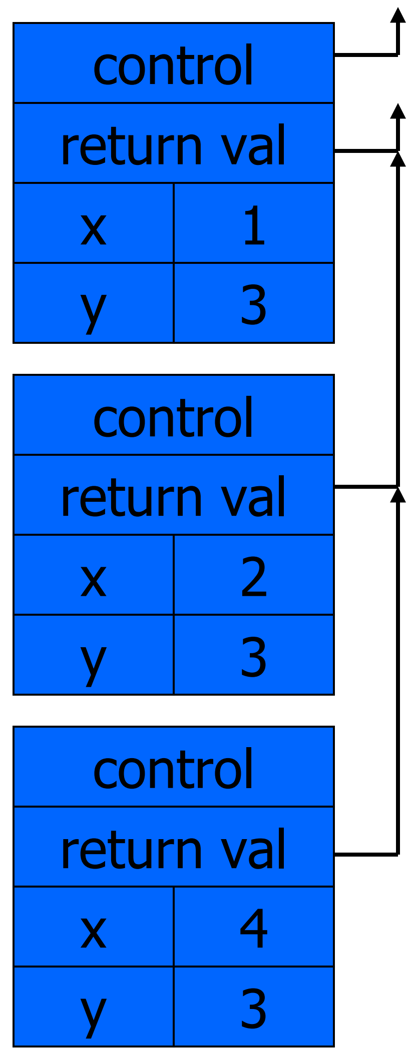
- Optimization
  - Can pop activation record on a tail call
  - Especially useful for recursive tail call
    - next activation record has exactly same form

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

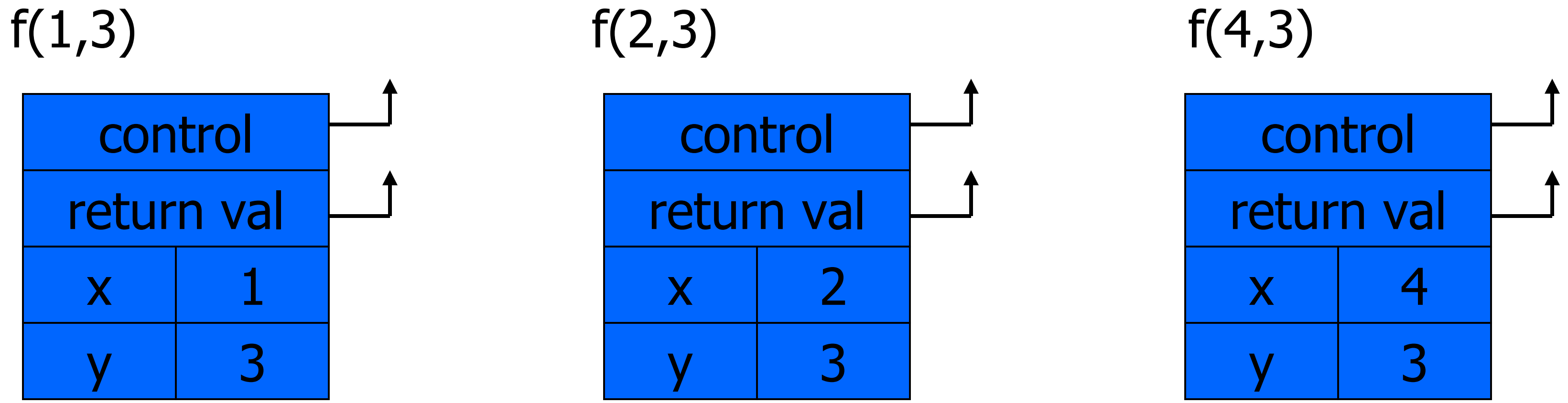
Question

- 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);
```

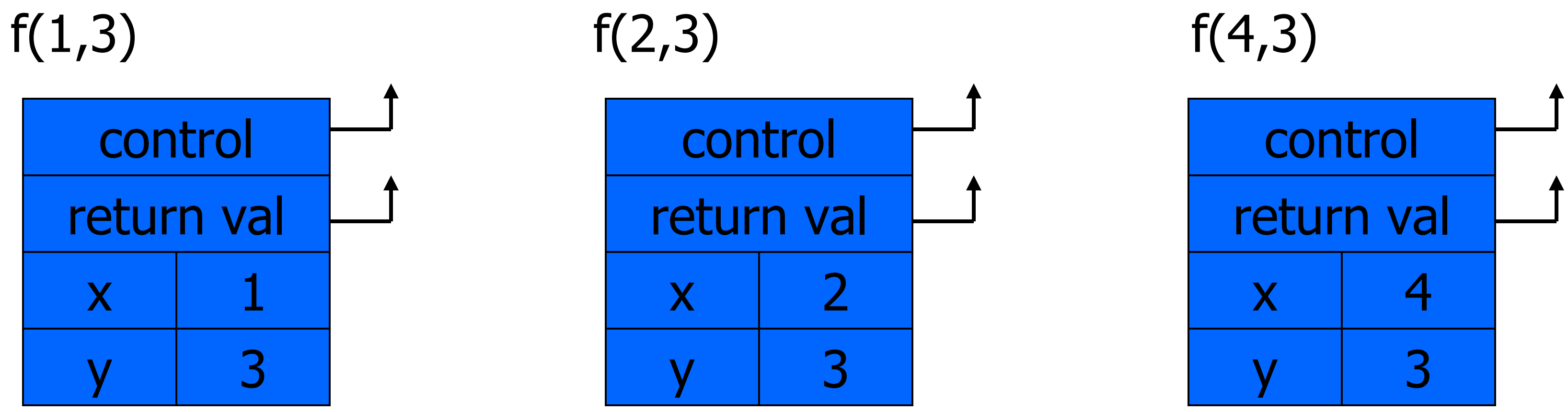
Optimization

- 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