

Scope, Function Calls and Storage Management

Lecture 10

Topics

◆ Block-structured languages and stack storage

- activation records
- storage for local, global variables

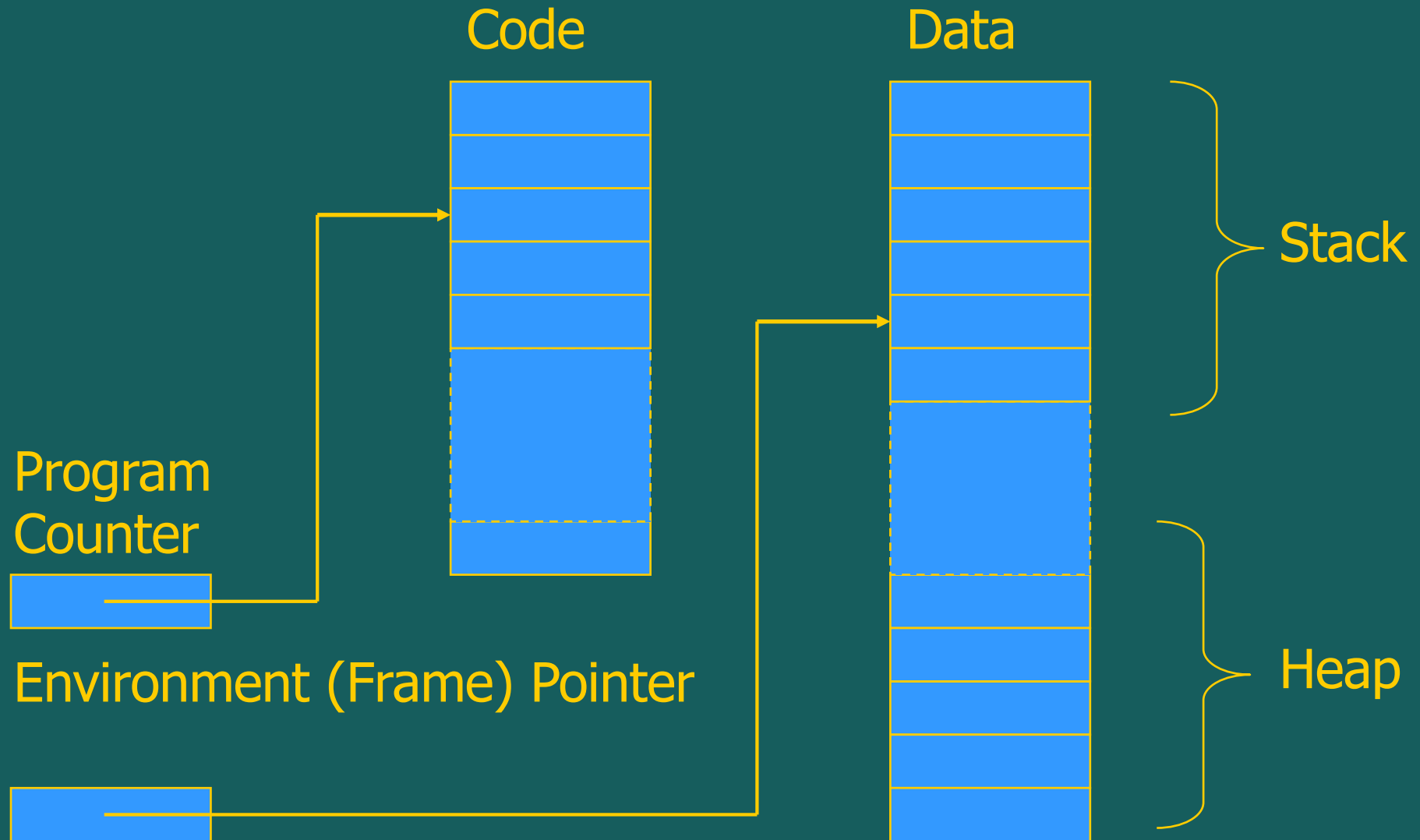
◆ First-order functions

- parameter passing (later)
- tail recursion and iteration

◆ Higher-order functions

- deviations from stack discipline
- language expressiveness => implementation complexity

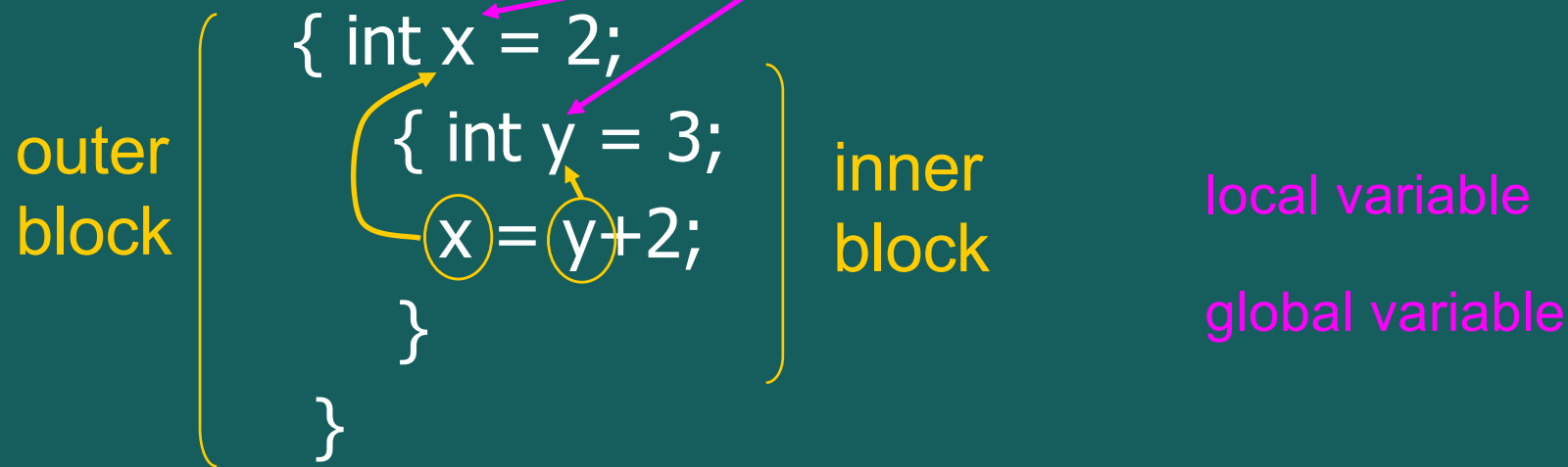
Simplified Machine Model



Block-Structured Languages

◆ Nested blocks, local variables

- Example



- Storage management

- Enter block: allocate space for variables
- Exits block: deallocate the space

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 = ... ;  
      ....  
    };  
  };  
};
```

A B C

- 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.

Example

```
let
  val x = 0
  val y = x + 1
in let val z = (x+y)*(x-y)
  in z
  end
end
```

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

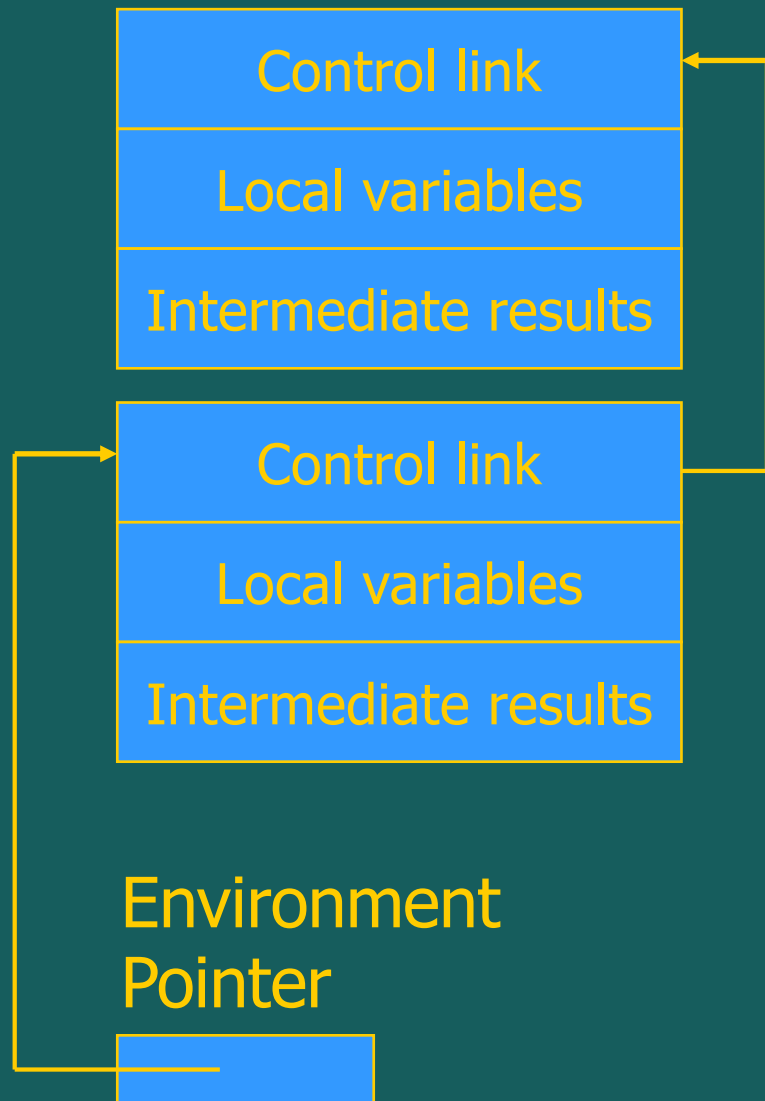
Set value of z

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 values of x, y

Push record for inner block

Set value of z

Pop record for inner block

Pop record for outer block

Control link	
x	0
y	1

Control link	
z	-1
x+y	1
x-y	-1

Environment
Pointer



Scoping rules

◆ Global and local variables

- x, y are local to outer block
- z is local to inner block
- x, y are global to inner block

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

◆ Static scope

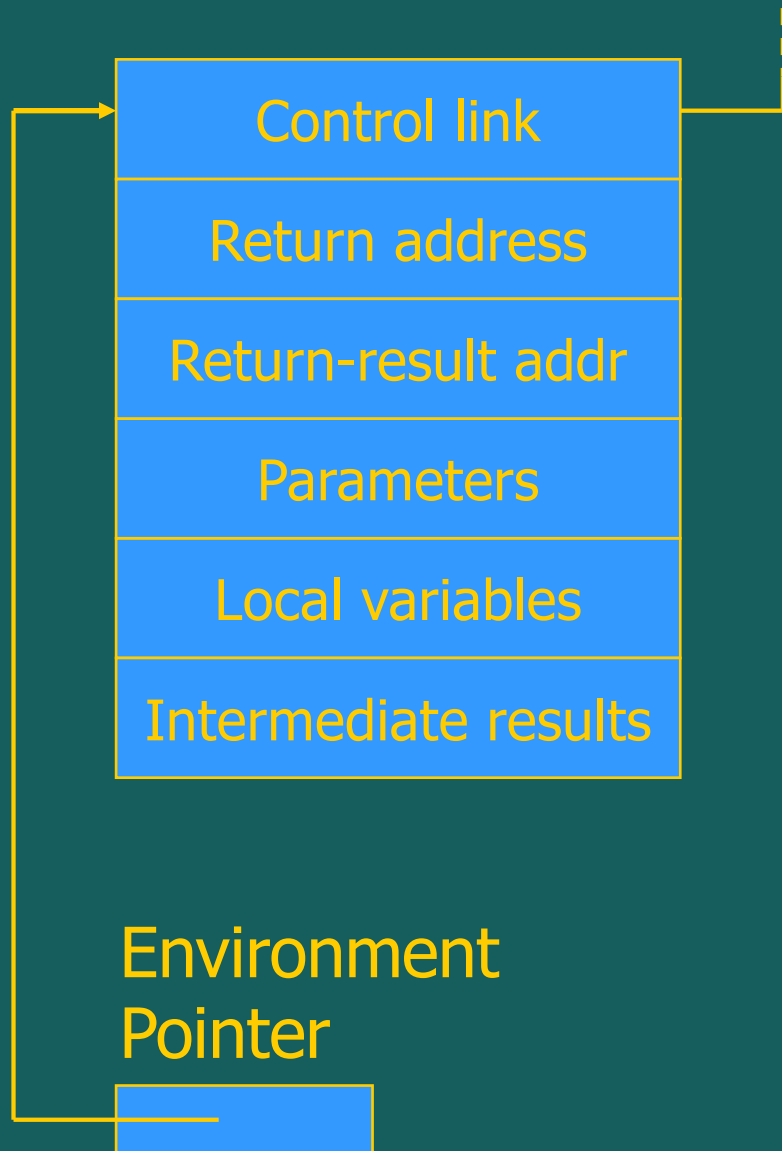
- global refers to declaration in closest enclosing block

◆ Dynamic scope

- global refers to most recent activation record

These are same until we consider function calls.

Activation record for function



◆ Return address

- Location of code to execute on function return

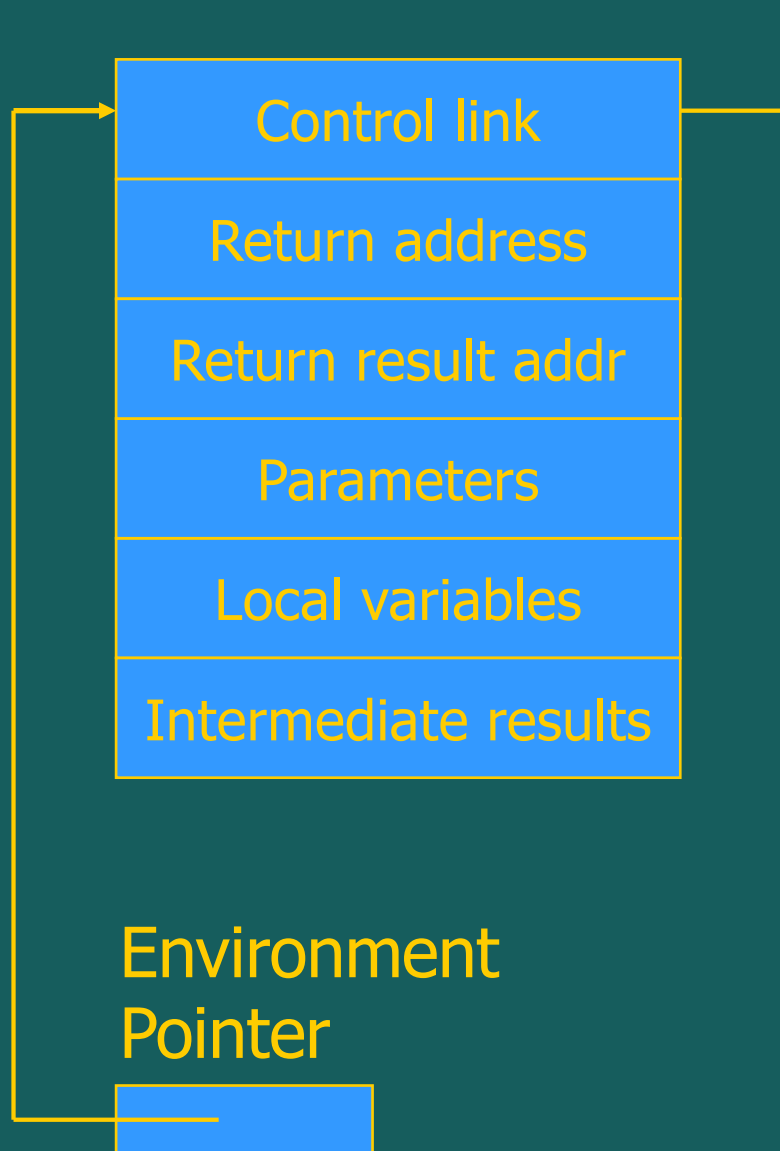
◆ Return-result address

- Address in activation record of calling block to receive return address

◆ Parameters

- Locations to contain data from calling block

Example



◆ Function

$\text{fact}(n) = \text{if } n \leq 1 \text{ then } 1$
 $\text{else } n * \text{fact}(n-1)$

- Return result address
- location to put $\text{fact}(n)$

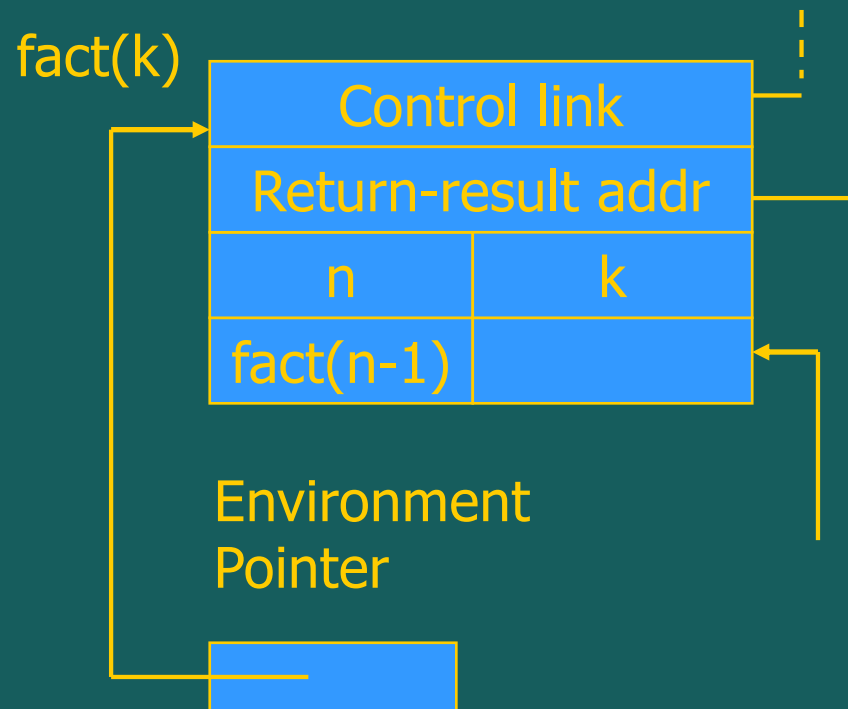
◆ Parameter

- set to value of n by calling sequence

◆ Intermediate result

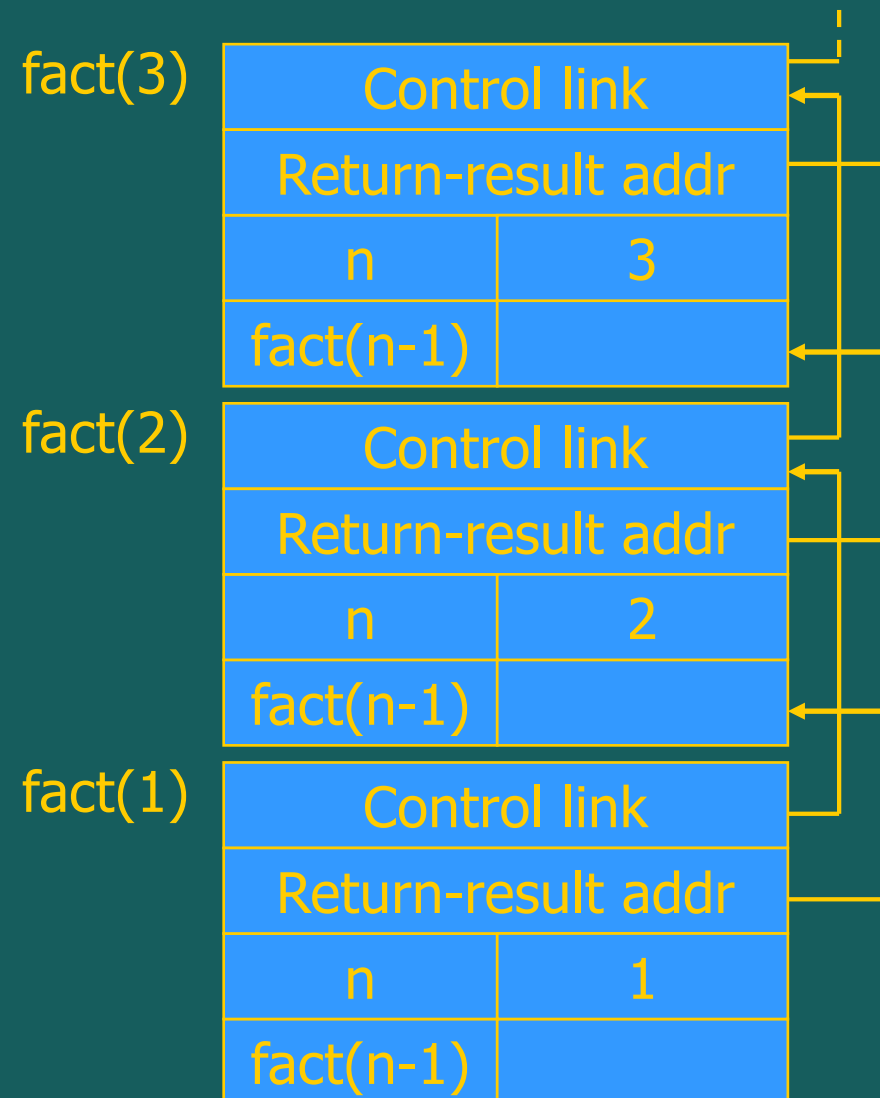
- locations to contain value of $\text{fact}(n-1)$

Function call



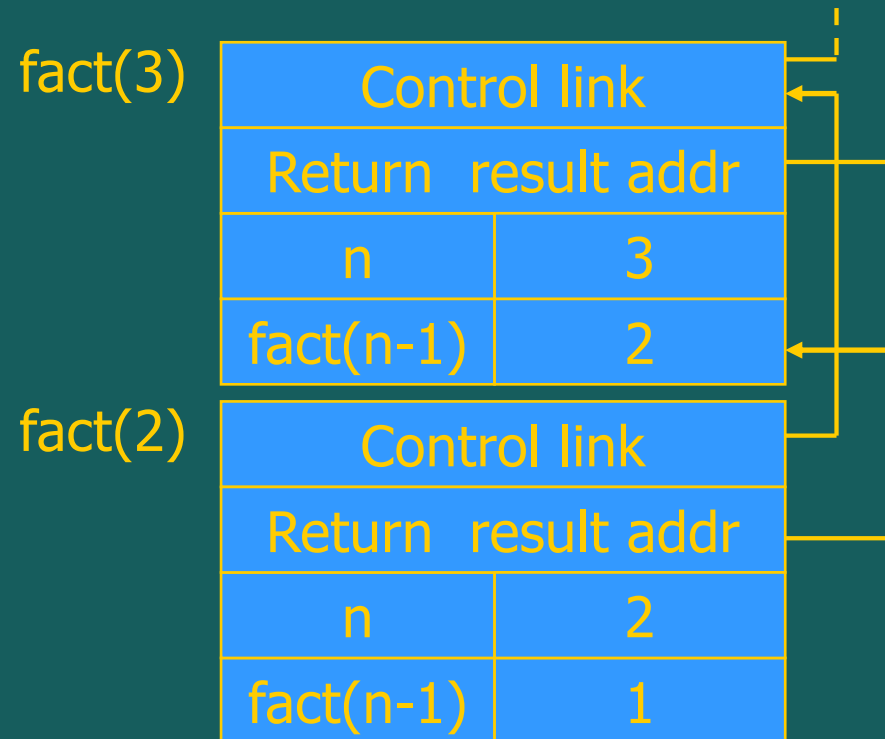
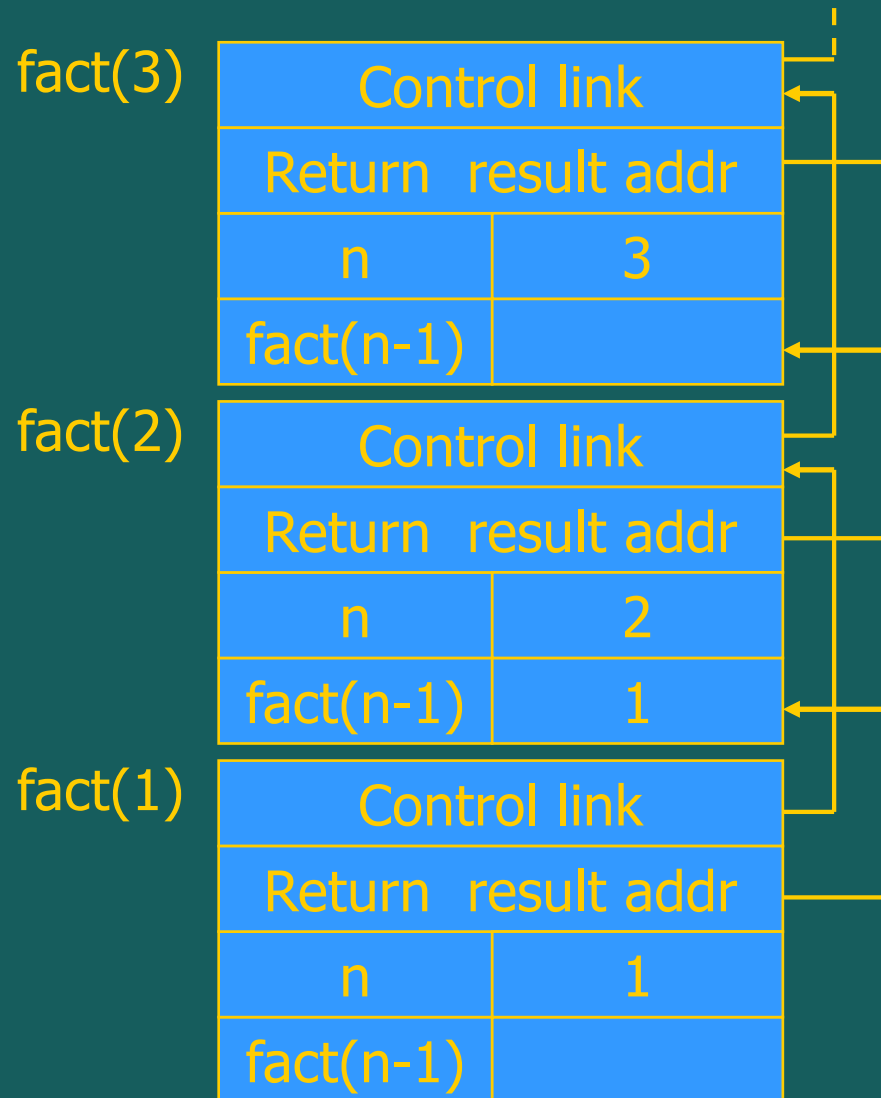
fact(n) = if $n \leq 1$ then 1
else $n * \text{fact}(n-1)$

Return address omitted; would
be ptr into code segment



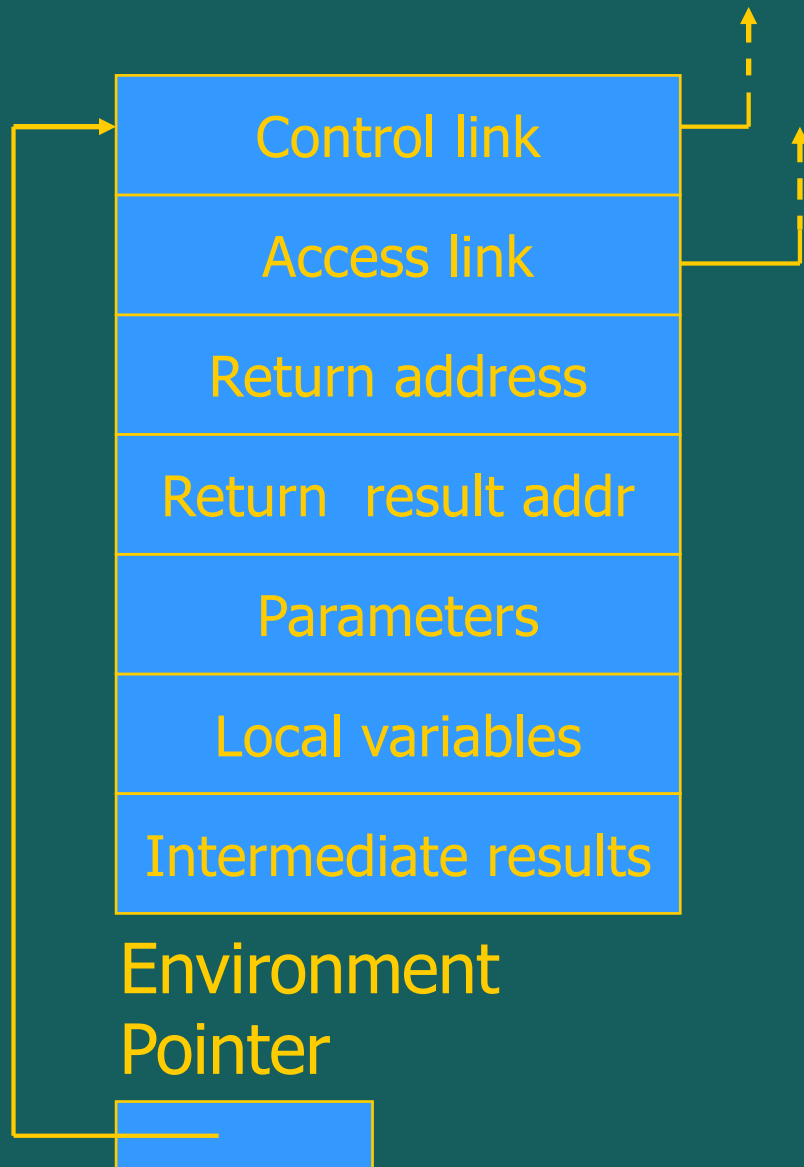
Function return next slide →

Function return



$\text{fact}(n) = \text{if } n \leq 1 \text{ then } 1$
 $\text{else } n * \text{fact}(n-1)$

Activation record for static scope



◆ Control link

- Link to activation record of previous (calling) block

◆ Access 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

Access to global variables

◆ Two possible scoping conventions

- Static scope: refer to closest enclosing block
- Dynamic scope: most recent activation record on stack

◆ Example

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

outer block

x	1
---	---

f(3)

y	3
x	4

g(12)

z	12
---	----

Which x is used for expression x+z ?

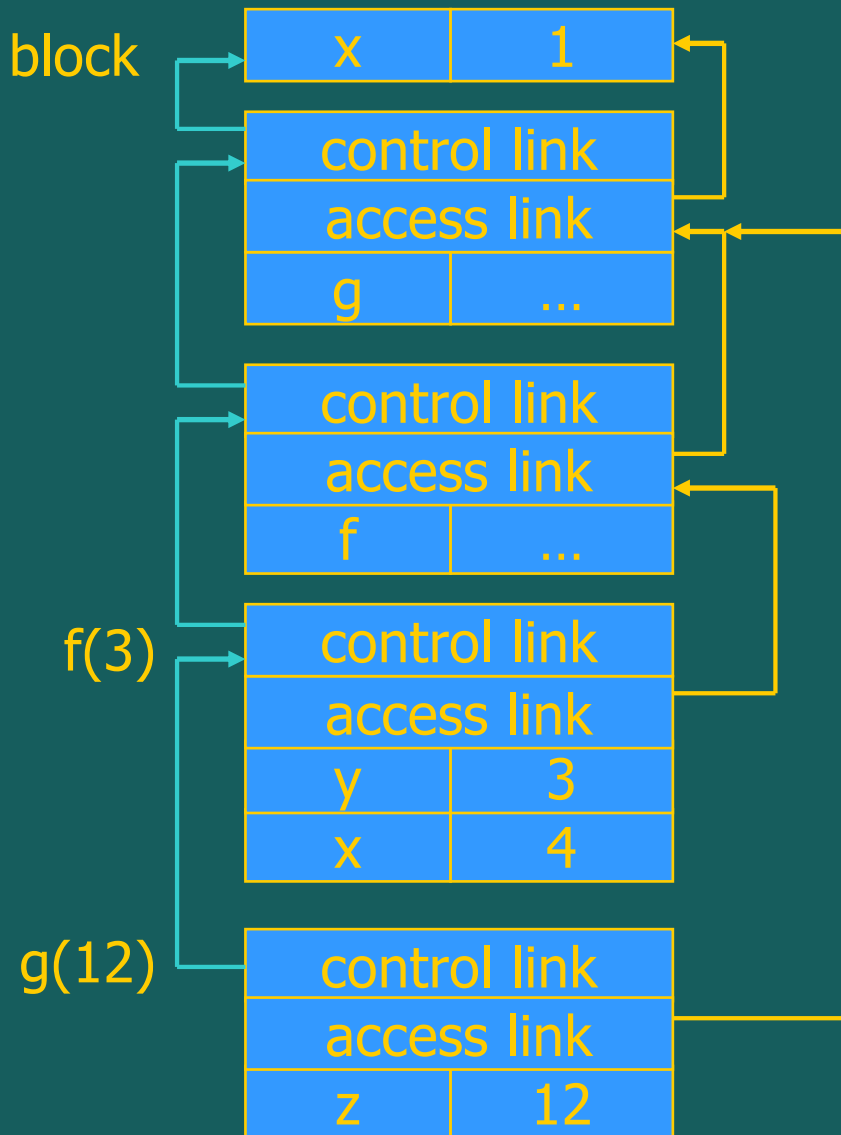
Static scope with access links

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

outer block



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

Pass function as argument

JavaScript

```
let val x = 4 in
  let fun f(y) = x*y in
    let fun g(h) = let
      val x=7
      in
        h(3) + x end
    in g(f) end end end
```

```
{ let x = 4;
  { function f(y) {return x*y};
    { function g(h) {let x=3;
      return h(3) + x;
    };
    g(f);
  }
}
```

There are two declarations of **x**

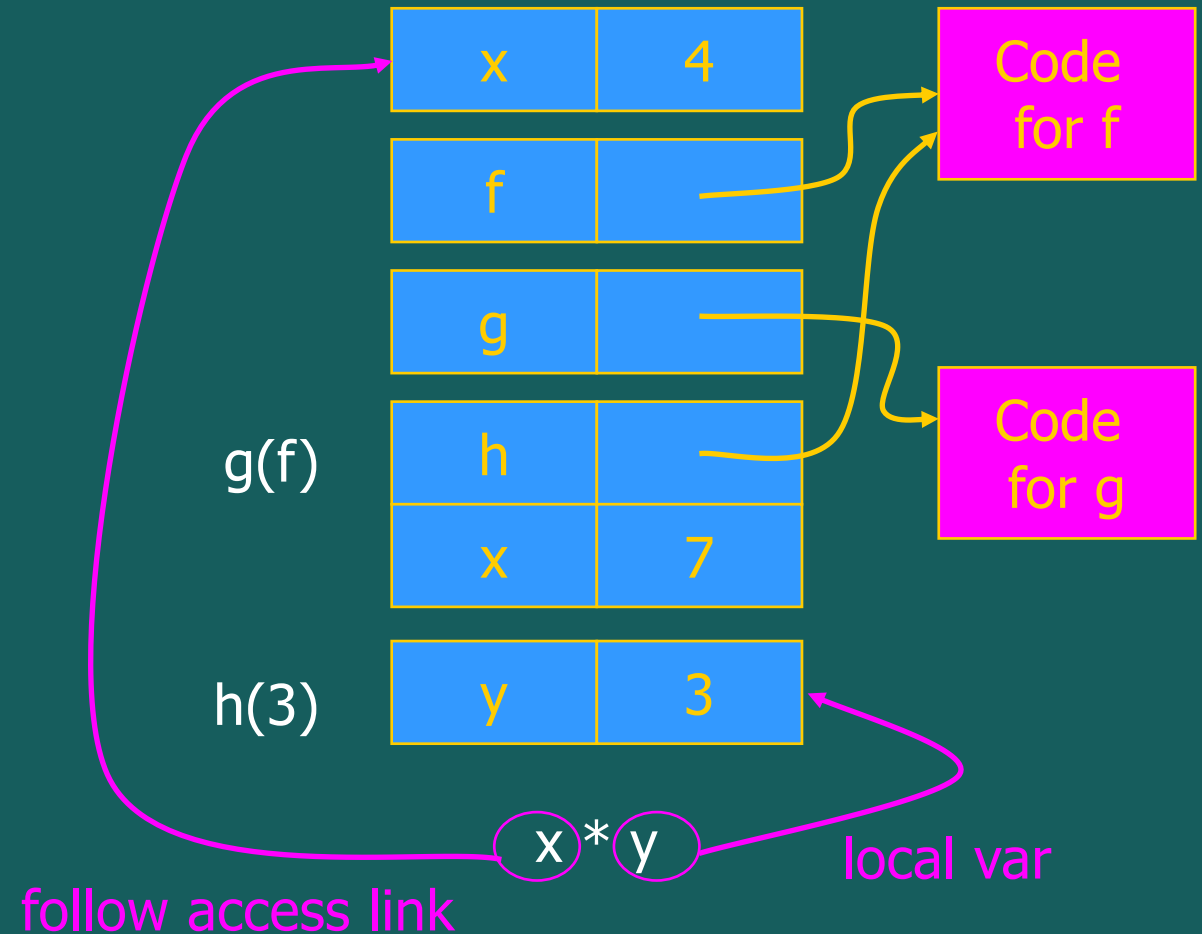
Which one is used for each occurrence of **x**?

Closures

- ◆ Function value is pair *closure* = $\langle env, code \rangle$
- ◆ When a function represented by a closure is called,
 - Allocate activation record for call (as always)
 - Set the access link in the activation record using the environment pointer from the closure

Static Scope for Function Argument

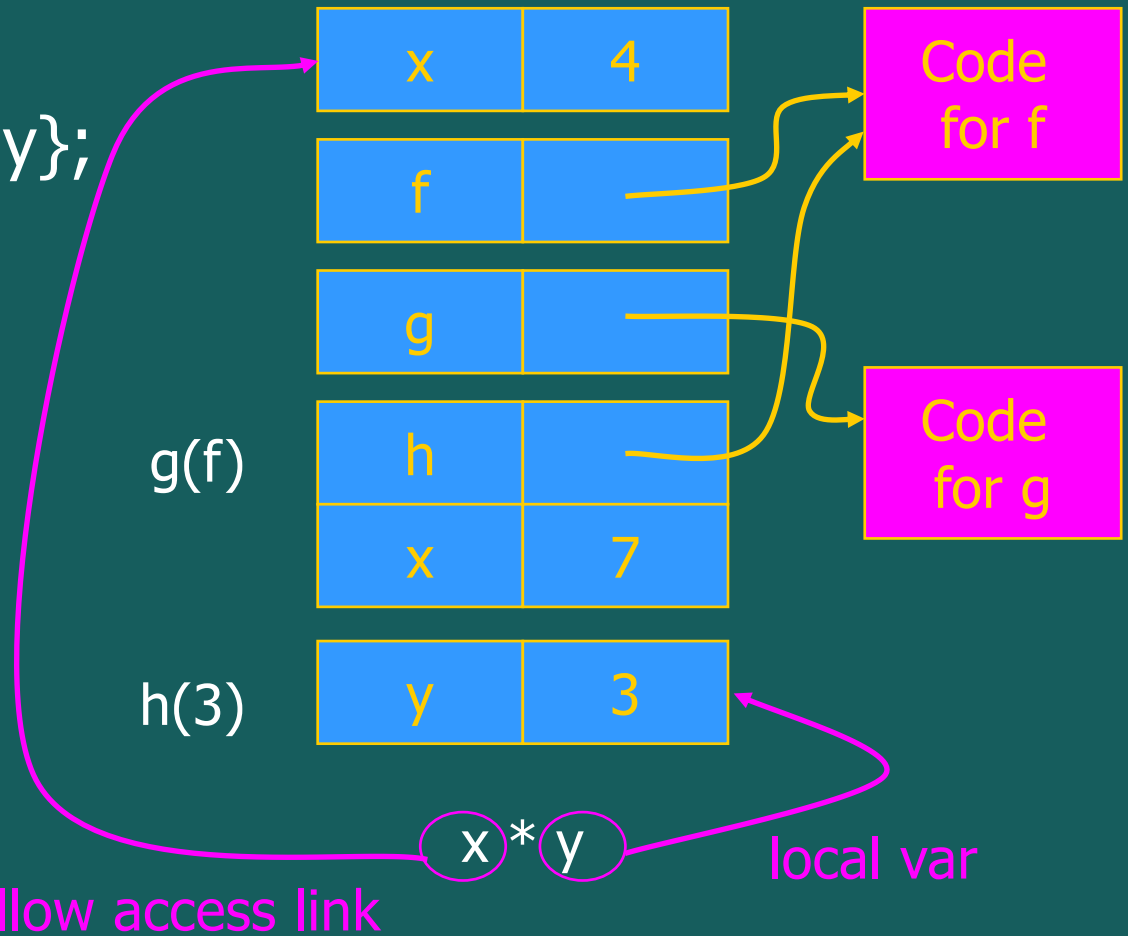
```
val x = 4;  
  fun f(y) = x*y;  
    fun g(h) =  
      let  
        val x=7  
      in  
        h(3) + x;  
      g(f);
```



How is access link for $h(3)$ set?

Static Scope for Function Argument

```
{ let x = 4;  
  { function f(y) {return x*y};  
    { function g(h) {  
      let x=7;  
      return h(3) + x;  
    };  
    g(f);  
  }  
}
```

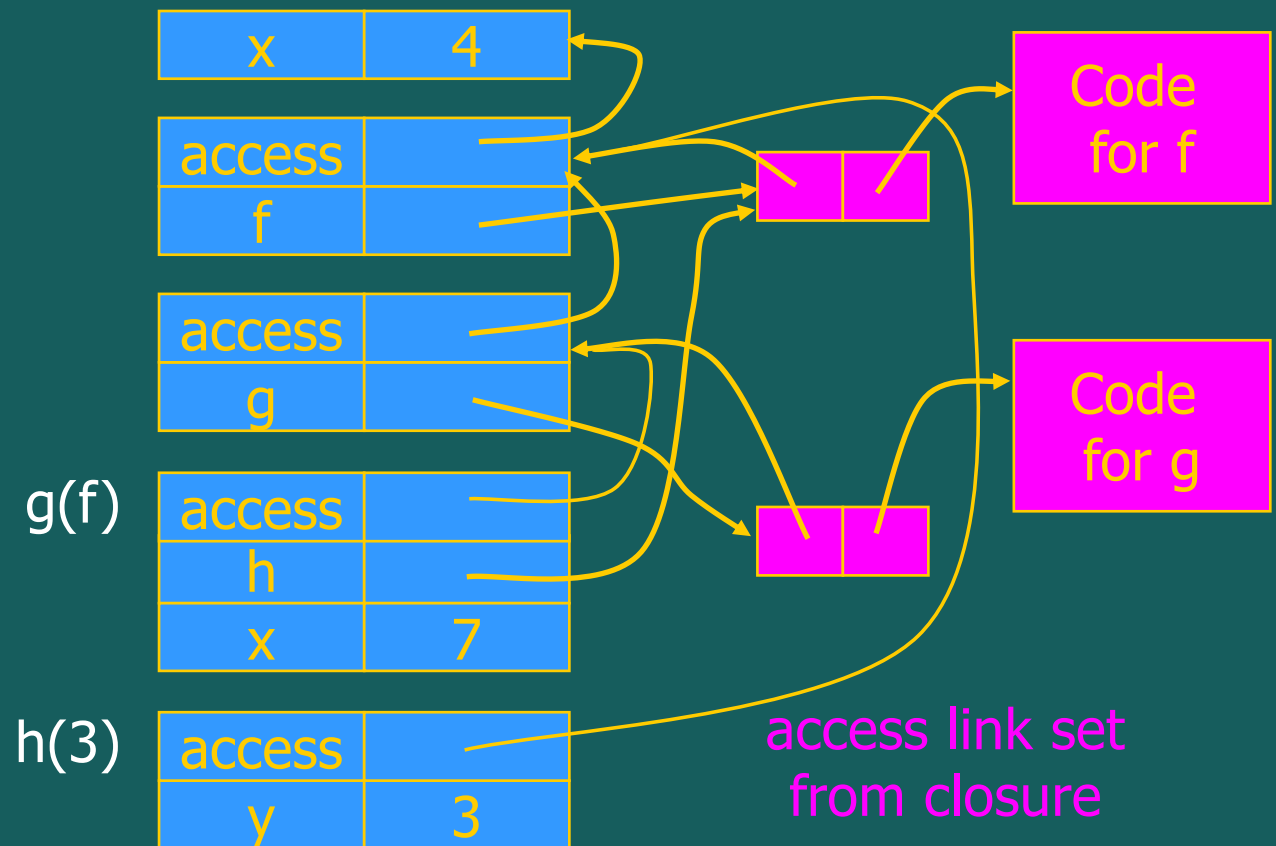


How is access link for $h(3)$ set?

Function Argument and Closures

Run-time stack with access links

```
let x = 4;  
  fun f(y) = x*y;  
  fun g(h) =  
    let  
      val x=7  
    in  
      h(3) + x;  
    g(f);
```



Summary: Function Arguments

- ◆ Use closure to maintain a pointer to the static environment of a function body
- ◆ When called, set access link from closure
- ◆ All access links point “up” in stack
 - May jump past activ records to find global vars
 - Still deallocate activ records using stack (lifo) order

Return Function as Result

◆ Language feature

- Functions that return “new” functions
- Need to maintain environment of function

◆ Example

```
function compose(f,g)
    {return function(x) { return g(f (x)) } };
```

◆ Function “created” dynamically

- expression with free variables
values are determined at run time
- function value is closure = $\langle \text{env}, \text{code} \rangle$
- code *not* compiled dynamically (in most languages)

Summary: Return Function Results

- ◆ Use closure to maintain static environment
- ◆ May need to keep activation records after return
 - Stack (lifo) order fails!
- ◆ Possible “stack” implementation
 - Forget about explicit deallocation
 - Put activation records on heap
 - Invoke garbage collector as needed
 - Not as totally crazy as it sounds
 - May only need to search reachable data

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 (later)
- ◆ 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