Scope, Function Calls and Storage Management

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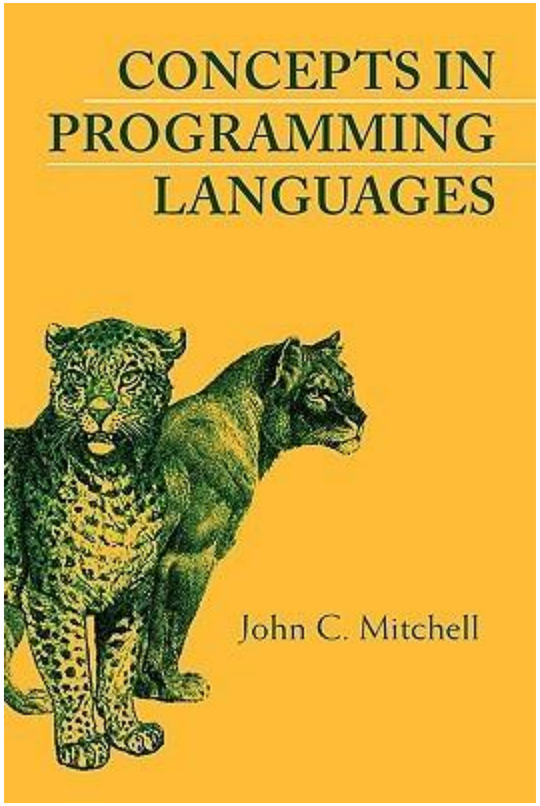
Reading

"Concepts in Programming Languages"

- Chapter 7: Scope, Functions, and Storage Management

- http://theory.stanford.edu/people/jcm/books.html
- https://homepages.dcc.ufmg.br/~camarao/lp/concepts.pdf

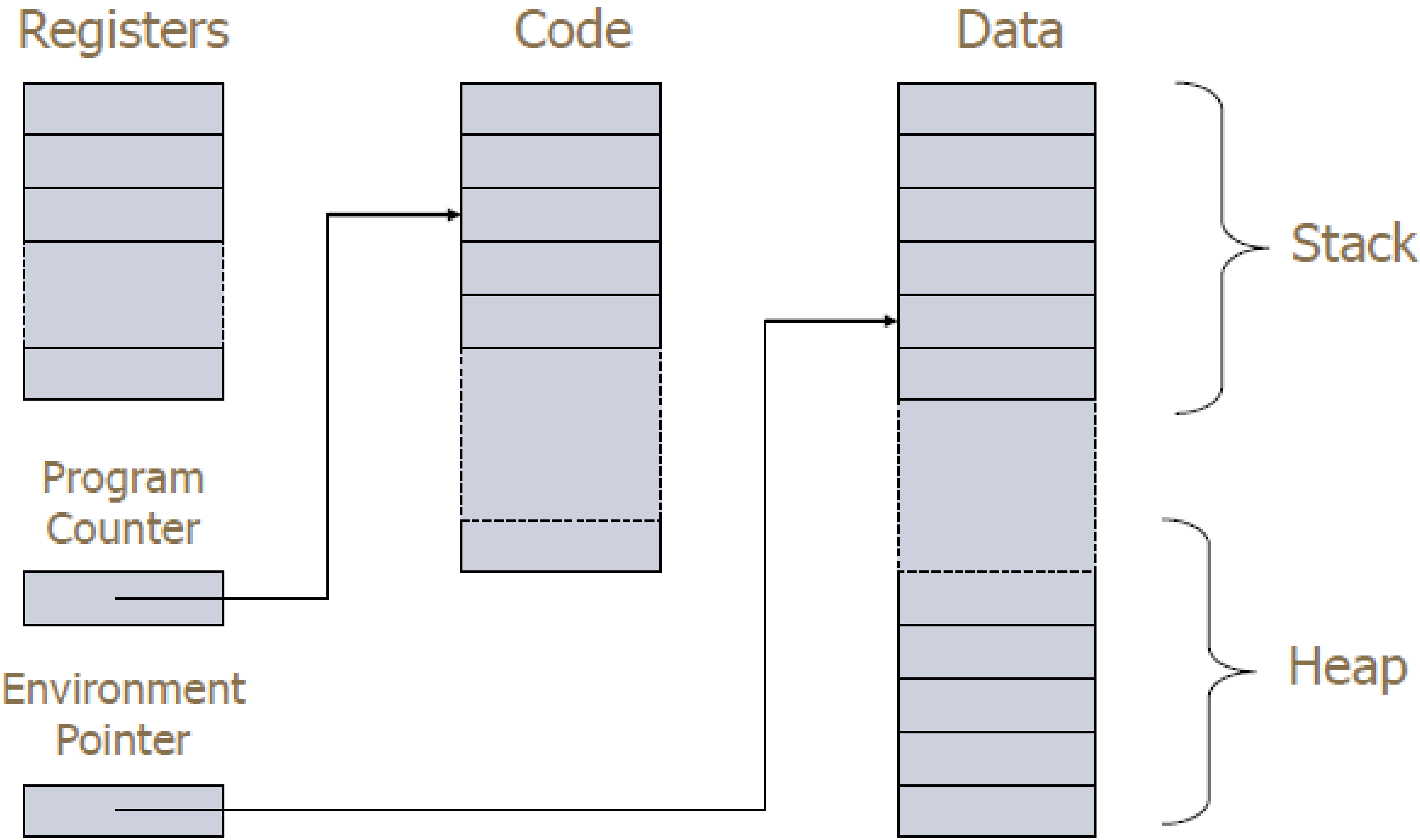


Scope

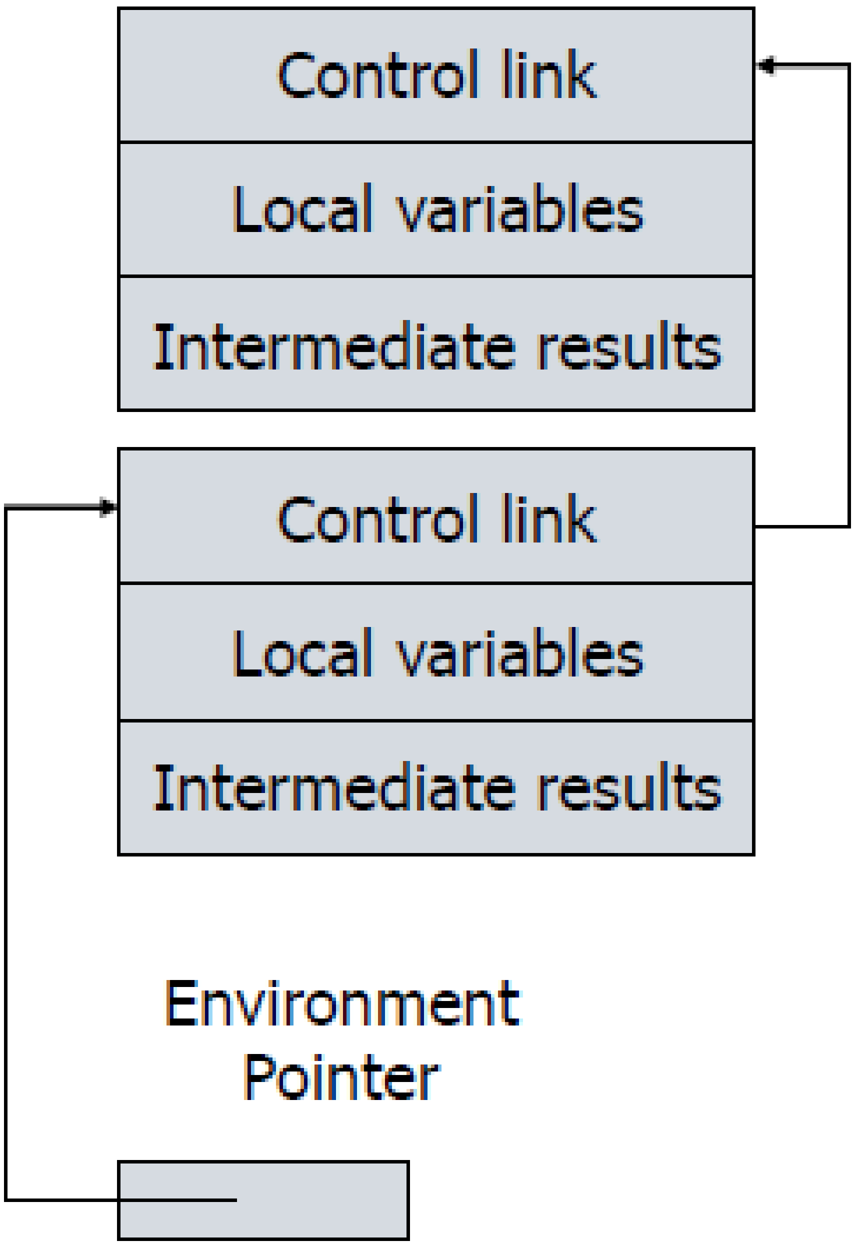
```
local z = 0
if true then
    local z = 1
    print(z)
    z = 2
    print(z)
end
print(z)
```

- Nested blocks, local variables
- Storage management
  - Enter block: allocate space for variables
  - Exits block: some or all space may be deallocated
- Static (lexical) scoping (Lua, etc.)
  - Global refers to declaration in closest enclosing block
- Dynamic scoping
  - Global refers to most recent activation record

Simplified Machine Model

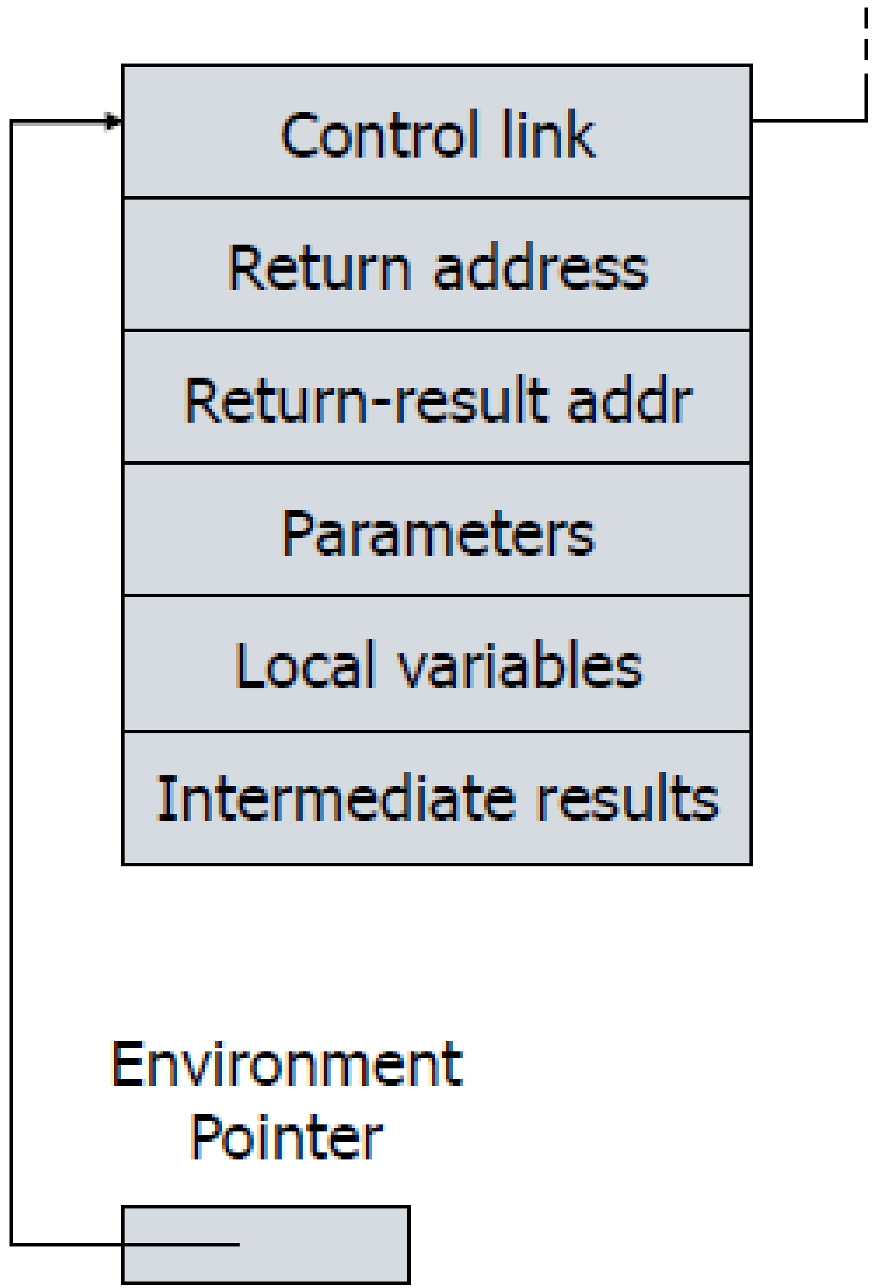


Activation Record for In-link Block



- 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

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 store function return val
- Parameters
  - Locations to contain data from calling block

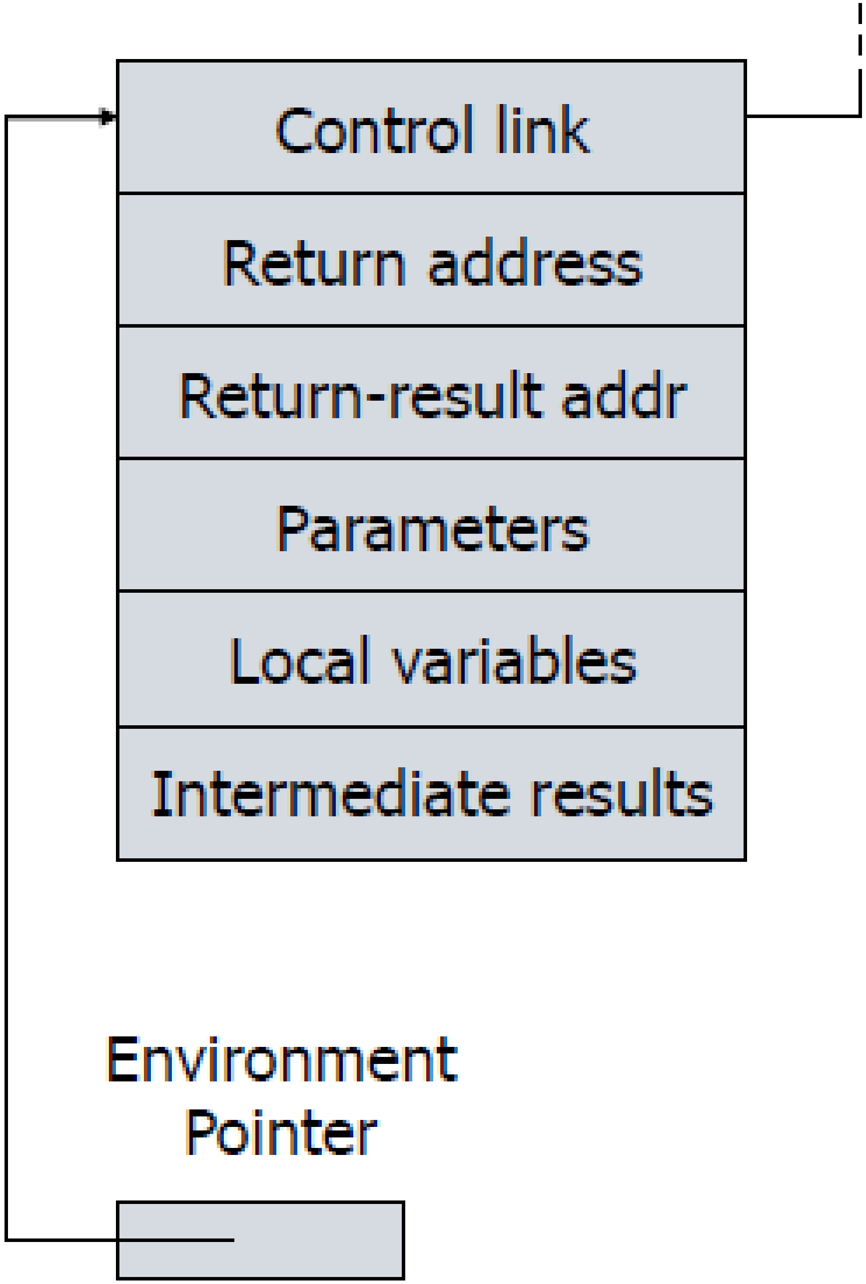
First-order Functions

- Parameter passing
  - **pass-by-value**: copy value to new activation record
  - **pass-by-reference**: copy pointer to new activation record

- Access to global variables
  - global variables are contained in an activation record higher “up” the stack

- Tail recursion
  - an optimization for certain recursive functions

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 program
  - Access link depends on static form of program text

Higher-order Functions

- Language features
  - Functions passed as arguments
  - Functions that return functions from nested blocks
  - Need to maintain environment of function

  Functions as first class values
- 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

Closures

- Function value is pair
  - closure = < env, code >

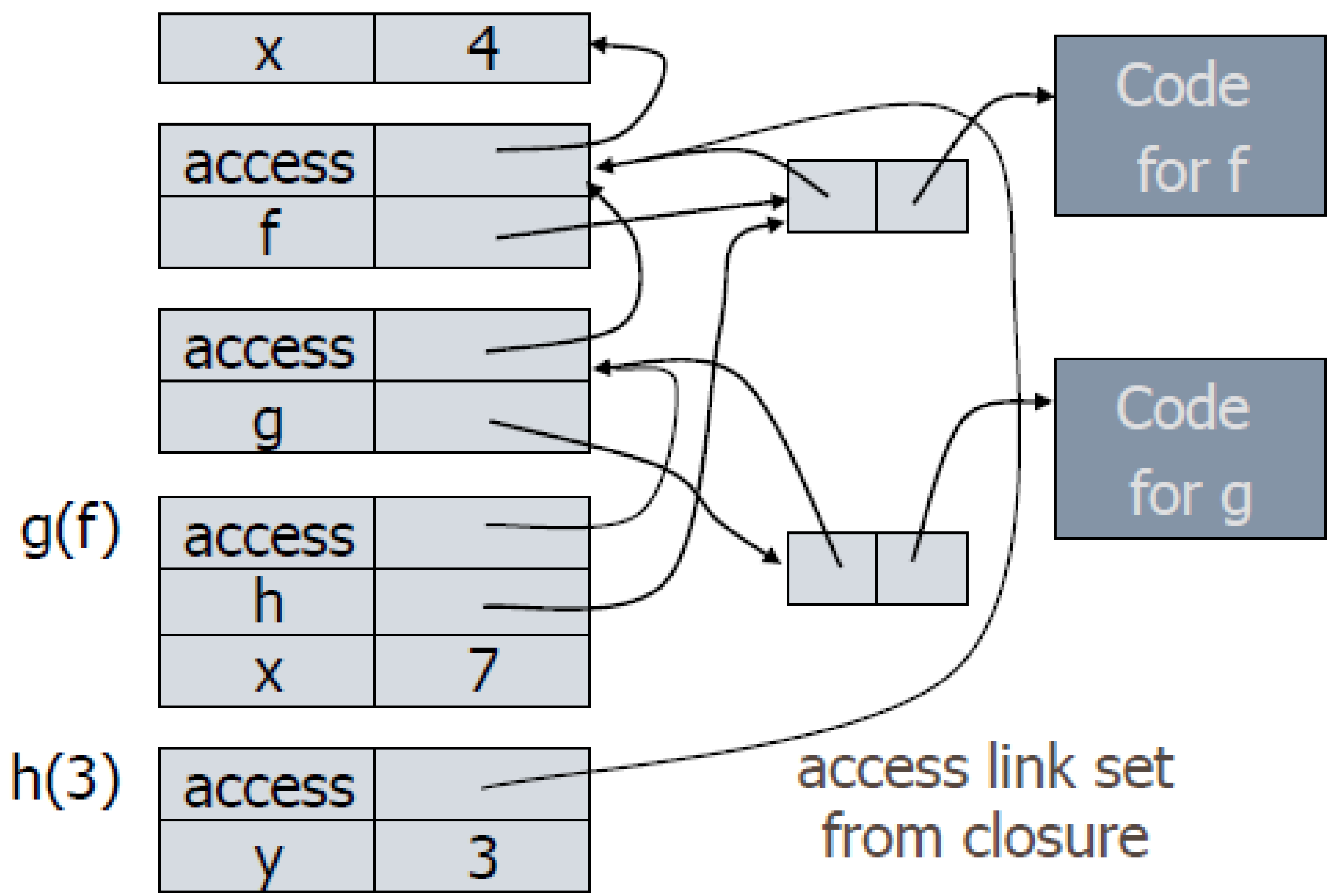
- When a function represented by a closure is called,
  - Allocate activation record for call (as always)
  - Set the access link in the activation record using the environment pointer from the closure

Function Argument and Closures

ML

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

Run-time stack with access links

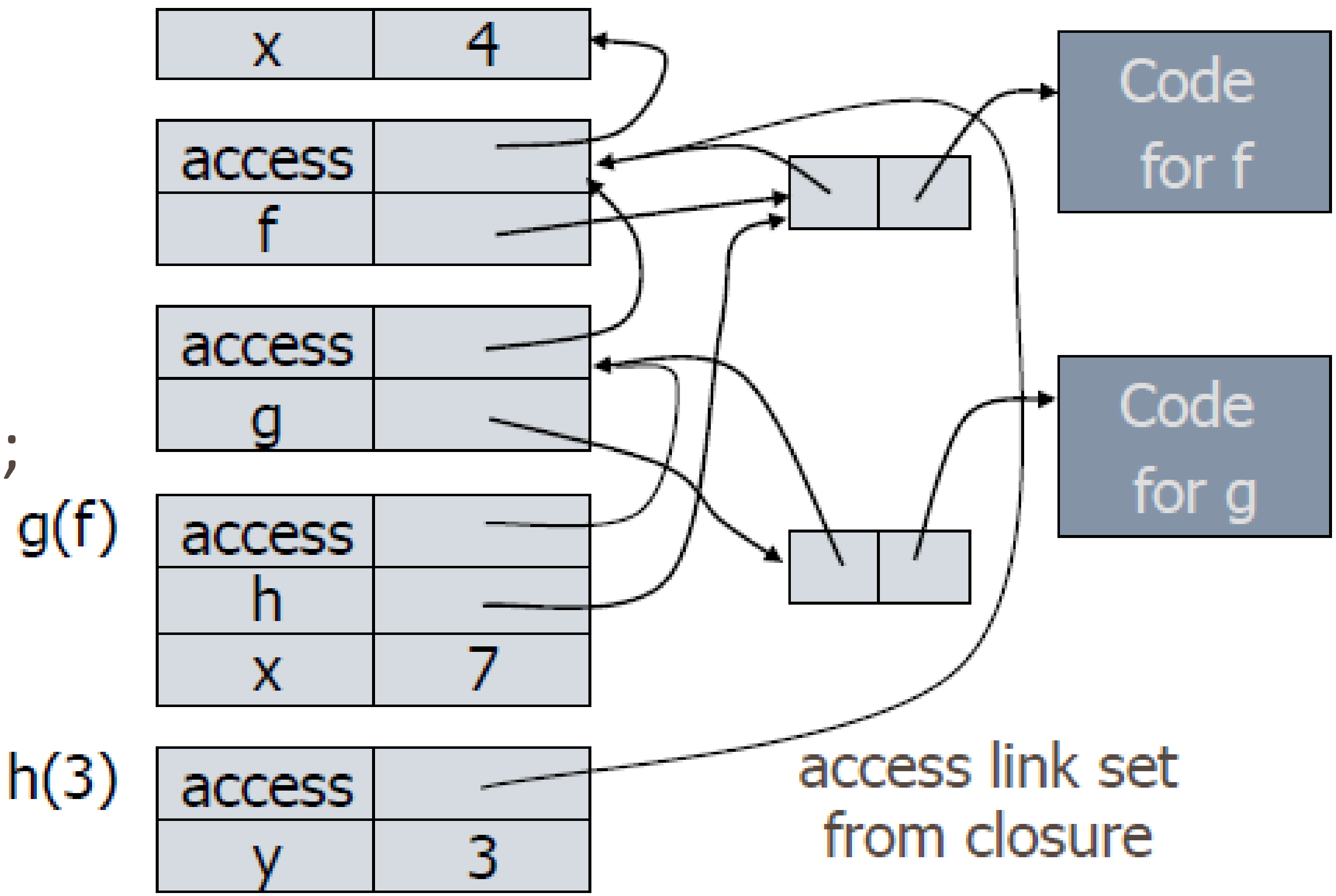


Function Argument and Closures

Lua

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

Run-time stack with access links



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 activation records to find global vars
  - Still deallocate activation 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 = env, code
  - code *not* compiled dynamically (in most languages)

Example: Return fctn with Private State

ML

mk_counter : int → (int → int)
c : int → int

```
fun mk_counter (init : int) =
    let   val count = ref init
          fun counter(inc:int) =
             (count := !count + inc; !count)
    in
          counter
    end;
val c = mk_counter(1);
c(2) + c(2);
```

Private variable count

closure

The value is a closure

- Function to "make counter" returns a closure
- How is correct value of count determined in c(2) ?

Example: Return fctn with private state

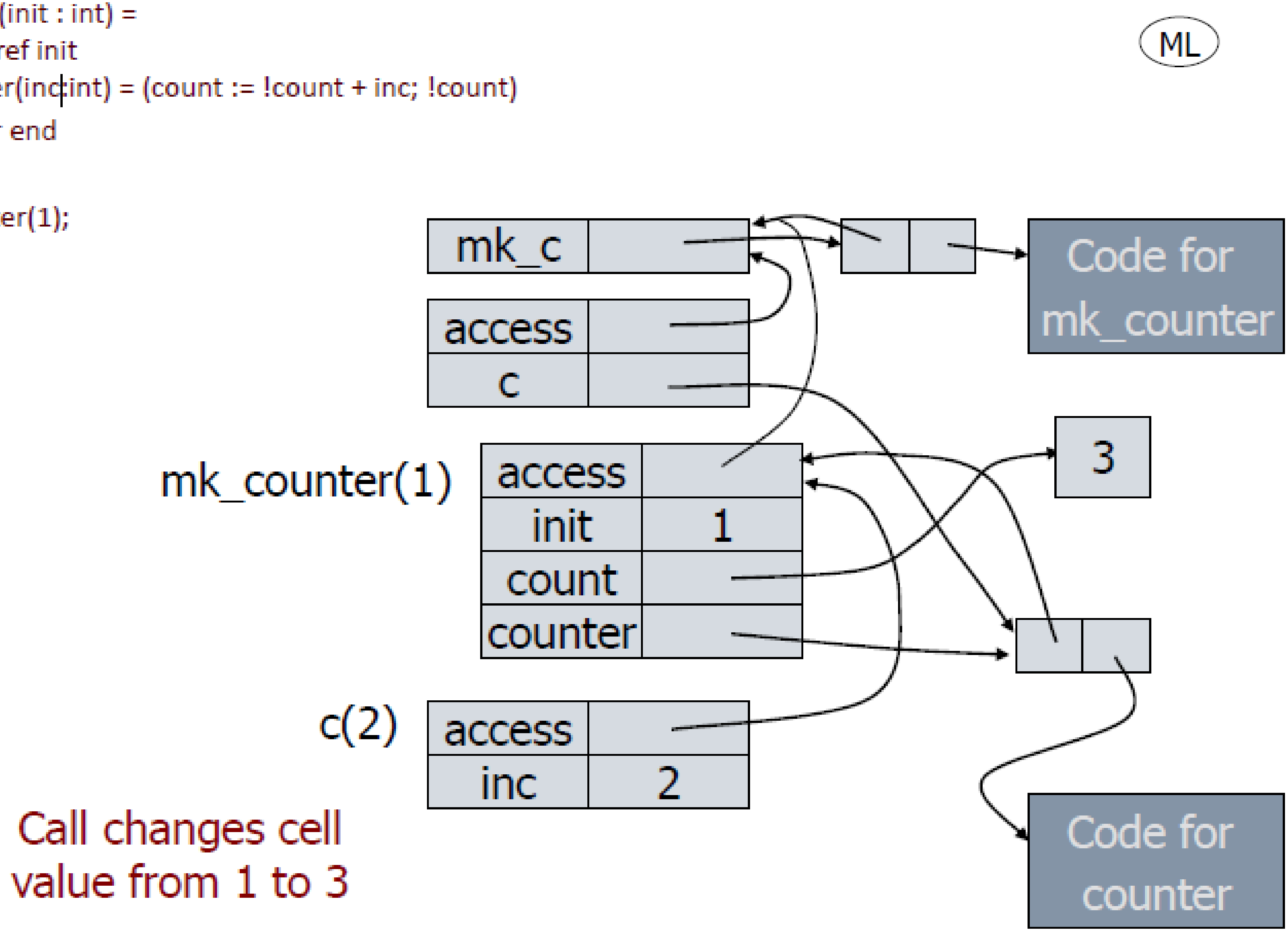
JS

```
function mk_counter (init) {
   var count = init;
   function counter(inc) {count=count+inc; return
   count};
   return counter};
var c  = mk_counter(1);
c(2) + c(2);
```

- Function to "make counter" returns a closure
- How is correct value of count determined in c(2) ?

Function Results and Closures

```
fun mk_counter (init : int) =
  let val count = ref init
        fun counter(inc:int) = (count := !count + inc; !count)
        in  counter end
  end;
val c = mk_counter(1);
c(2) + c(2);
```



Function Results and Closures

JS

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function mk_counter (init) {
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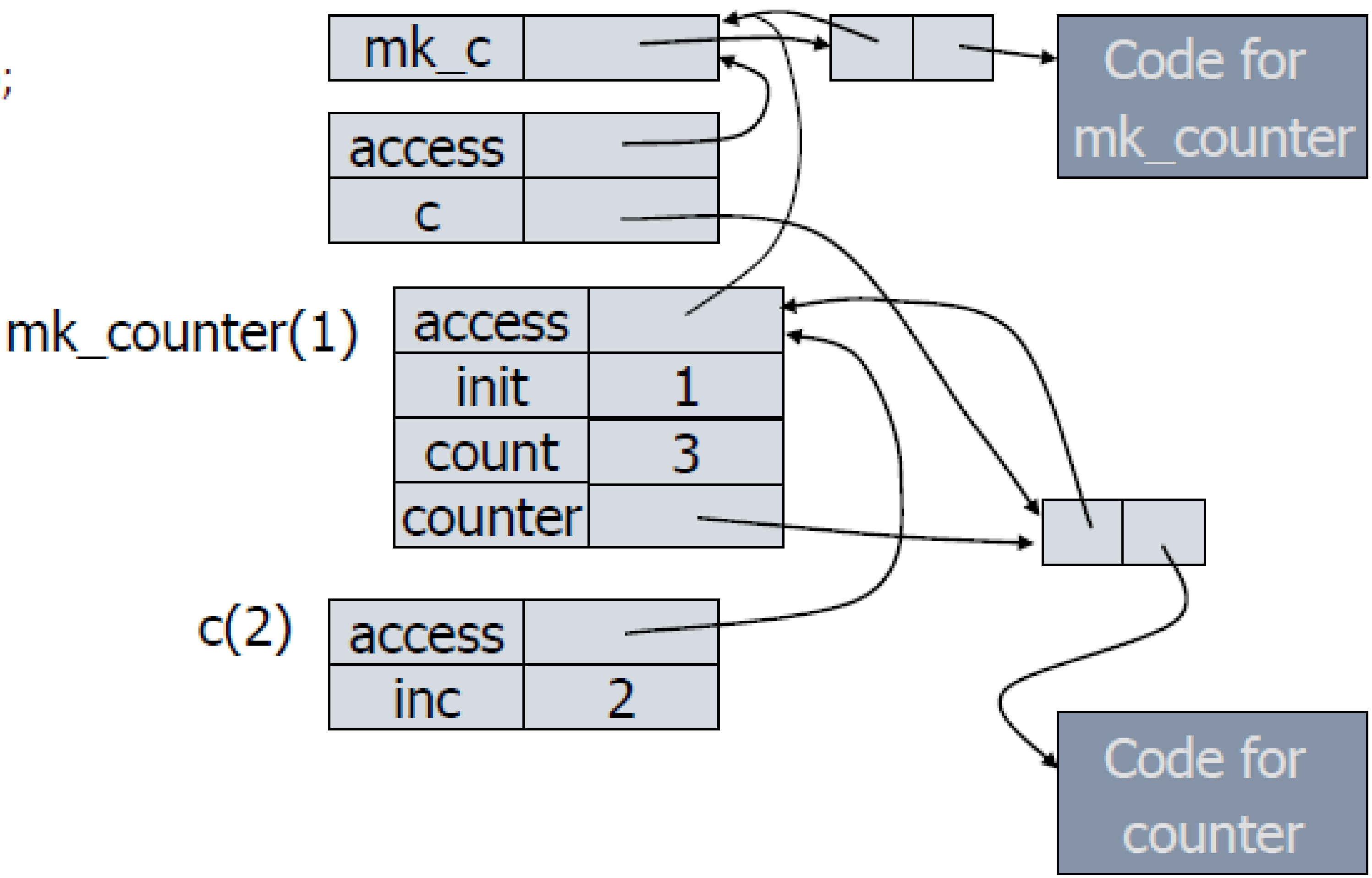

Summary of Scope Issues

- Block-structured language uses stack of activation 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 do *not* needed if functions not in nested blocks

Closures via "Upvalues"

- Lua authors wanted lexical scoping (词法作用域/静态作用域) early on
  - difficult due to technical restrictions
    - wanted to keep a simple array stack for activation records
    - one-pass compiler
- Lua 3.1 with a compromise called *upvalues*
  - In creating a function, make (frozen) copies of the values of any external variables used by a function.

```
function f ()    高阶函数：void →(void→int)
  local b = 1
  return (function () return %b + 1 end)  // b是外部的局部变量, upvalue
end
return f()() --> 2    upvalue 有些像C的static局部变量
```

Full Lexical Scoping

- Lua 5.0 got the real thing
- Solution: “Keep local variables in the (array-based) stack and only move them to the heap if they go out of scope while being referred by nested functions." (JUCS 11 #7)

```
function f ()
  local b = 1
  local inc_b = (function () b = b + 1 end)
  inc_b()
  return (function () return b end)
end
return f()() --> 2
```

closure: 一个匿名函数加上其可访问的upvalue

Tail Calls

- tail calls supported since 5.0
  - called function reuses the stack entry of the calling function
    - erases information from stack traces
- only for statements of the form `return f(...)`
  - `return n * fact(n-1)` does not result in a tail call

Coroutines

- *coroutines*—a general control abstraction
  - term introduced by Melvin Conway in 1963
  - has lacked a precise definition, but implies “the capability of keeping state between successive calls"
- have not been popular in mainstream languages
  - but used in Go
- classification:
  - *full coroutines* are stackful, and first-class objects
    - stackful coroutines can suspend their execution from within nested functions
  - an *asymmetric coroutine* is “subordinate” to its caller—can yield, caller can resume

Coroutines in Lua

- constraints: portability and C integration
  - cannot manipulate a C call stack in ANSI C
  - impossible: first-class continuations (as in Scheme), symmetric coroutines (e.g., in Modula-2)
- Lua 5.0 got *full asymmetric coroutines*, with `create`, `resume` and `yield` operations
  - ...and PUC-Rio guys gave proof of ample expressive power 里约热内卢天主教大学
  - capture only a partial continuation, from `yield` to `resume` — cannot have C parts there

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Coroutine Example

```
> return (string.gsub("abbc", "b",
        function (x) return "B" end))
aBBc
> return (string.gsub("abbc", "b",
        coroutine.wrap(function (x)
                coroutine.yield("B")
                coroutine.yield("C")
                end)))
aBCc
```

THANKS