Lecture 13: Run-Time Storage Management

CSC 131
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Attributes of Variable

- Scope Done!
- Lifetime
- Location
- Value

Lifetime

- FORTRAN - all allocated statically - ∞
- Stack-based (C/C++/Java/Pascal/...)
  - local vbles/ parameters: method/procedure/block entry to exit
  - allocate space in activation record on run-time stack
- Heap allocated variable
  - lifetime independent of scope
- Static - global vbles or static vbles

Value & Location

- Sometimes referred to as l-value & r-value
  - x = x + 1 *What does each occurrence of x stand for?*
  - location normally bound when declaration processed
- Normally values change dynamically
  - if frozen at compilation then called constants
  - Java final variables frozen when declaration processed.
  - Java static final bound at compile time.

Aliases

- x and y are aliases if both refer to same location.
- If x, y are aliases then changes to x affect value of y.
- Java has uniform model where assignment is by "sharing", so create aliases.
- Languages that mix are more confusing.
  - Common mistakes occur when not realize aliases. E.g, add elt to priority queue and then change it ...

Pointers

- "Pointers have been lumped with the goto statement as a marvelous way to create impossible to understand programs"
  - K & R, C Programming Language
- Problems
  - Dangling pointers -- leave pointer to recycled space
    - stack frame popped or recycled heap item
  - Dereference nil pointers or other illegal address
  - Unreachable garbage
  - in C: p+1 different from (int)p + 1

Program Units

- Separate segments of code allowing separate declarations of variables
  - Ex.: procedures, functions, methods, blocks
  - During execution represented by unit instance
    - fixed code segment
    - activation record with "fixed" ways of accessing items

Activation Record Structure

- Return address
- Access info on parameters (*how?*)
- Space for local vbles
- *How get access to non-local variables?*

Invoking Function

- Make parameters available to callee
  - E.g., put on stack or in registers
- Save state of caller (registers, prog. counter)
- Ensure callee knows where to return
- Enter callee at first instruction

Returning from Function

- If function, leave result in accessible location
- Get return address and transfer execution
- Caller restores state

Parameter Passing

- Call-by-reference (FORTRAN, Pascal, C++)
  - pass address (l-value) of parameter
- Call-by-copying (Algol 60, Pascal, C, C++)
  - pass (r-)value of parameter
  - options: in, out, in-out
- Call-by-name (Algol 60)
  - pass actual expression (as "thunk") - not macro!
  - re-evaluate at each access
  - lazy gives efficient implementation if no side effects

Call-by-name

```
procedure swap(a, b : integer);
  var temp : integer;
  begin
    temp := a;
    a := b;
    b := temp
  end;
```

- Won't always work!
- swap(i, a[i]) with i = 1, a[1] = 3, a[3] = 17
- Can't write swap that always works!

What about Java?

- Conceptually call-by-sharing
- Implemented as call-by-value of a reference

Static Memory allocation

- FORTRAN
  - All storage known at translation time
  - Activation records directly associated with code segments
  - At compile time, instructions and vbles accessed by (unit name, offset)
  - At link time, resolve to absolute addresses.
  - Procedure call and return straightforward

Stack-based Allocation

- Pascal, C, C++, Java, ...
  - Activation records on stack
  - Problem: static (scope) vs dynamic (return address)
  - Activation records pushed on call and popped on return
  - Activation record contains:
    - return address
    - return-result address -- *if necessary*
    - control or dynamic link -- *to next stack frame*
    - access or static link -- *to nearest stack frame of enclosing scope*
    - parameters, local vbles, & intermediate results.

Accessing non-local vbles

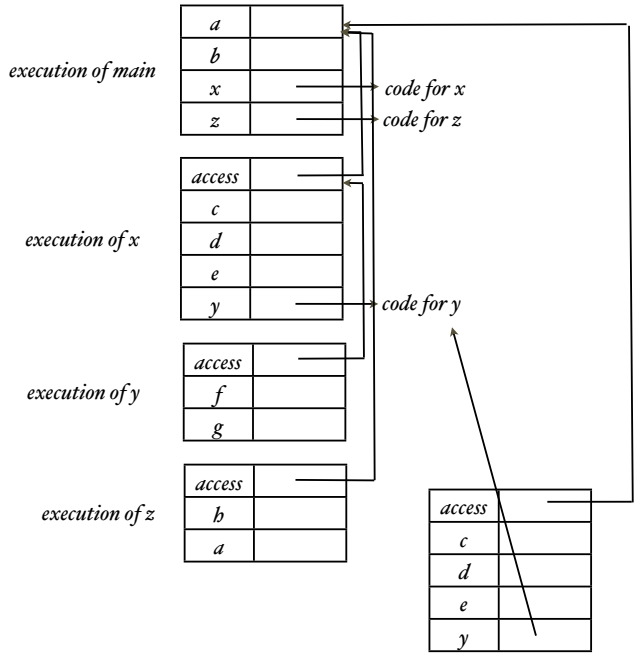
```
program main;
   type array_type = array [1..10] of real;
   var a : integer;
       b : array_type;
   procedure x (var c : integer; d : array_type);
   |  var e : array_type;
   |  procedure y (f : array_type);
   |  |  var g : integer;
   |  |  begin
   |  |     z(a+c);
   |  |  end; {y}
   |  begin {x}
   |     : ..... := b[6].......
   |     y(e);
   |  end; {x}
```

```
procedure z (h : integer);
|  var a : array_type;
|  begin
|        :
|     x (h,a);
|        :
|  end;
begin {main}
      :
   x (a,b);
      :
end. {main}
```

Assign Variables Offsets

Name	Level	Name	Level
main	0	y	2
a	1	f	3
b	1	g	3
x	1	z	1
c	2	h	2
d	2	a	2
e	2		

Look at run time stack when: main calls x, which calls y, which calls z, which calls x, which calls y, ...



Accessing non-local Variables

- Length of access chain from any fixed procedure to main is always same length
- Any non-local variable found after some fixed number of access links (independent of activation record)
- # of links = constant determinable at compile time
- Access via <chain position, offset> where 1st is # of access links to traverse, 2nd is offset in activation record.

Allocating Activation Record

- Static - sizes of all local variables and parameters known at compile time
  - Fixed size activation records
- Size known at unit activation
  - Array bounds depend on parameters
  - Space for parameter descriptors at fixed offset
- Dynamic
  - Flexible arrays and pointers
  - Allocate on heap w/reference on stack

Tail-Recursive Functions

- Recursion less efficient (space & time) than iteration because of activation records.
- A call to function f in body of g is tail if g returns immediately after call of f terminates.
  - Ex: fun g x = if x > 0 then f x else f (-x)
- Tail calls use stack space more efficiently
- Tail recursive functions even better!

Tail-recursive Functions

- *Compare*:

```
rev [] = []
rev (fst:rest) = (rev rest)++[fst]
```

- *and*

```
reverse l = tlrev l [] where
                tlrev [] r = r
                tlrev (fst:rest) r =
                        tlrev rest (fst:r)
```

- *Can accumulate answer ...*

```
fact n = tlfact(n,1)
tlfact (n,ans) = if n <= 1 then ans
                          else tlfact(n-1,n*ans);
```

Fibonacci

```
int fib(int n) {
  int current = 1;
  int next = 1;
  while (n > 0) {
    int temp = current;
    current = next;
    next = next + temp;
    n = n - 1;
  }
  return current;
}
```

or recursively:

```
fib 0 = 1
fib 1 = 1
fib n = fib (n-1) + fib(n-2);
```

Replace while loops

Can replace while by tail recursive function where all variables used become parameters:

```
fastfib n = fibloop n 1 1
```

where

```
fibloop 0 current next = current
fibloop n current next =
              fibloop (n-1) next (current + next);
```

Correctness

- Let a_0, a_1, ... be list of Fibonacci numbers
- Lemma: For all n, k ≥ 0,
  fibloop n a_k a_{k+1} = a_{k+n}
- fastfib n = fibloop n 1 1
  = fibloop n a_0 a_1
  = a_n

Function Parameters

- Harder to cope with because need environment defined in. Two problems:
  - Downward funarg:

```
x = 47
f y = x + y;
g(h) = let val x = 17
       in h(1)
> g(f)
```

  - When evaluate f(1), is in environment where x = 17!