CS 536 Announcements for Monday, April 8, 2024

Last Time
- parameter passing
- terminology
- different styles
  - what they mean
  - how they look on the stack

Today
- wrap up parameter passing
  - compare and contrast
- accessing variables at runtime
  - how do we deal with variables and scope?
  - how do we organize activation records?
  - how do we retrieve values of variables from activation records?

Next Time
- code generation

Code generation and parameter passing

Efficiency considerations (calls, accesses by callee, return)

Pass by value
- copy values into callee's AR - slow
- callee directly accesses AR locations - fast

Pass by reference
- copy addresses into callee's AR - fast
- access in callee via indirection - slow

Pass by value-result
- strictly slower than pass by value
- need to know where to copy values back on return

Handling objects

In Java, variables hold the addresses of objects
- no overhead of copying entire objects

In C++, variables are objects in the stack

- use pointers to objects in heap for efficiency

Compare and contrast

Pass by value

- no aliasing – fewer unwanted side effects
- easier for static analysis (esp. optimization)
- called function (callee) is faster – no indirection

  but call (& copying of values) may take time

Pass by reference

- more efficient when passing large objects
- can modify actuals

  const ref in C++ – pass by ref but not allowed to be modified – compiler checks & gives warning/error

Pass by value-result

- more efficient than pass by refence for small objects – no indirection
- if no aliasing, can be implemented as pass by reference for large objects – so still efficient

  but determining **if** there is aliasing (and **what** is aliased) is a challenging task (in general)

Accessing variables at runtime

local variables

- declared and used in the same function
- further divided into "block" scope in base

global variables

- declared at the outermost level of the program
- in C/C++/base – globals integer x.
- in Java – class (static) data members

  ↑ Java keyword

non-local variables (i.e., from nested scopes)

- for static scope: variables declared in an outer scope
- for dynamic scope: variables declared in the calling context

compile-time vs run-time

nested class (Java)

nested procedures (Pascal)

Accessing local variables at runtime

Local variables

- includes parameters and all local variables in a function
- stored in activation record of function in which they are declared
- accessed using offset from frame pointer

Accessing the stack

- general anatomy of MIPS instruction

  opcode operand1 operand2

- use "load" and "store" instructions
  - every memory cell has an address
  - calculate that memory address, then move data from/to that address

```
void test(int x, int y) {
    int a, b;
    ...
    if (...) {
        int s;
        ...
    }
    else {
        int t, u, v;
        ...
        u = b + y;
    }
}
```

Activation record for `test`

← sp

v		-28
u		-24
t		-20
s		-16
b		-12
a		-8
	control link	-4
	return address	← fp
x		4
y		8

MIPS code for `u = b + y`

← comment symbol

```
lw   $t1, -12($fp)      # load b
```

load word ↑ reg ↑ offset + framepointer

loads contents of a given address into given register

```
lw   $t2, 8($fp)        # load y
add  $t3, $t1, $t2      # b+y
sw   $t3, -24($fp)      # store into u
```

Simple memory-allocation scheme

Reserve a slot for each variable in the function

Algorithm (for each function)

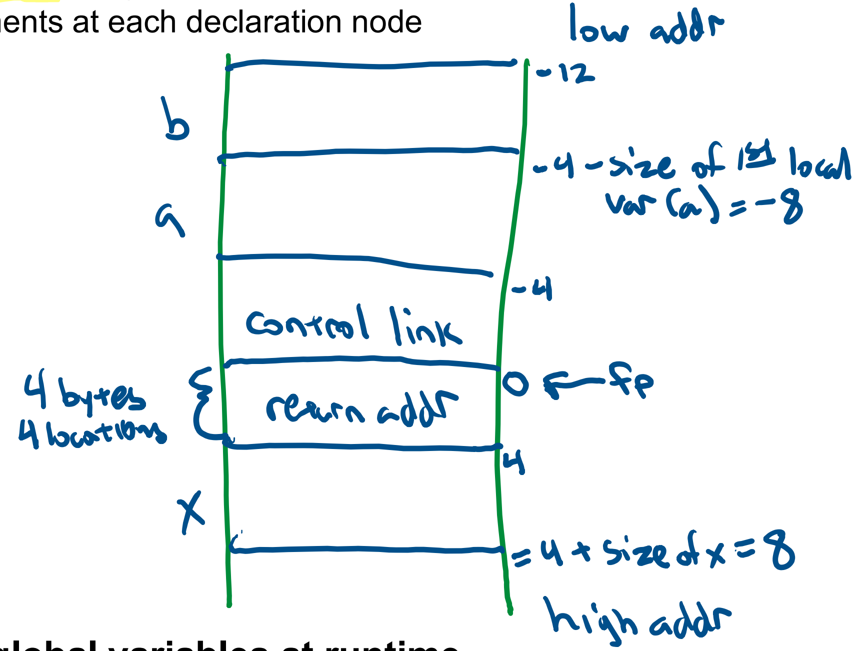
```
set offset = +4  ← start of 1st param

for each parameter
    add name to symbol table w/ current offset
    offset += size of parameter

offset = -4  to account for control link

offset -= size of callee saved registers

for each local
    offset -= size of variable
    add name to symbol table w/ current offset
```

Implementation (in P6)

- add an offset field to each symbol table entry
- during name analysis, add the offset along with the name
- walk the AST performing decrements at each declaration node

Example

```
void test(int x, int y) {
     int a, b;
     if (...) {
          int s;
     }
     else {
          int t, u, v;
          u = b + y;
     }
}
```



Accessing global variables at runtime

Place in static data area

.data

.text directive for code

- in MIPS, handled with a special storage directive
- variables referred to by name, not address

instead of indirectly through $fp, $sp, registers

Note: space allocated directly at compile time (never needs to be deallocated)

Example

initial value

```
.data
_x: .word 10

.text
lw $t0, _x    # load from x into $t0
sw $t0, _x    # store from $t0 into x
```

Accessing non-local variables at runtime

Two situations

- static scope
  - variable declared in one procedure and accessed in a nested one
- dynamic scope
  - any variable x that is not declared locally resolves to instance of x in the AR closest to the current AR

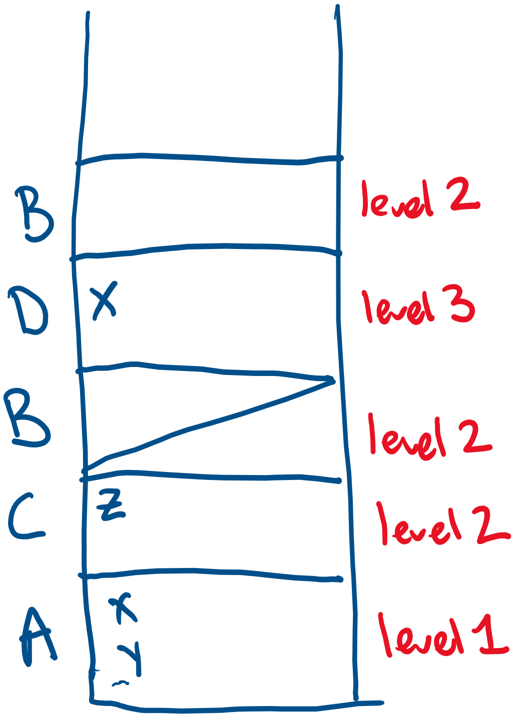
Example: static non-local scope

```
function main() {
    int a = 0;

    function subprog() {
        a = a + 1;
    }
}
```

- each function has its own AR
- variable stored in AR of procedure that declared it
- inner function accesses outer function's AR at runtime

Example: static non-local scope

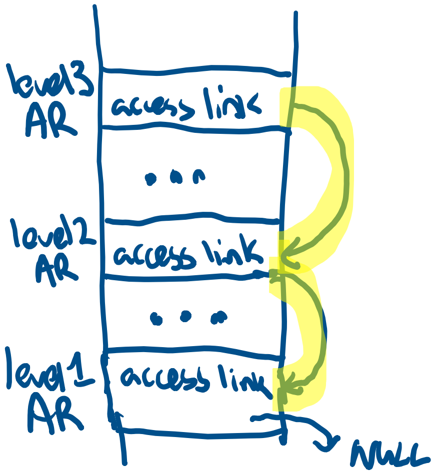
```
void procA() { // level 1
    int x, y;
    void procB() { // level 2
        print x;  x_1 (always)
    }
    void procC() { // level 2
        int z;
        void procD() { // level 3
            int x;
            x = z + y;  x_3 = z_2 + y_1
            procB();
        }

        x = 4;  x_1 = 4
        z = 2;  z_2 = 2
        procB();
        procD();
    }
    x = 3;  x_1 = 3
    y = 5;  y_1 = 5
    procC();
}
```



Access links

Add additional field in the AR (called access link, or static link)

points to locals area (or fp) of enclosing procedure



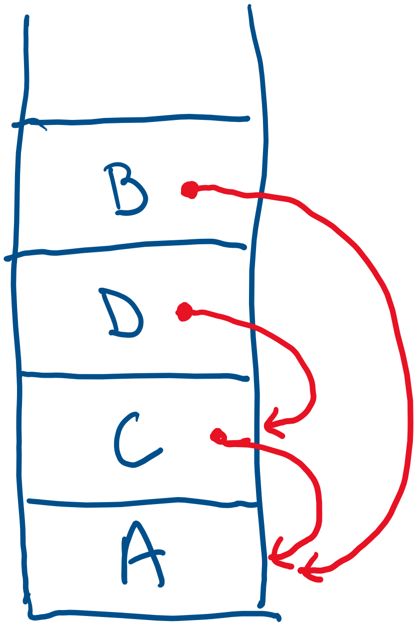
How access links work

- we know how many *levels* to traverse statically

current scope is at nesting level 3
& variable to access is at nesting level 1
- go back 3 − 1 = 2 access levels

Setting up access links

```
void procA() { // level 1
   int x, y;
   void procB() { // level 2
      print x;
   }
   void procC() { // level 2
      int z;
      void procD() { // level 3
         int x;
         x = z + y;
         procB();
      }

      x = 4;
      z = 2;
      procB();
      procD();
   }
   x = 3;
   y = 5;
   procC();
}
```



Handling use of non-local variable x (at compile time)

- each variable keeps track of nesting level in which it is declared
- when x is used in procedure P
  - follow predetermined # of links to get to AR for procedure in which x is declared

L_x = level of x's decl L_p = level of P

\# links to follow is $L_p - L_x$

MIPS (assume $fp is location of access link)

```
lw $t0, 0($fp)  # 1 link followed
lw $t0,  ($t0)  # 2 links followed
     . . .
lw $t0, -12($t0) # use x's offset in AR of declaring procedure
```

Using a display

Idea: avoid run-time overhead of following access links by having a global array (called the display) containing links to the procedures that lexically enclose the current procedure

How it works

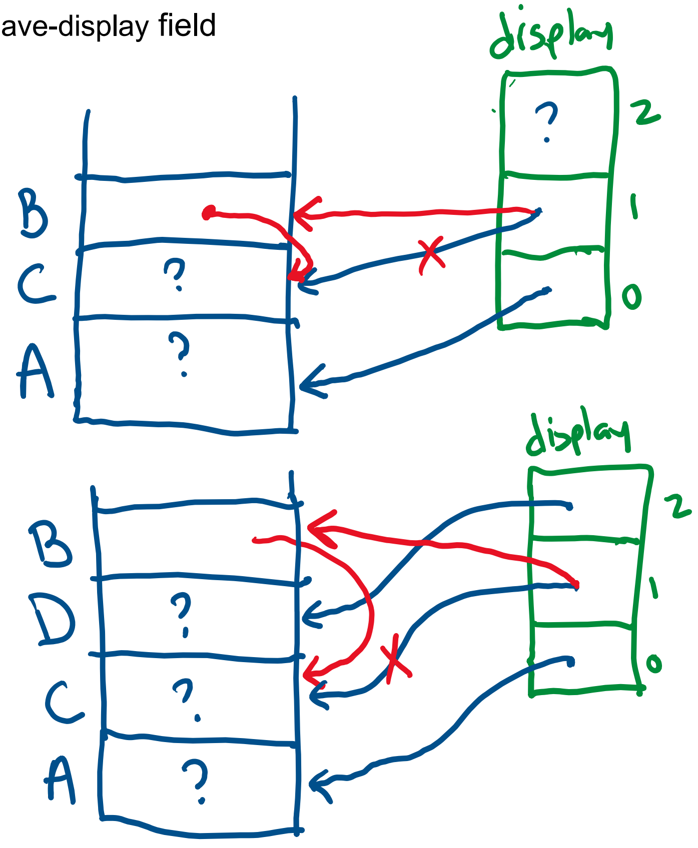
- given procedure `P` at nesting level `k` is currently executing
- `display[0], display[1], ..., display[k-2]` hold pointers to ARs of the most recent activations of the `k-1` procedures that enclose `P`
- `display[k-1]` holds pointer to `P`'s AR
- to access non-local variable `x` declared in nesting level `n`
    - use `display[n-1]` to get to AR that holds `x`
    - then use regular offset (within AR) to get to `x`

How to maintain the display in the code

- add new "save-display" field to AR
- when procedure `P` at nesting level `k` is called
    - save current value of `display[k-1]` in save-display field of `P`'s AR
    - set `display[k-1]` to point to save-display field of `P`'s AR
- when procedure `P` is ready to return
    - restore `display[k-1]` using value in save-display field

Example

```
void procA() {
   int x, y;
   void procB() {
      print x;
   }
   void procC() {
      int z;
      void procD() {
         int x;
         x = z + y;
         procB();
      }

      x = 4;
      z = 2;
      procB();
      procD();
   }
   x = 3;
   y = 5;
   procC();
}
```



Dynamic non-local scope

Example

```
function main() {
    int a = 0;
    fun1();
    fun2();
}
function fun2() {
    int a = 27;
    fun1();
}
function fun1() {
    a = a + 1;
}
```

Key point – we don't know *which* non-local variable we are refering to

Two ways to set up dynamic access

- deep access – somewhat similar to access links
- shallow access – somewhat similar to displays

Deep access

- if the variable isn't local
    - follow control link to caller's AR
    - check to see if it defines the variable
    - if not, follow the next control link down the stack
- note that we need to know if a variable is defined *with that name* in an AR
    - usually means we'll have to associate a name with a stack slot

Shallow access

- keep a table with an entry for each variable declaration
- compile a direct reference to that entry
- at function call on entry to function F
    - F saves (in its AR) the current values of all variables that F declares itself
    - F restores these values when it finishes