# 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
- callee directly accesses AR locations

Pass by reference

- copy addresses into callee's AR
- access in callee via indirection

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

## Compare and contrast

**Pass by value**

- no aliasing
- easier for static analysis
- called function (callee) is faster

**Pass by reference**

- more efficient when passing large objects
- can modify actuals

**Pass by value-result**

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

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
- in Java

**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

# 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

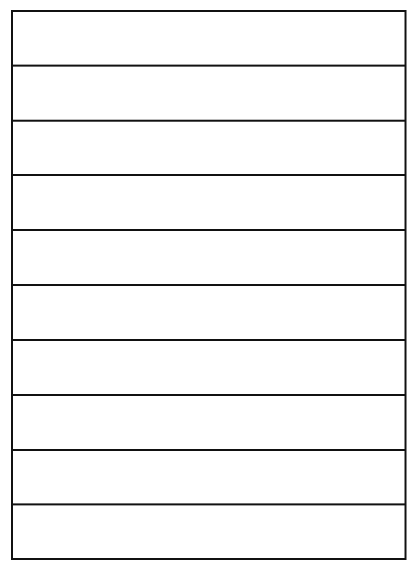
**Accessing the stack**

- general anatomy of MIPS instruction

- 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`**



**MIPS code for `u = b + y`**

```
lw  $t1, -12($fp)
```

```
lw  $t2, 8($fp)
add $t3, $t1, $t2
sw  $t3, -24($fp)
```

## Simple memory-allocation scheme

**Reserve a slot for each variable in the function**

**Algorithm** (for each function)

```
set offset = +4

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

offset = -4

offset -= size of callee saved registers

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

**Implementation**

- 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**

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

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

**Example**

```
.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;
   }
}
```

## Example: static non-local scope

```
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();
}
```

# Access links

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

### How access links work

- we know how many *levels* to traverse statically

### Setting up access links

```
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();
}
```

### 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

**MIPS** (assume $fp is location of access link)

```
lw $t0, 0($fp)
lw $t0,   ($t0)
     . . .
lw $t0, -12($t0)
```

## 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