CS 536

Runtime Access to Variables

Roadmap

- Last time
  - Discussed runtime environments
  - Described some conventions for assembly
    - Functions via stack
    - Dynamic memory via a heap
- Today
  - How do we deal with variables and scope

Scope

- We mostly worry about 3 flavors
  - Local
    - Declared and used in the same function
    - Further divided into “block” scope in YES
  - Global
    - Declared at the outermost level of the program
  - Non-local
    - For state scope: variables declared in an outer nested sub-program
    - For dynamic scope: variables declared in the calling context

Local variables: Examples

- What are the local variables here?

```
int fun(int a, int b){
    int c;
    c  = 1;
    if (a == 0){
        int d;
        d = 4;
    }
}
```

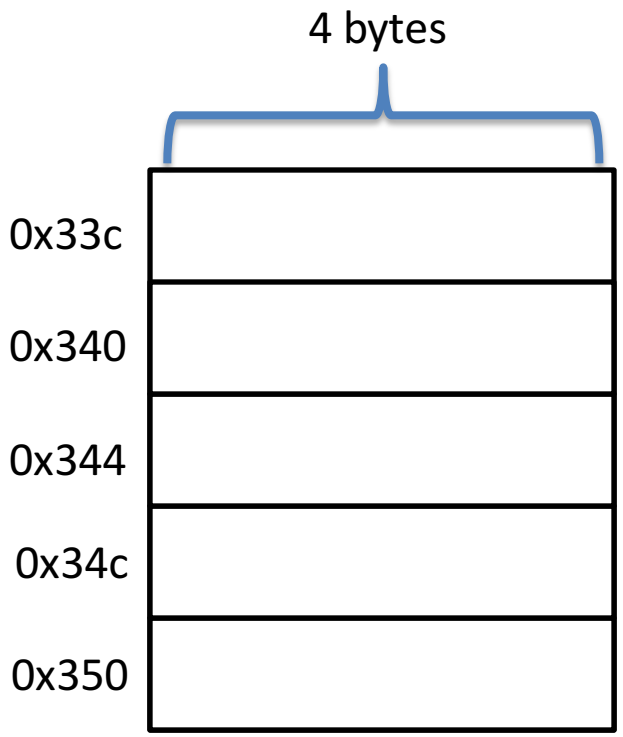
How do we access the Stack?

- Need a little MIPS knowledge
  - Full tutorial next week
  - General anatomy of a MIPS instruction

```
opcode Operand1 Operand2
```

How do we access the Stack?

- Use “load” and “store”instructions
  - Recall that every memory cell has an address
  - Calculate that memory address, then move data from/to that address



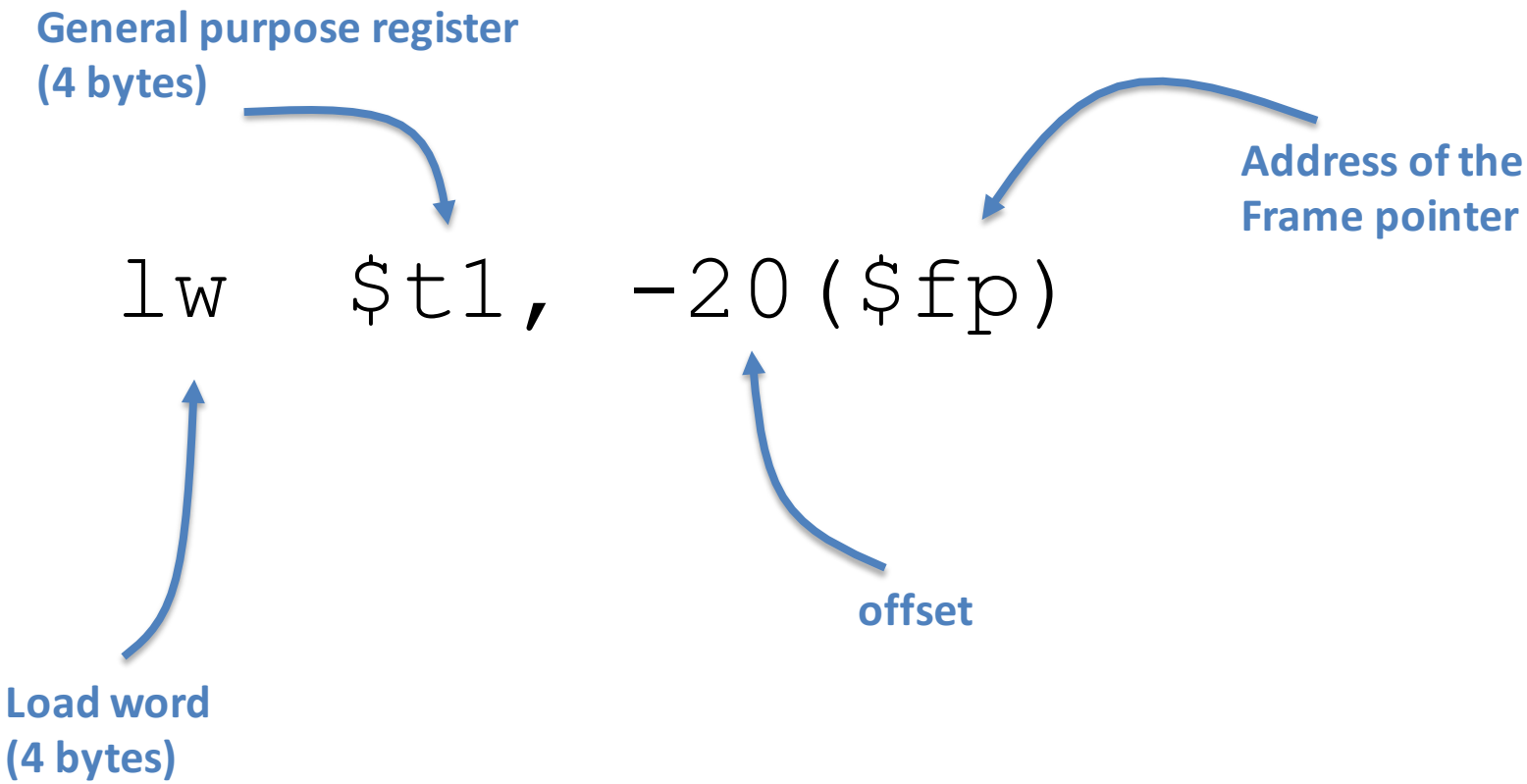
Basic memory operations

```
lw register memoryAddress

sw register memoryAddress
```

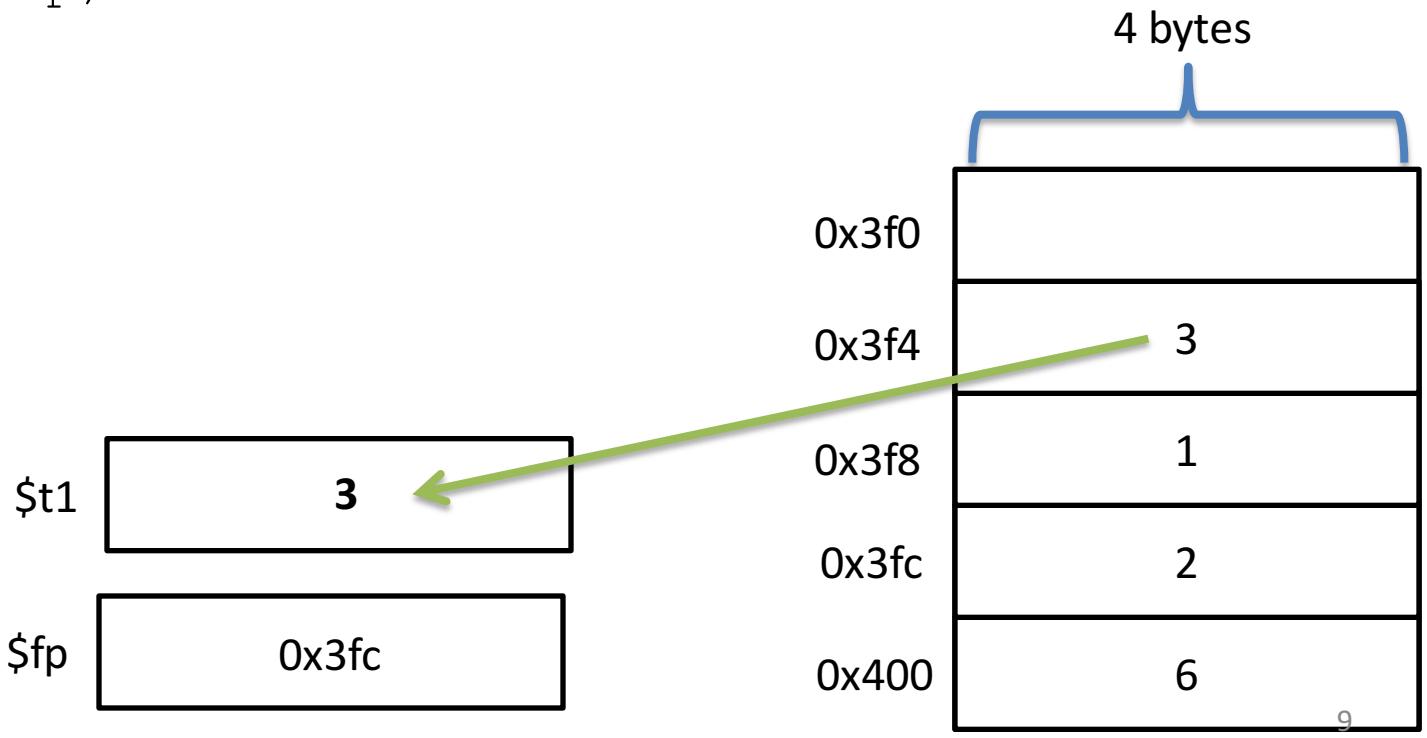
Load Word Example

```
opcode register memoryAddress
```



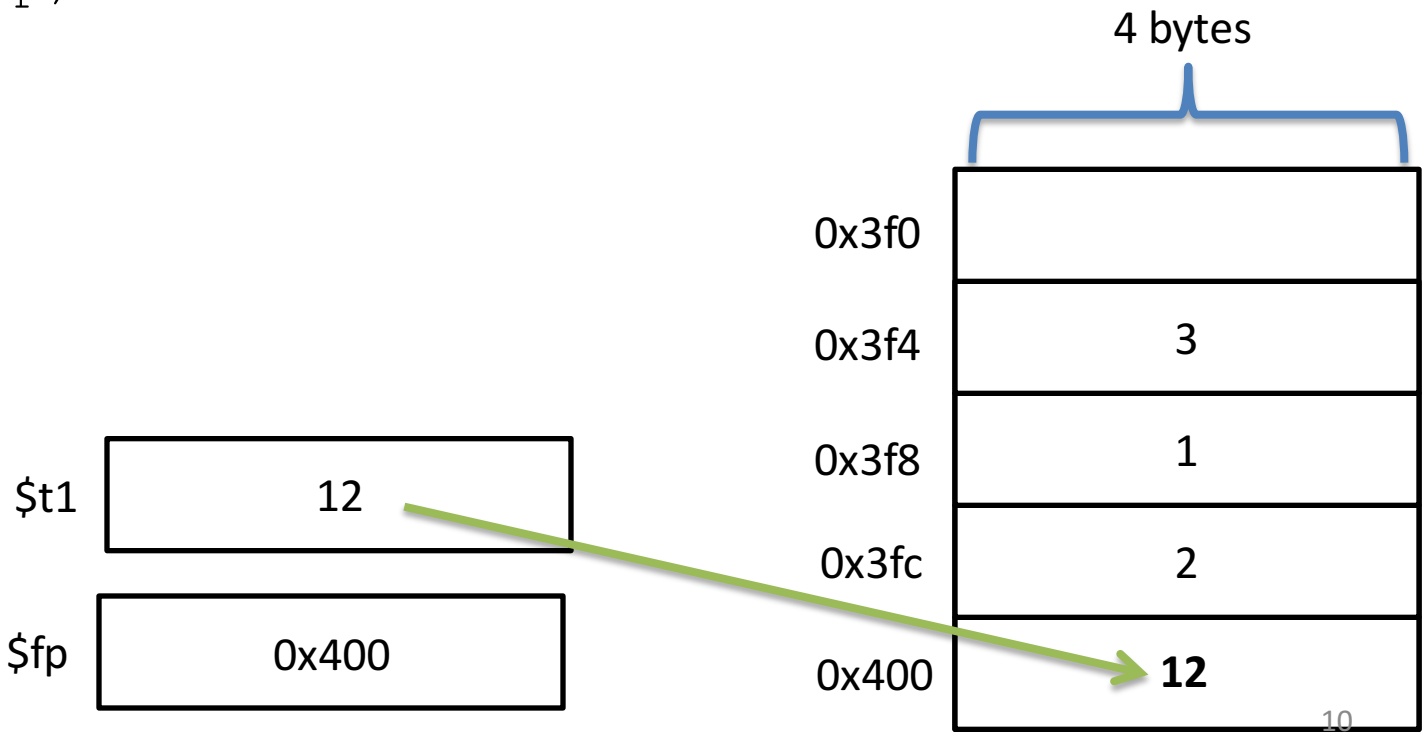
Load Word in Action

```
lw   $t1, -8($fp)
```



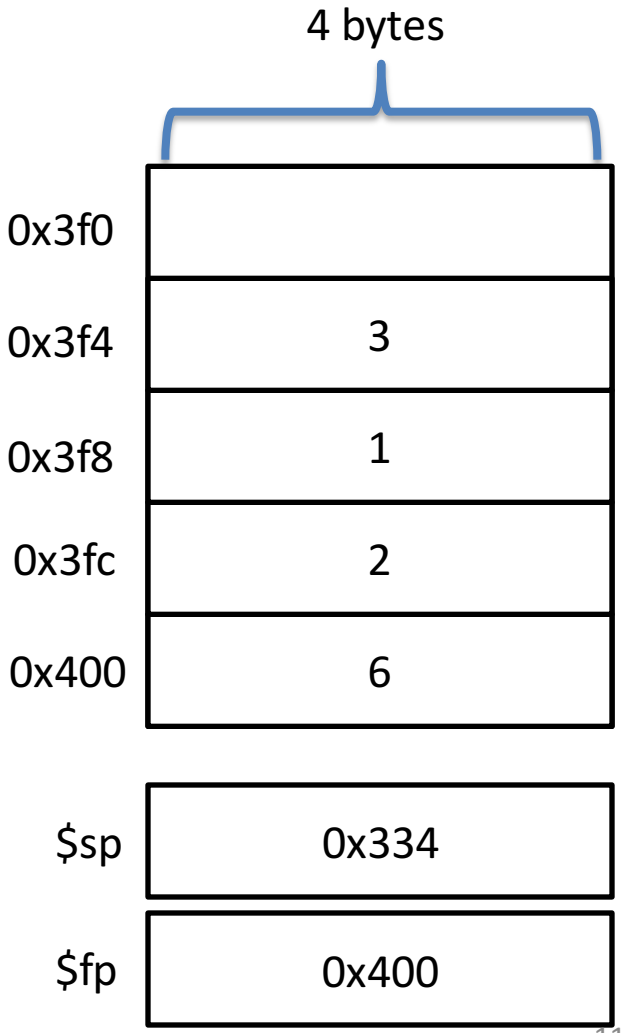
Store Word in Action

```
sw   $t1, 0($fp)
```



Relative Access for Locals

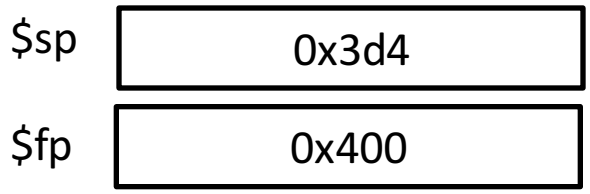
- Why do we access locals from $fp?
  - That's where the activation record starts
- What if we used $sp instead?

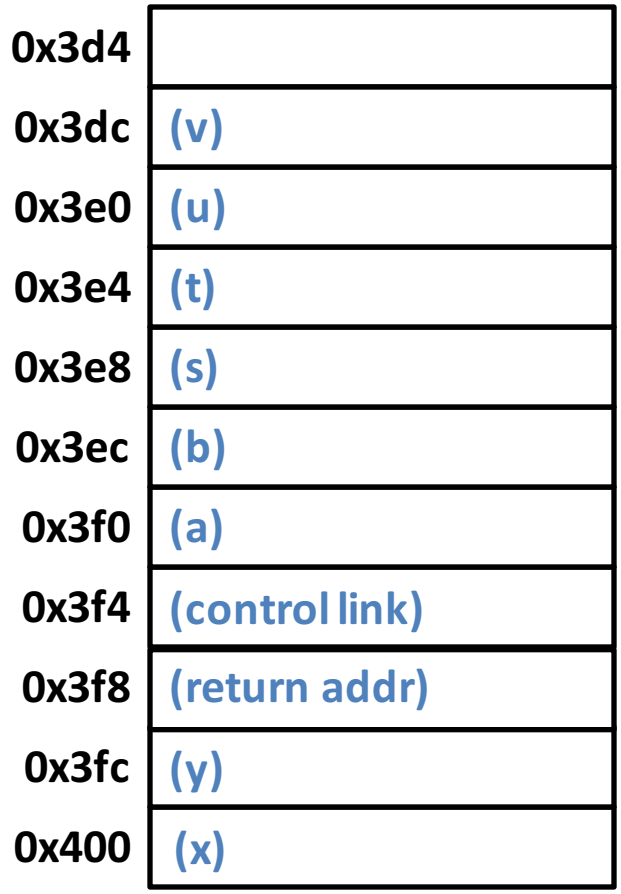


Simple Memory-Allocation Scheme

- Reserve a slot for each variable in the function

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





Simple Memory-Allocation Algorithm

```
For each function
Set offset = 0
for each parameter
    add name to symbol table
    offset -= size of parameter
offset -= size of return address
offset -= size of control link
offset -= size of callee saved registers
for each local
   add name to symbol table
   offset -= size of variable
```

Simple Memory-Allocation Implementation

- Add an offset field to each symbol table entry
- During name analysis, add the offset along with the name (Wait until Project 6 to do this)
- Walk the AST performing decrements at each declaration node

Algorithm Example

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

What about Global Variables?

- Space allocated directly at compile time (instead of indirectly via $fp and $sp registers)
- Never needs to be deallocated

Handling Global Variables

- In a sense, globals easier to handle than locals
  - Space allocated directly at compile time (instead of indirectly via **$fp** and **$sp** registers)
  - Never needs to be deallocated
- Place in static data area
  - In MIPS, handling with a special storage directive
  - Variables referred to by name, not by address

Memory Region Example

```
.data
_x: .word 10
_y: .byte 1
_z: .asciiz “I am a string”
.text
lw $t0, _x  #Load from x into $t0
sw $t0, _x  #Store from $to into x
```

Accessing non-local variables

- Static scope
  - Variable declared in one procedure and accessed in a nested one
- Dynamic scope
  - Any variable use not locally declared

Static non-local scope example

- Each function has it's own AR
  - Inner function accesses the outer AR

```
function main(){
    a = 0;
    function subprog(){
        a = a + 1;
    }
}
```

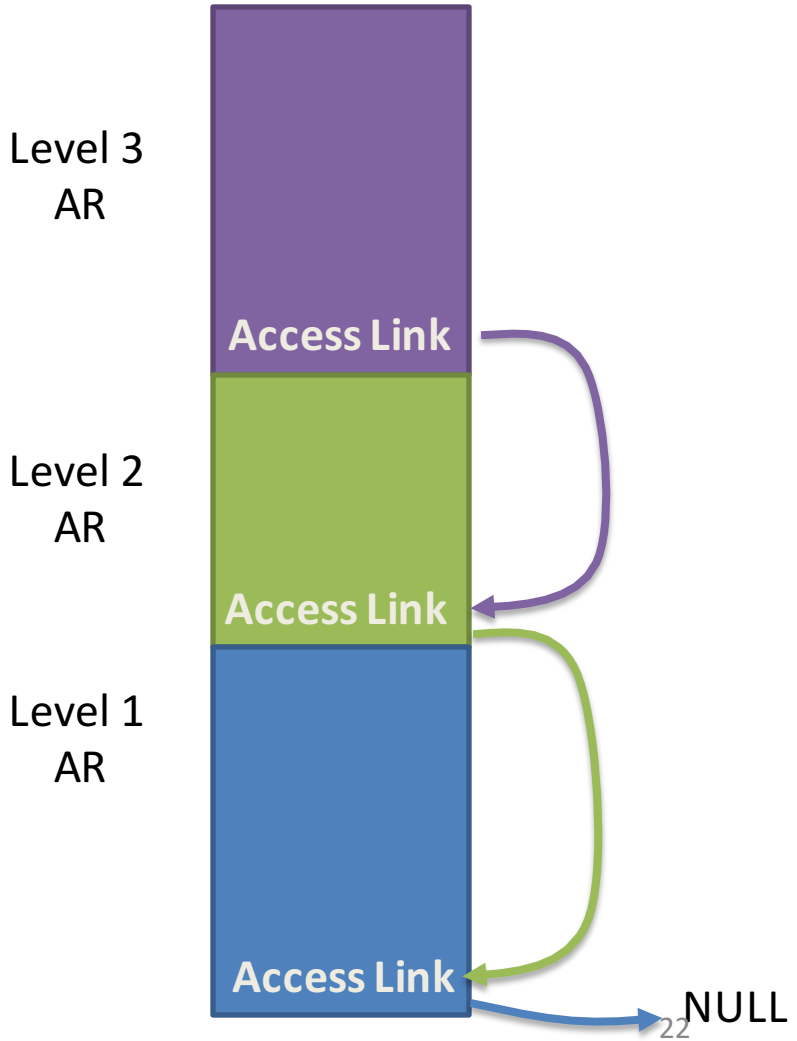
Static non-local scope memory access

```
void procA(){  // level 1
  int x, y;
  void procB(){ // level 2

    void procC(){ //level 3
      int z;
      void procD(){
        int x;
        x = z + y;
        procB();
      }
      x = 4;
      z = 2;
      procB();
      procD();
    }
    x = 3;
    y = 5;
}
```

Access Links

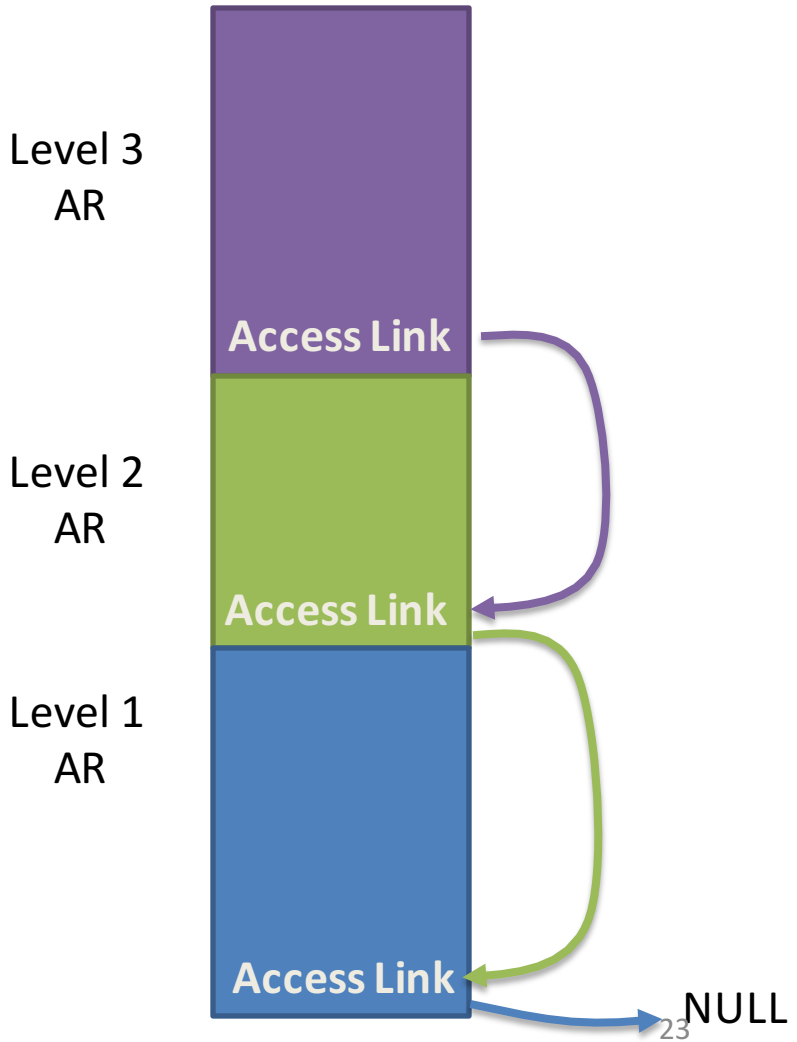
- Add an additional field to the AR
  - Points to the locals area of the outer function
  - Sometimes called the static link (since it refers to the static nesting)



How Access Links Work

- We know how many *levels* to traverse statically
  - Example: In nesting level 3 and the variable is in nesting level 1: go back access links

    (3 – 1) 2 levels



Setting up access links

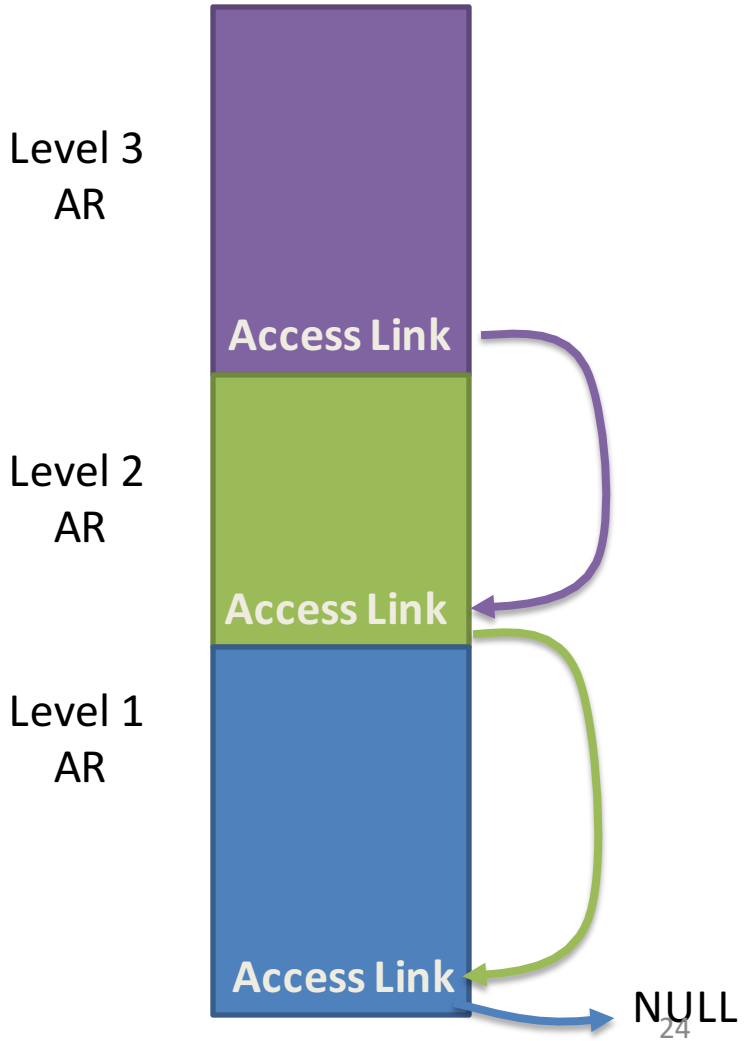
- Using 1 access link

```
lw $t0, -4($fp)
lw $t0, -12($t0)
```

Where
$fp -4 is the location of the access link
the variable in the outer scope
at offset 12 from outer AR

- Using 2 access links

```
lw $t0, -4($fp)
lw $t0, ($t0)
lw $t0, -12($t0)
```



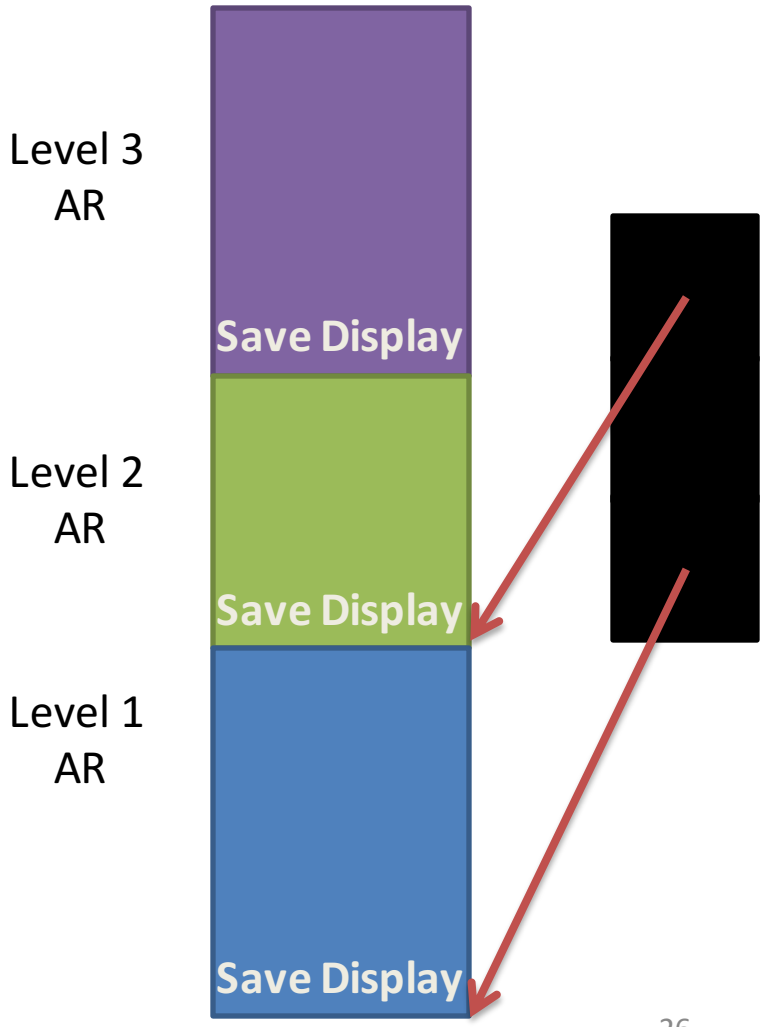
Thinking about access links

- We know the variable we want to access statically
  - Why don't we just index into the parent's AR using a large positive offset from $fp?

```
lw $t0 38($fp)
```

Displays

- High-level idea:
  - Keep the transitive effects of multiple access link traversals
  - Uses a side-table of this info
- Tradeoffs v Access Links
  - Faster to call far up the heirarchy
  - Takes extra space



Questions about Static Scope?

Dynamic non-local scope example

```
function main(){
    a = 0;
    fun();
}

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

Dynamic Scope Storage

- Key point
  - We don't know *which* non-local variable we are referring to
- Two ways to set up dynamic access
  1. Deep Access – somewhat similar to Access links
  2. Shallow Access – somewhat similar to displays

Deep Access

- If the variable isn't local
  - Follow the control link to the caller's AR
  - Check to see if it defines the variable
  - If not, follow the next control link down the stack
- Note that we somehow need to know if a variable is defined *by 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 a function call
    - Save all locals in the *caller*'s AR
    - Restore locals when the *callee* is finished