Runtime Access to Variables

Roadmap

Last Time

- Parameter passing strategies

This time

- How do we deal with variables and scope
- How do we store variables on stack

Scope

We mostly worry about 3 flavors

- Local
  - Declared and used in the same function
  - Further divided into “block” scope in your language
- Global
  - Declared at the outermost level of the program
- Non-local
  - For static 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

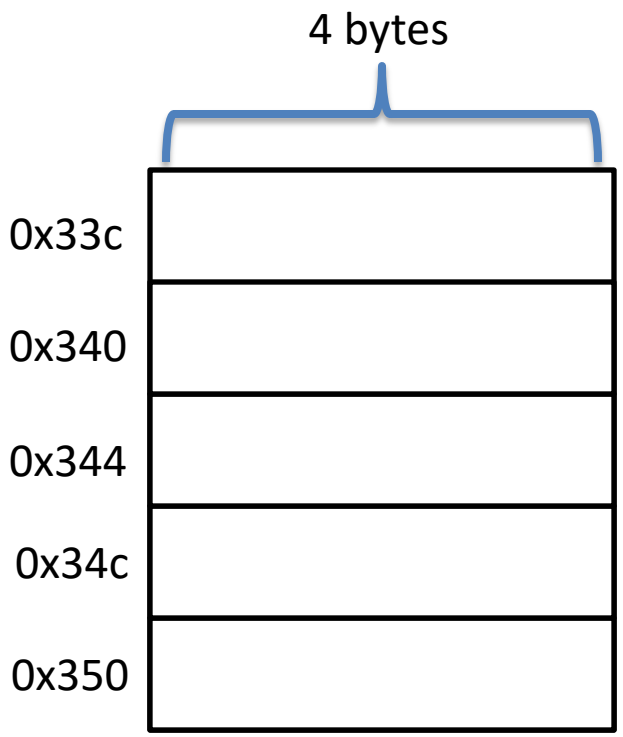
- Full tutorial next week
- General anatomy of a MIPS instruction

```
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



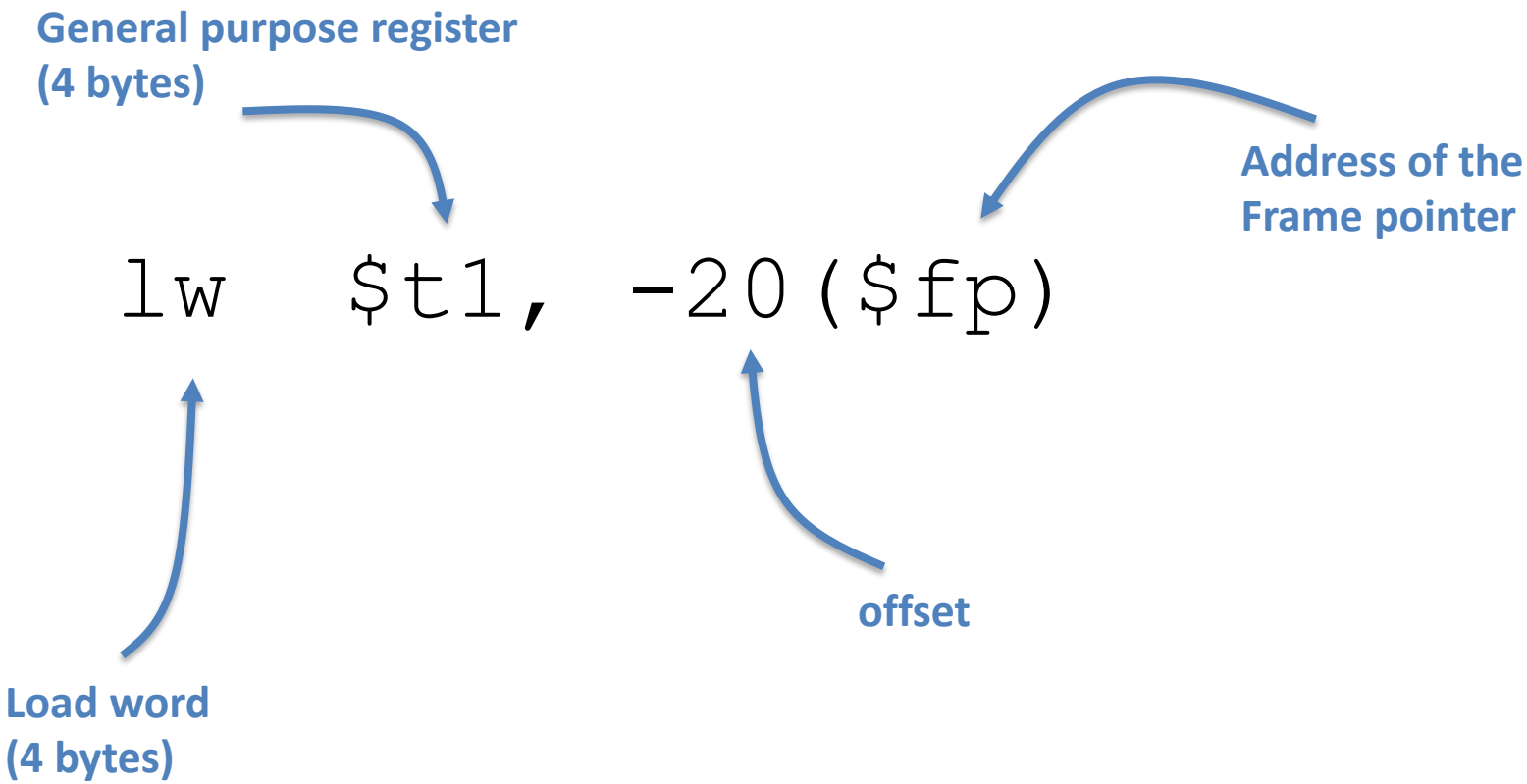
Basic memory operations

```
lw register memoryAddress

sw register memoryAddress
```

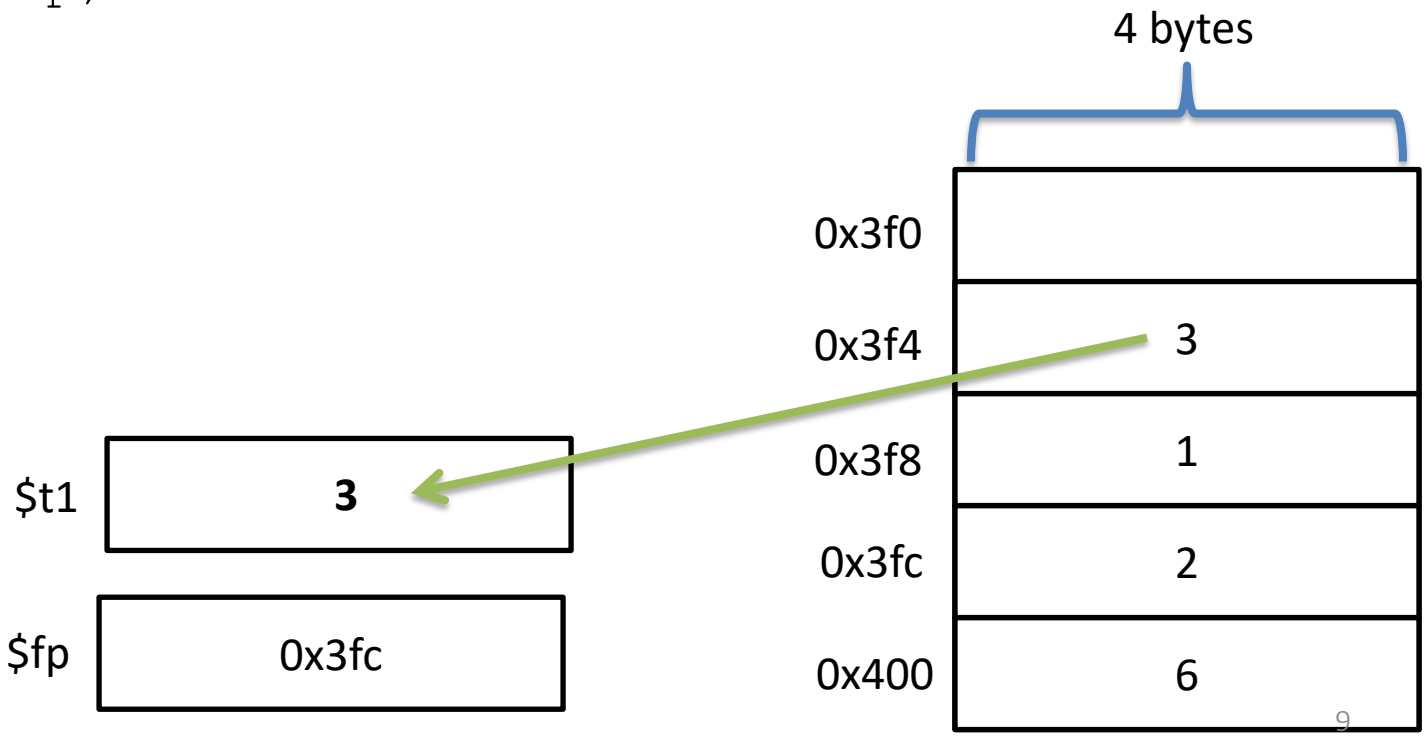
Load Word Example

```
opcode register memoryAddress
```



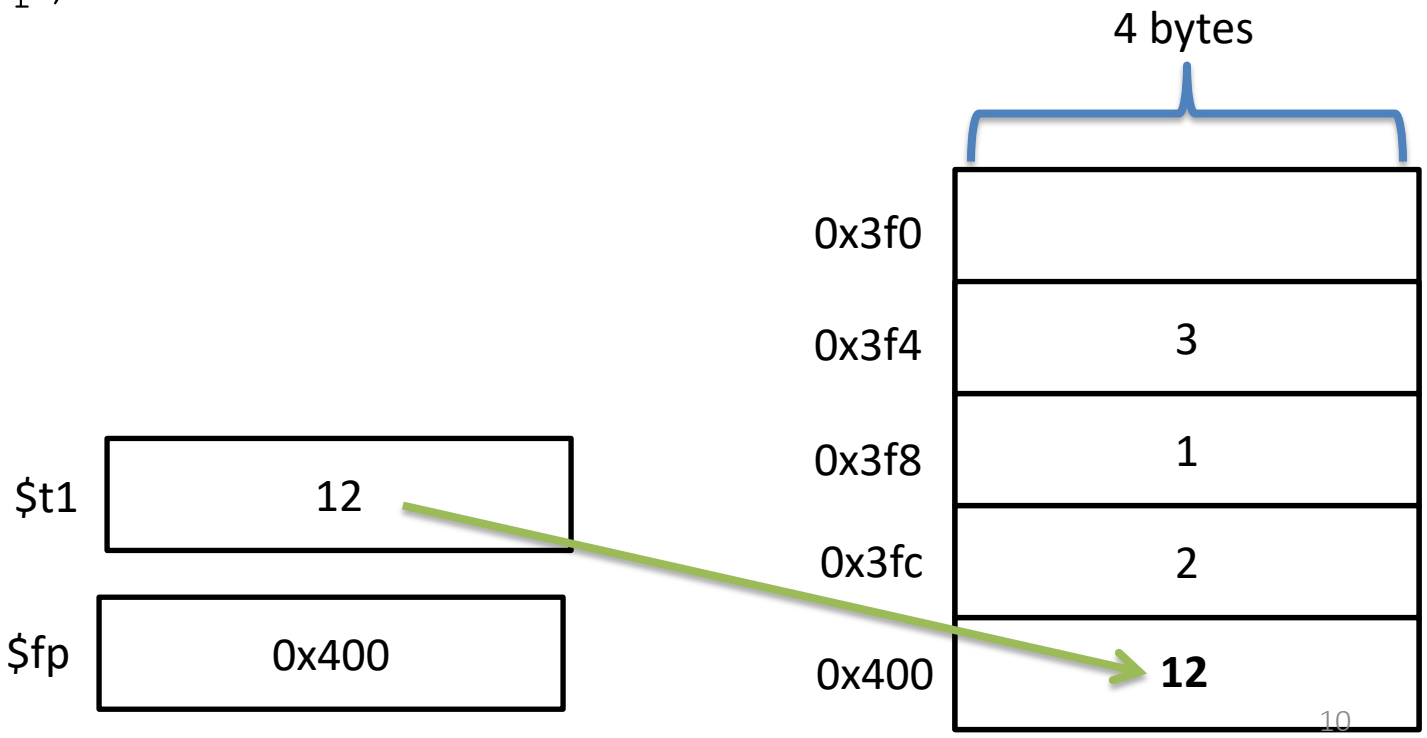
Load Word in Action

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



Store Word in Action

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



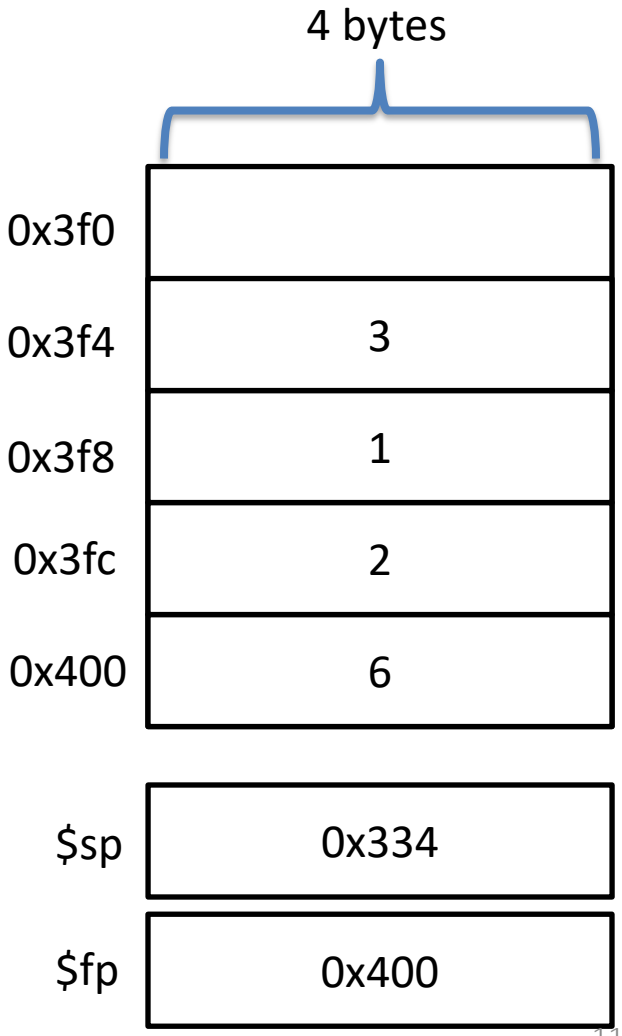
Relative Access for Locals

Why do we access locals from $fp?

- That's where the activation record starts

What if we used $sp instead?

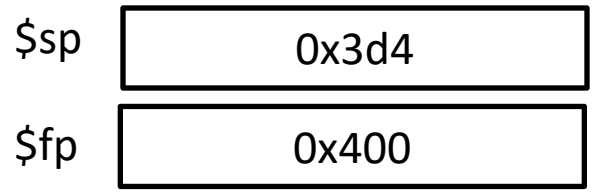
$sp keeps changing all the time, while $fp remains fixed. So all local variables are accessed with an offset from $fp, which is fixed throughout one function call.

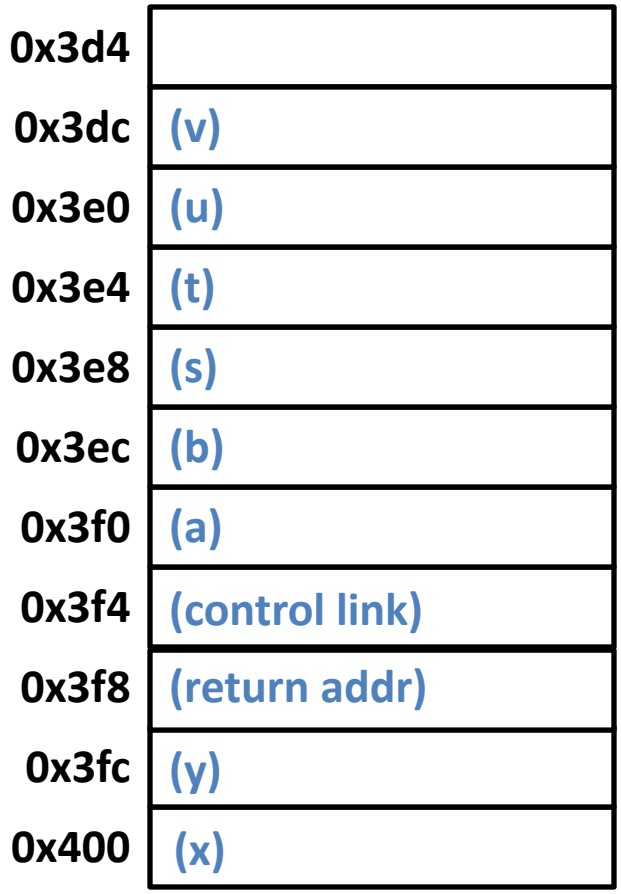


Simple Memory-Allocation Scheme

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
```

Assuming $fp points to the 1st parameter pushed by the caller. This's is a bit different from the lecture note, but consistent with the online note.

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;
  }
}
```

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

Static non-local scope memory access

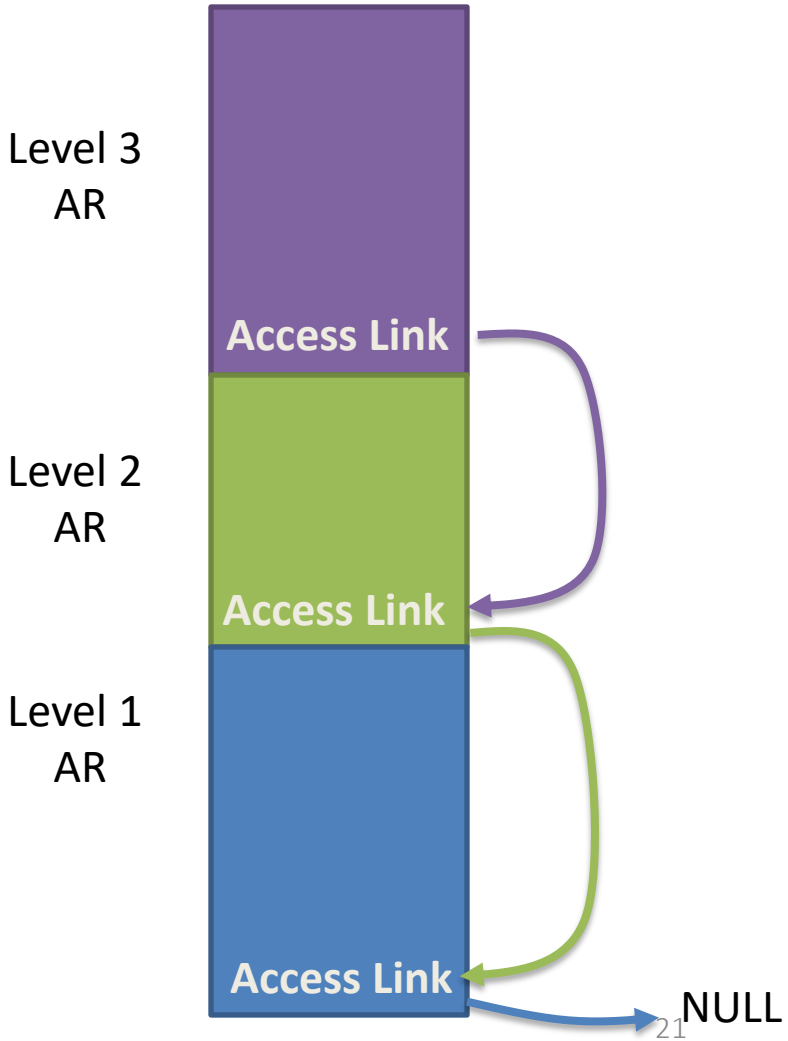
```
void procA(){  // level 1
  int x, y;
  void procB(){ // level 2

    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)



Two kinds of links:
control link: store $fp of the caller
access link: point to local areas of the **outer** function.

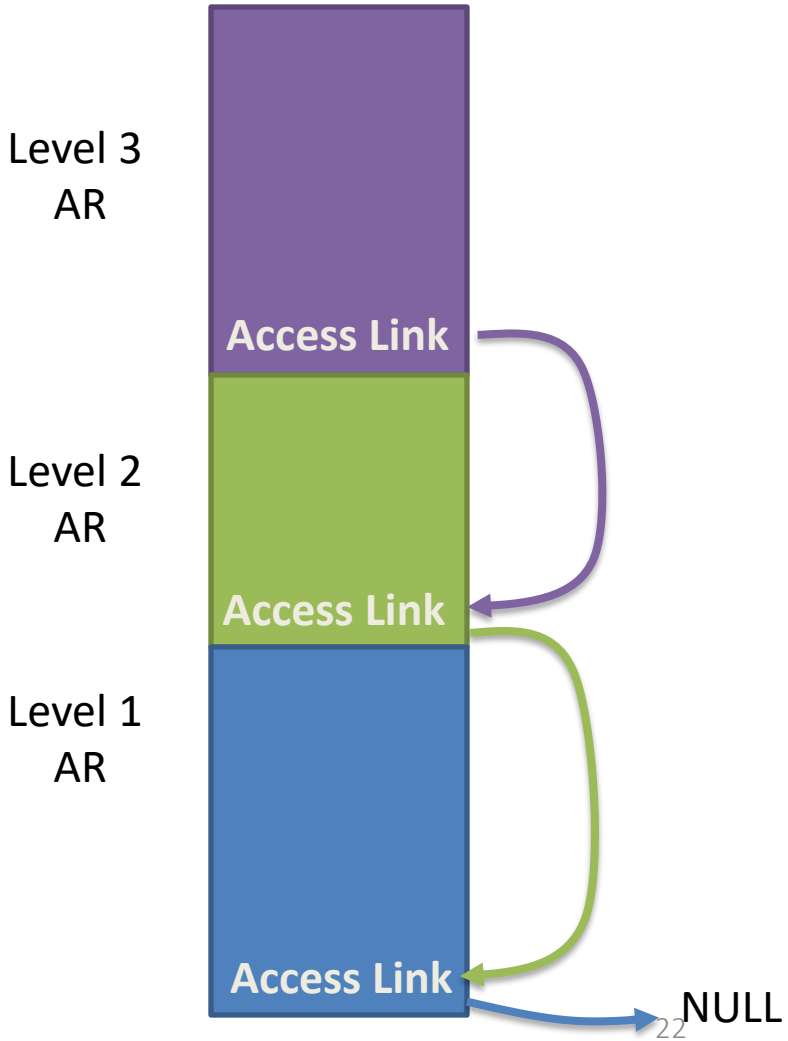
Note: outer function is not necessarily the caller!

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



Why the access link is needed when we already stored $fp of the caller?

Consider function f1 has a nested function f2 which refers to local variable in f1. Now f1 calls f2, which makes recursive call to f2 itself.

Now we have two f2 activation records above f1, but both want to access local variables defined in f1. In this case, simply storing $fp of the caller is not enough.
Caller function is not necessarily the outer function.

Setting up access links

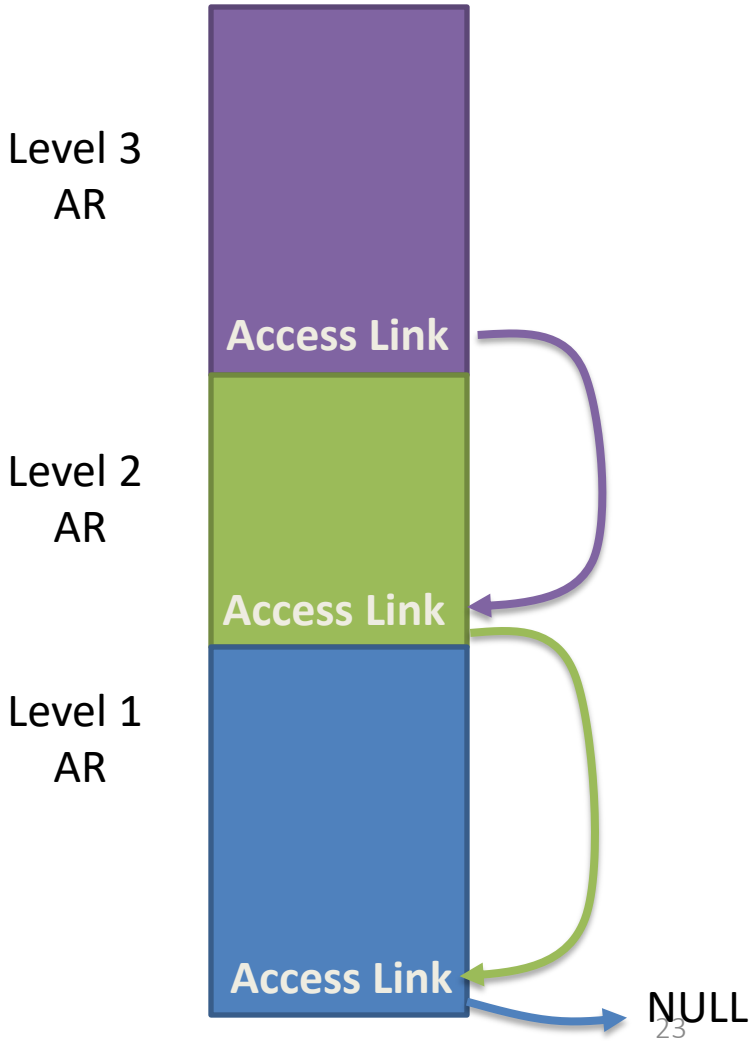
Using 1 access link

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

Where $fp -4 is the location of the access link and the variable in the outer scope is 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?

This is an option.

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

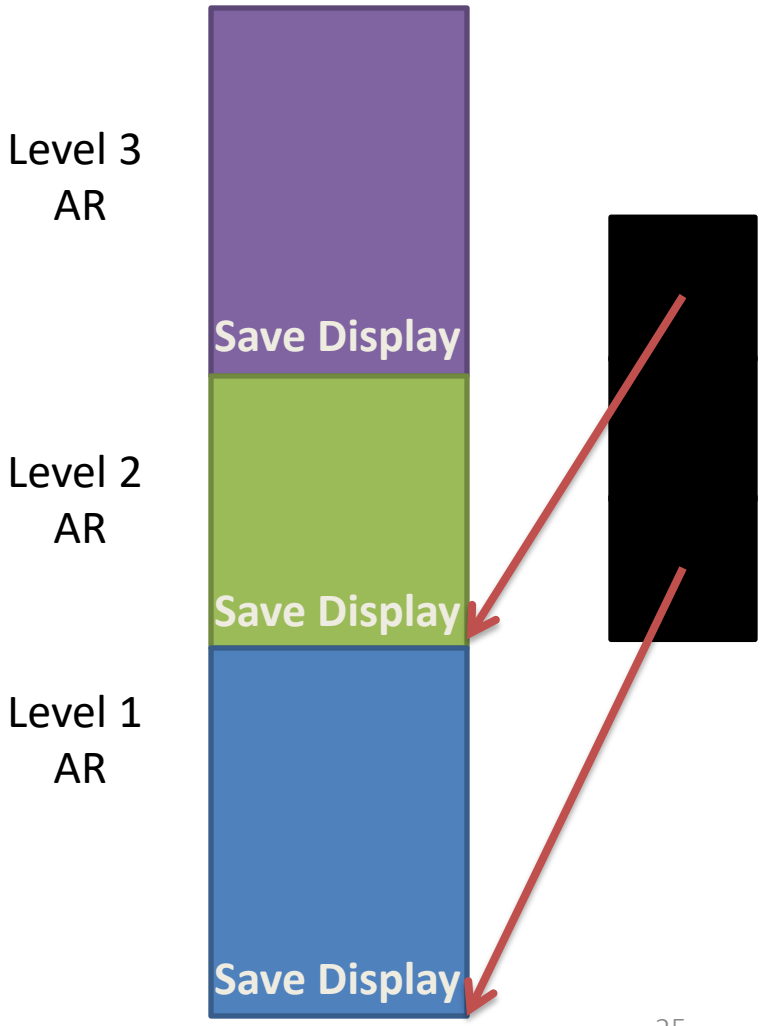
Displays

High-level idea:

- Keep the transitive effects of multiple access link traversals
- Uses a side-table of this info

Tradeoffs vs Access Links?

- Faster to call far up the hierarchy
- 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

Roadmap

We learned about variable access

- Local vs global variables
- Static vs dynamic scopes

Next time

- We'll start getting into the details of MIPS
- Code generation