Runtime Access to Variables

Roadmap

Last Time

- Parameter-passing conventions

This time

- How do we deal with variables and scope?
- How do we organize activation records?
- How do we retrieve values of variables from activation records?

Scope

We mostly worry about 3 flavors

- Local
  - Declared and used in the same function
  - Further divided into “block” scope in b
- Global
  - Declared at the outermost level of the program
- Non-local (i.e., from nested scopes)
  - For static scope: variables declared in an outer scope
  - 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

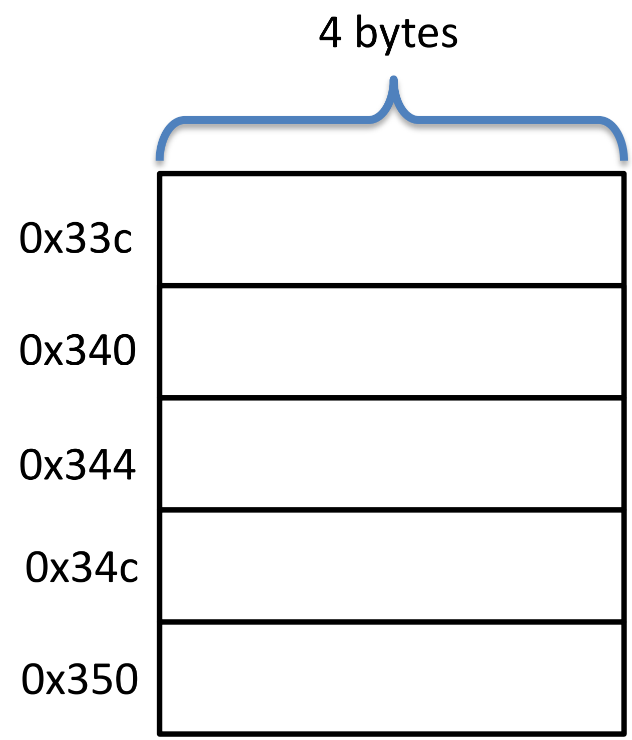
- Full tutorial next week
- General anatomy of a MIPS instruction

```
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

register = *memoryAddress;

*memoryAddress = register;

```
lw register memoryAddress
```

```
sw register memoryAddress
```

Load-Word Example

opcod

$t1 = *($fp - 20);

General pu
(4 bytes)

```
lw   $t1, -20($fp)
```

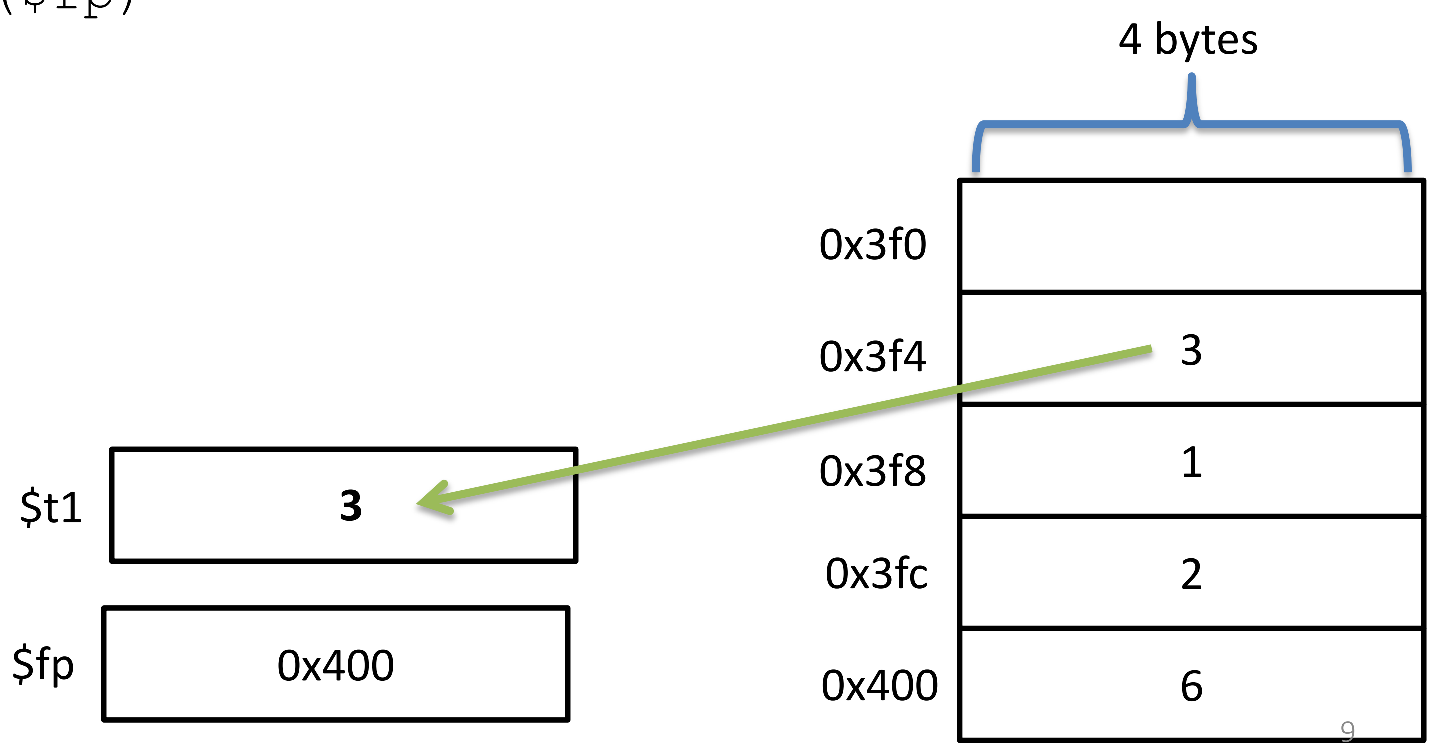
Address of the
Frame pointer

offset

Load word
(4 bytes)

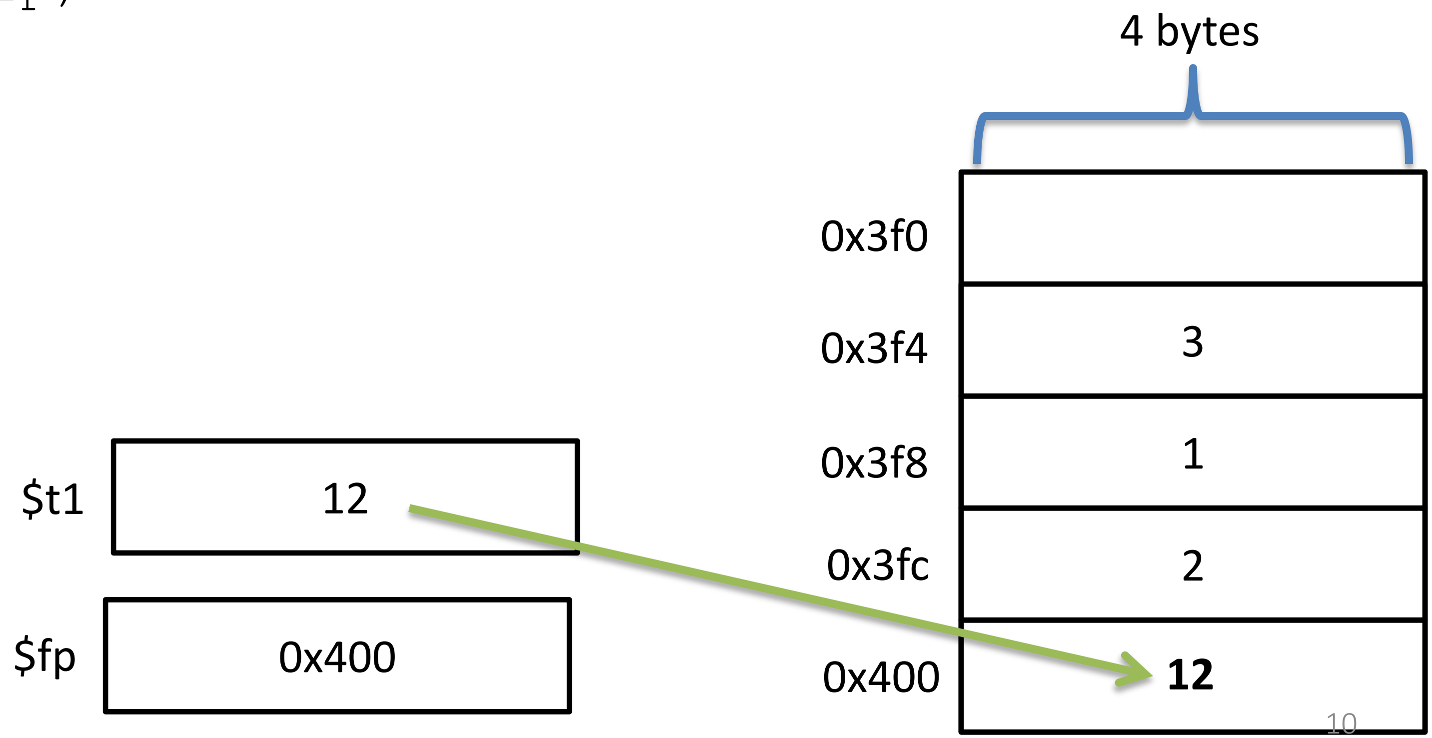
Load Word in Action

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



Store Word in Action

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

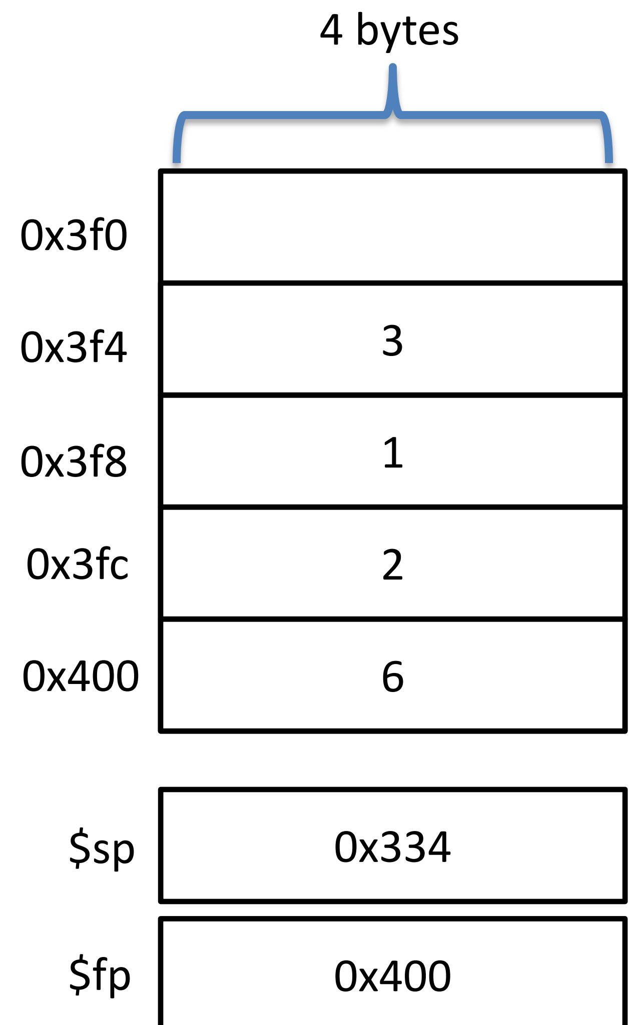


Relative Access for Locals

Why do we access locals from $fp?

- That's where the activation record starts

What if we used $sp instead?



A 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;
  }
}
```

$sp	0x3d4
$fp	0x3f8

0x3d4	
0x3dc	(v)
0x3e0	(u)
0x3e4	(t)
0x3e8	(s)
0x3ec	(b)
0x3f0	(a)
0x3f4	(control link)
0x3f8	(return addr)
0x3fc	(x)
0x400	(y)

Simple Memory-Allocation 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
```

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 x used that is not declared locally resolves to instance of x in the AR closest to the current AR

Example: Static Non-Local Scope

Each function has its own AR

– Inner function accesses the outer AR

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

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

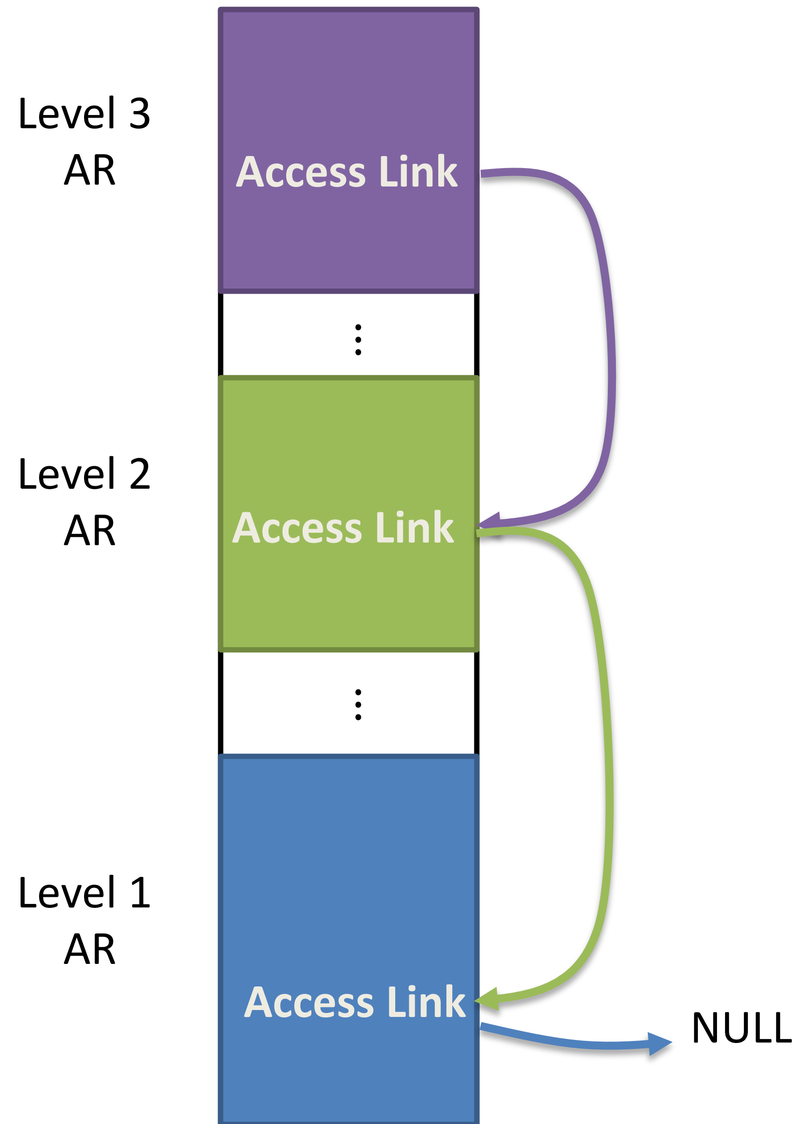
Memory Access: Static Non-Local Scope

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

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

Access Links

Add an additional field in the AR

- Points to the locals area of the outer function
- Sometimes called the static link (since it refers to the static nesting)

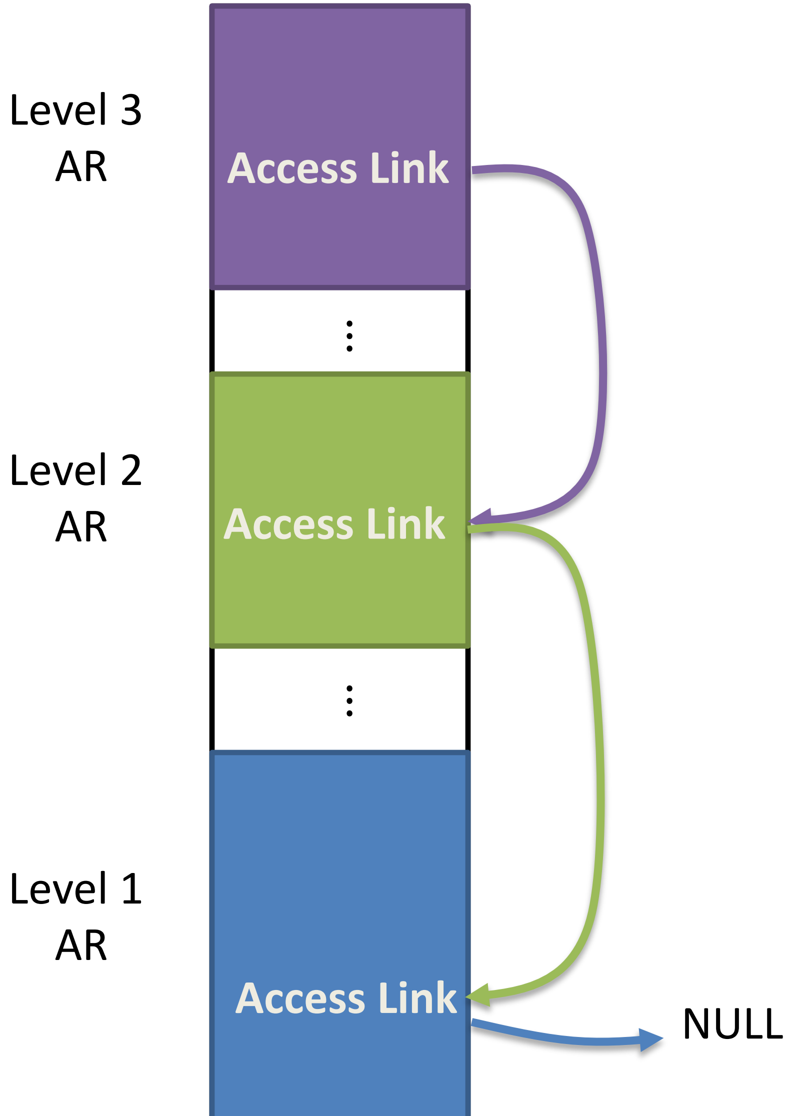


How Access Links Work

We know how many *levels* to traverse statically

- Example: When current scope is at nesting level 3 and the variable that we want to access is at nesting level 1: go back 2 access links

    (3 – 1) 2 levels



Traversing Stack Using Access Links

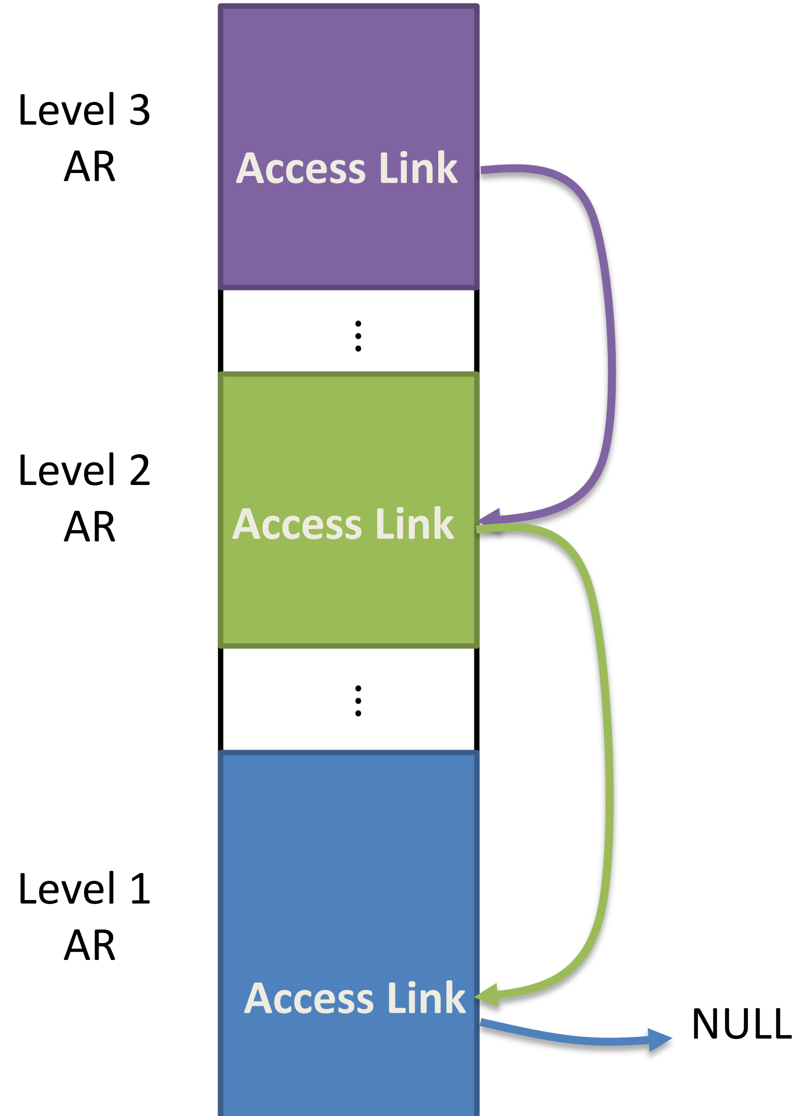
Using 1 access link

```
lw $t0, 0($fp)
lw $t0, -20($t0)
```

Where $fp is the location of the access link, and the variable in the outer scope is at offset 20 in its AR

Using 2 access links

```
lw $t0, 0($fp)
lw $t0, ($t0)
lw $t0, -20($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 $t0 380($fp)
```

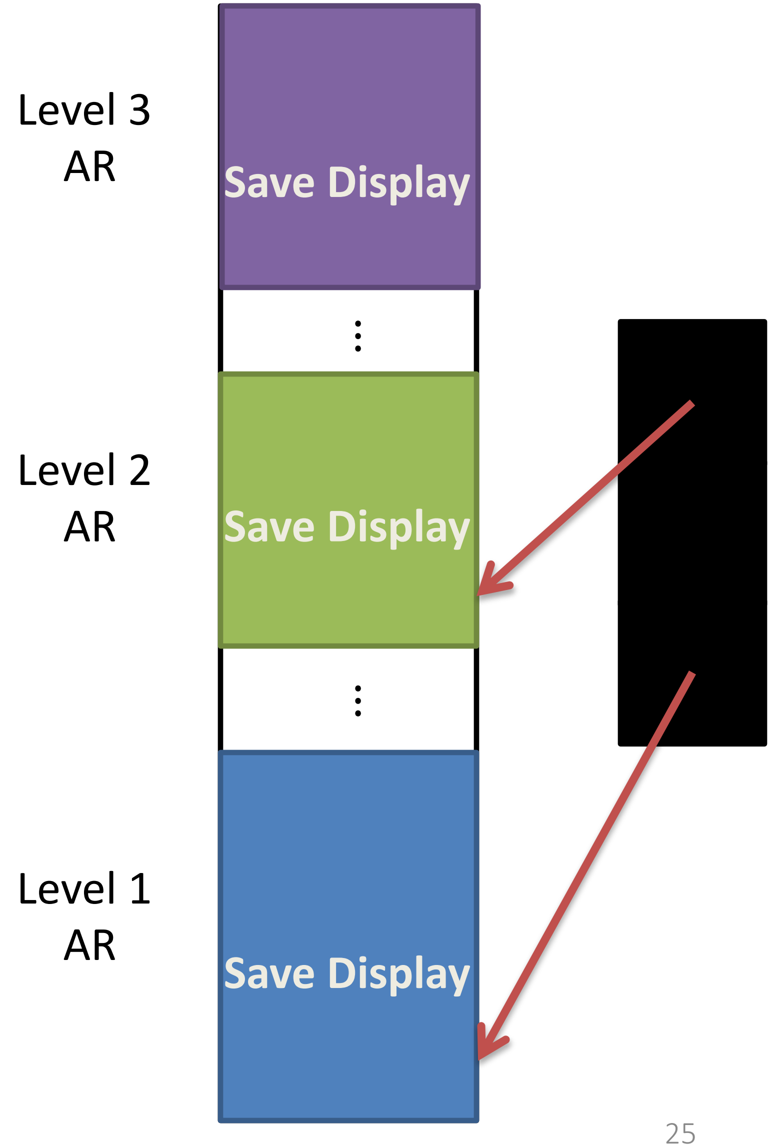
Displays

High-level idea:

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

Tradeoffs vs. Access Links?

- Faster to call far up the hierarchy
- Takes extra space
  - At most the maximum nesting depth in the entire program
  - Therefore, the display can be an array (a stack no bigger than a known maximum size)



Displays (Example)

```
program Main;
  var x: integer;

  procedure P;
    write(x);

  procedure Q;

    call R;
    call P;
    if x < 5 call Q;

  x = 2;
  call P;
  call Q;
```

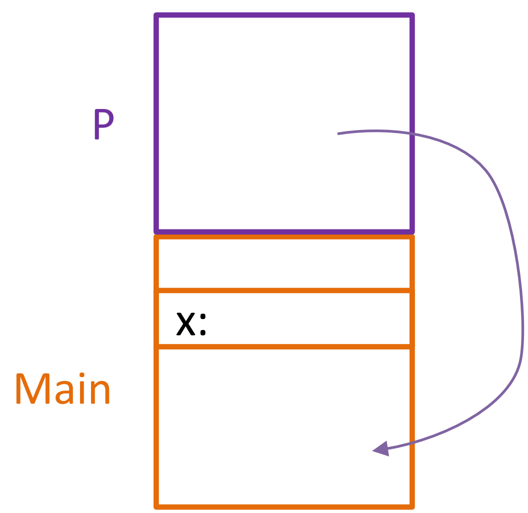
Level (1)

Level (2)

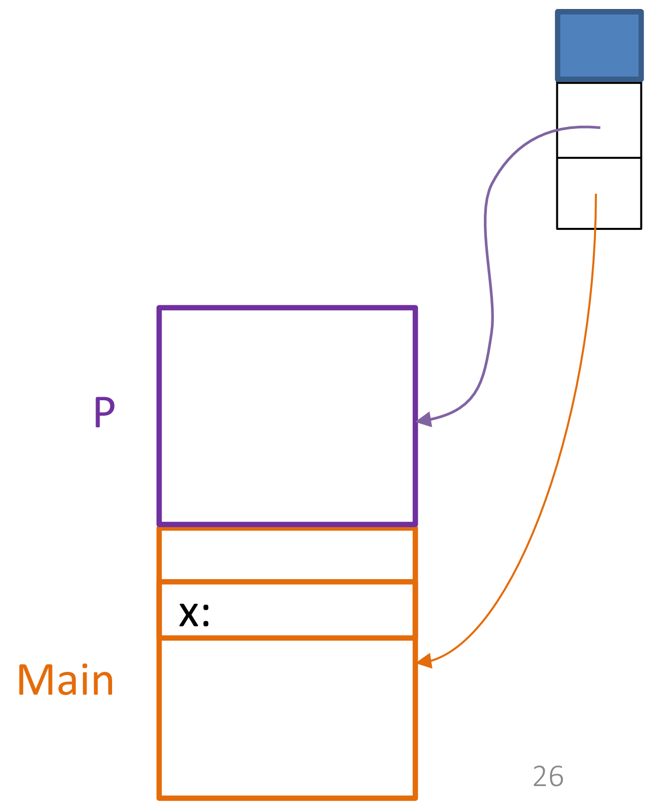
Level (2)

Level (3)

With access links



With a display



Displays (Example)

```
program Main;
  var x: integer;

  procedure P;
    write(x);

  procedure Q;
    var y: integer = x;

    procedure R;
      x = x + 1;
      y = y + x;
      if y<6 call R;
      call P

    call R;
    call P;
    if x < 5 call Q;

  x = 2;
  call P;
  call Q;
```

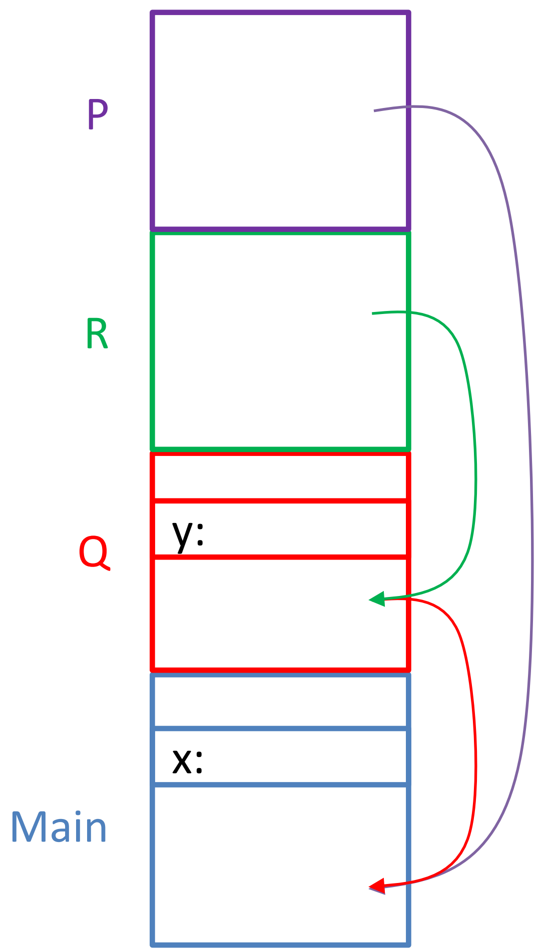
Level (1)

Level (2)

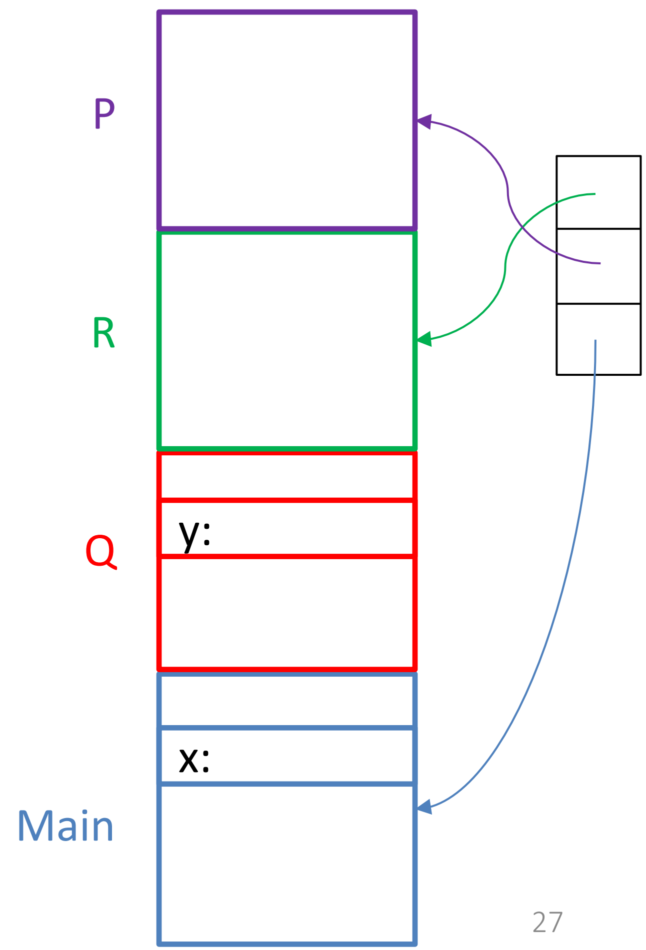
Level (2)

Level (3)

With access links



With a display

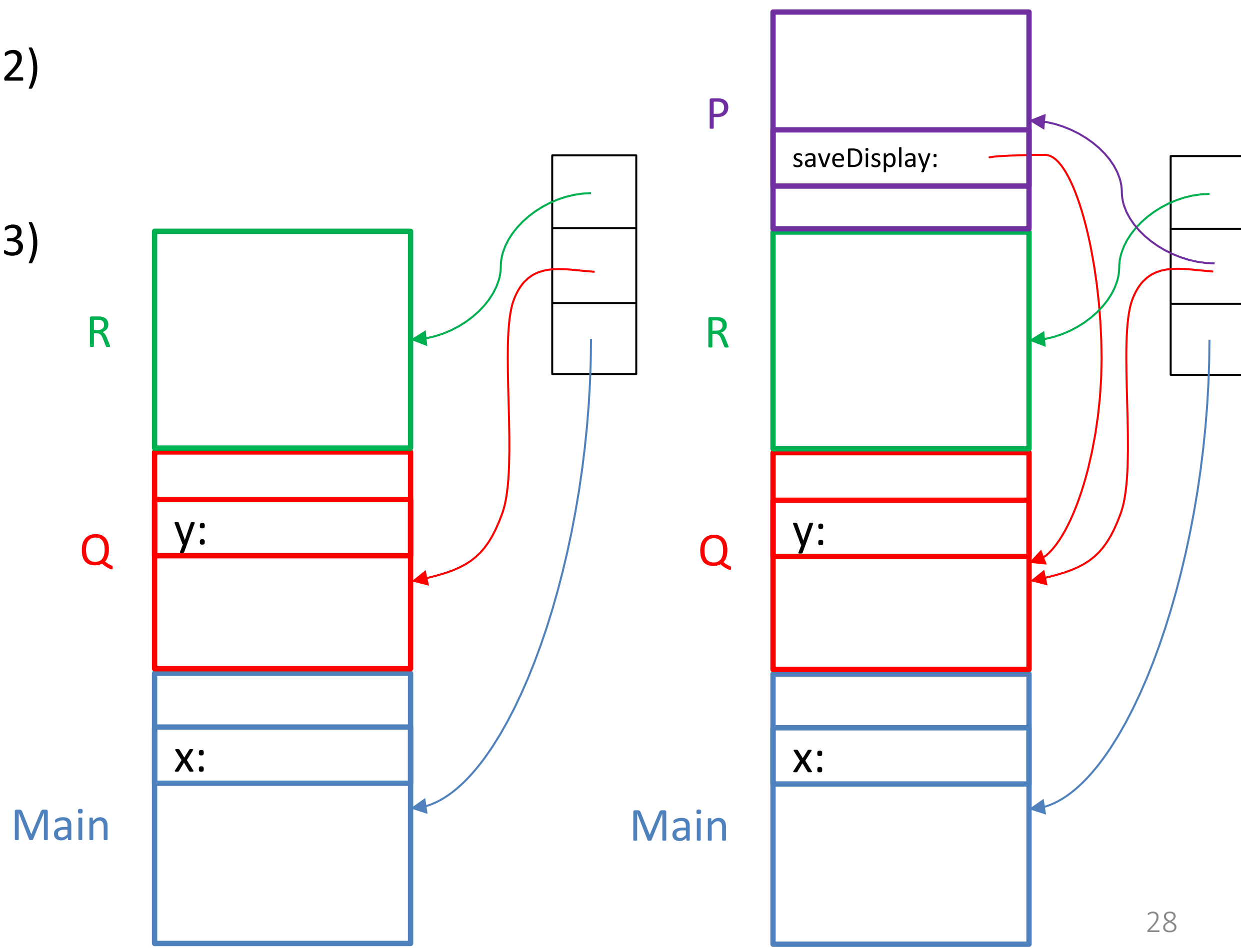


Displays (Example)

```
program Main;                       Level (1)
  var x: integer;

  procedure P;                      Level (2)
    write(x);

  procedure Q;                      Level (2)
    var y: integer = x;

    procedure R;                    Level (3)
      x = x + 1;
      y = y + x;
      if y<6 call R;
      call P

    call R;
    call P;
    if x < 5 call Q;

  x = 2;
  call P;
  call Q;
```

Before R calls P

With a display



Questions about Static Scope?

Example: Dynamic Non-Local Scope

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

function fun1(){
    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 *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 a function call on entry to function F
  - F saves, in its own AR, the current values of all of the variables that F declares itself
  - F restores those values when it finishes

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