CS 536

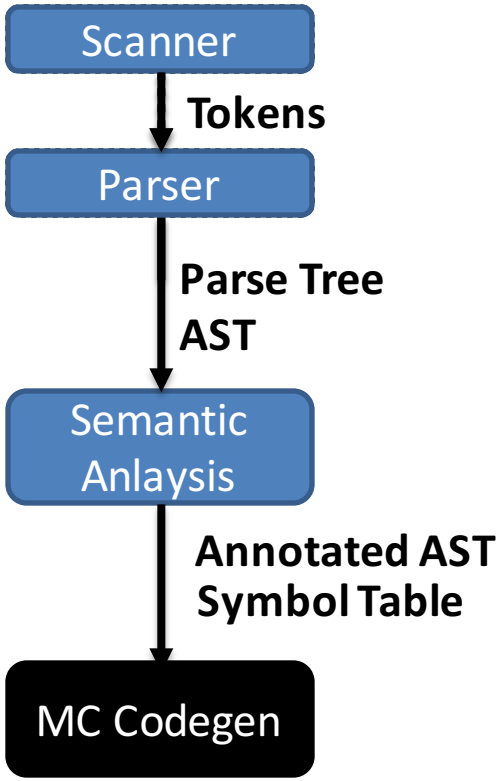
Code Generation, Continued

How to be a MIPS Master

- It's really easy to get confused with assembly
  - Try writing a program by hand before having the compiler generate it
  - Draw lots of pictures of program flow
  - Have your compiler output detailed comments
- Get help
  - Post on piazza

Roadmap

- Last time:
  - Talked about compiler backend design points
  - Decided to go with direct to machine code design for our language
- This time:
  - Run through what the actual codegen pass will look like



Review: Global Variables

- Showed you one way to do declaration last time:

```
.data
.align 2
_name: .space 4
```

- Simpler form for primitives:

```
.data
_name: .word <value>
```

Review: Functions

- Preamble
  - Sort of like the function signature
- Prologue
  - Set up the function
- Body
  - Do the thing
- Epilogue
  - Tear down the function

Function Preambles

```
int f(int a, int b){
    int c = a + b;
    int d = c - 7;
    return c;
}
```

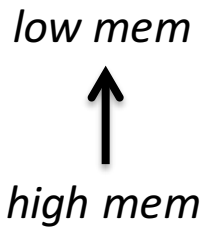
```
.text
f:
#... Function body ...
```

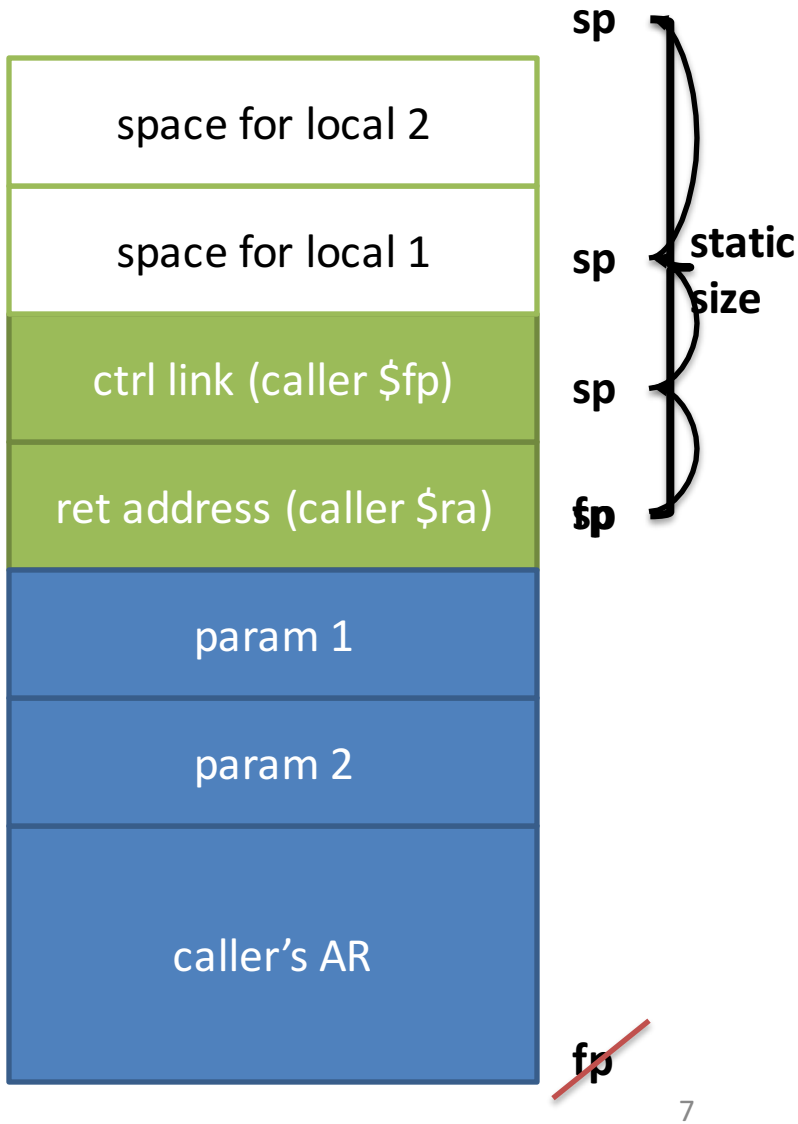
This label gives us something to jump to

```
jal f
```

Function Prologue

- Recall our view of the Activation Record
  1. save the return address
  2. save the frame pointer
  3. make space for locals
  4. update the frame ptr





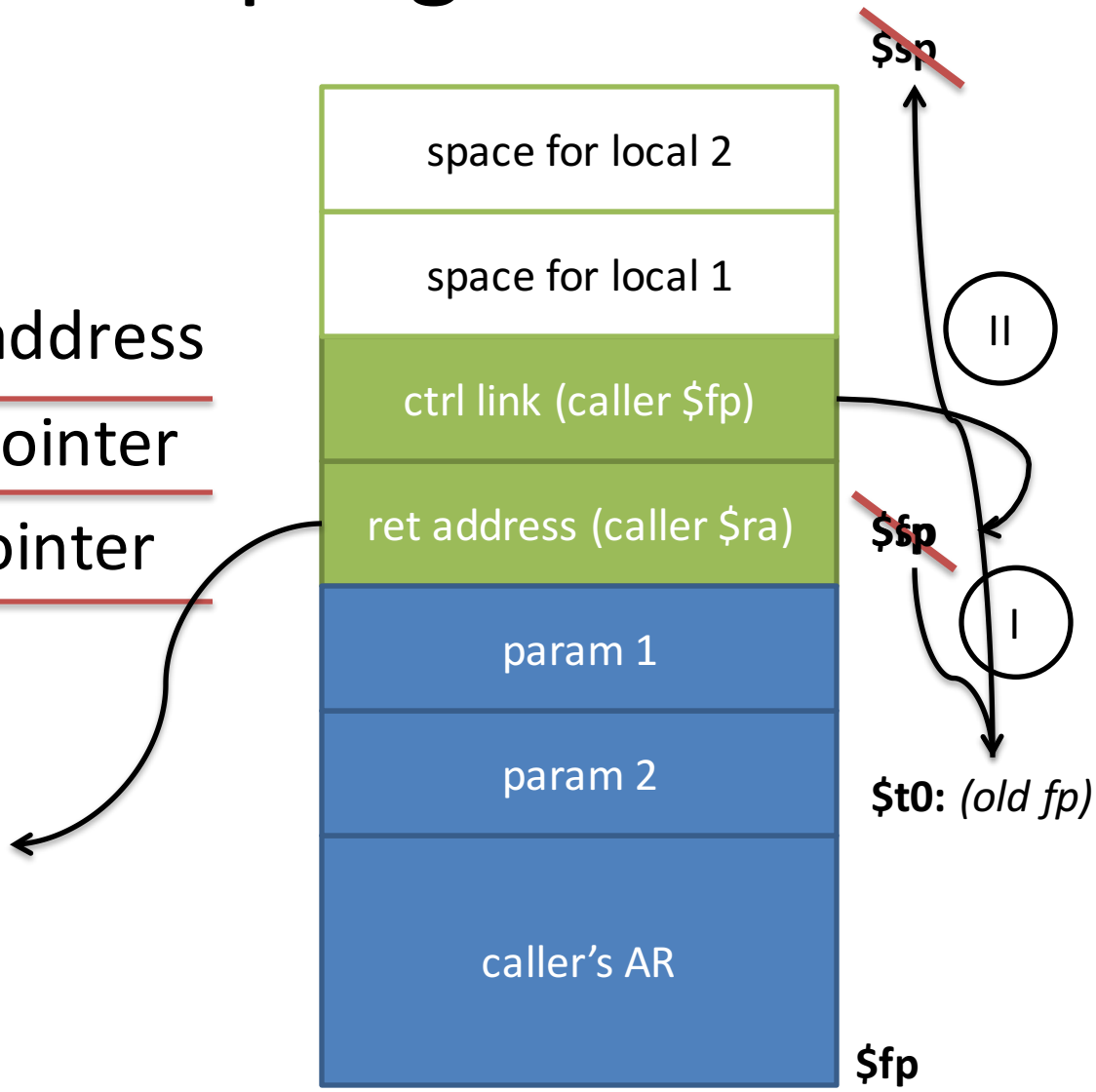
Function Prologue: MIPS

- Recall our view of the Activation Record
  1. save the return address
  2. save the frame pointer
  3. make space for locals
  4. update the frame ptr

```
.text
f:
  sw $ra 0($sp)    #call lnk
  subu $sp $sp 4   # (push)
  sw $fp 0($sp)    #ctrl lnk
  subu $sp $sp 4   # (push)
  subu $sp $sp 8   #locals
  addu $fp $sp 16 #update fp
```

Function Epilogue

- Restore Caller AR
  1. restore return address
  2. restore frame pointer
  3. restore stack pointer
  4. return control



Function Epilogue: MIPS

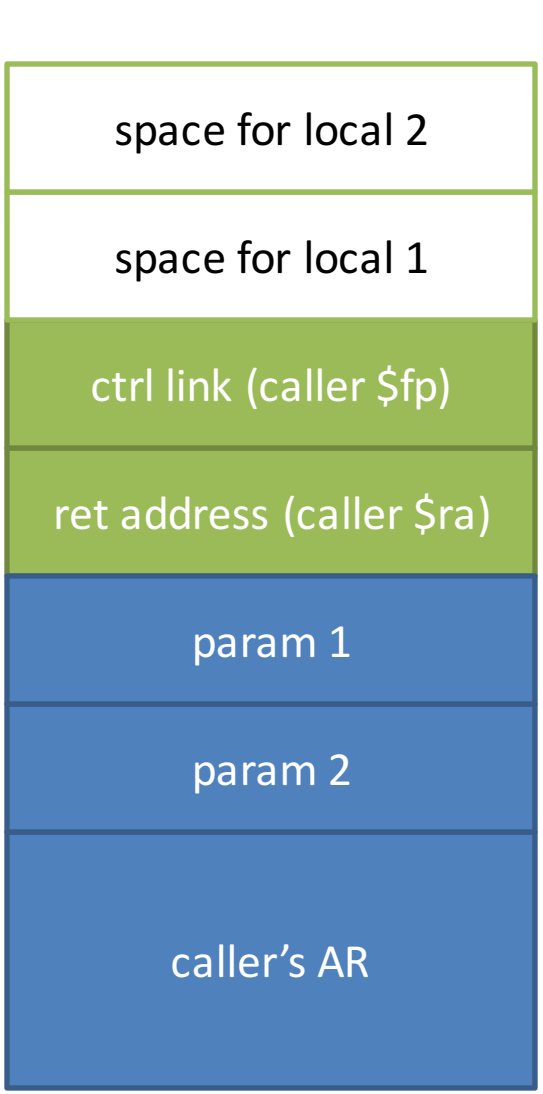
- Restore Caller AR
  1. restore return address
  2. restore frame pointer
  3. restore stack pointer
  4. return control

```
.text
f:
   sw $ra 0($sp)
   subu $sp $sp 4
   sw $fp 0($sp)
   subu $sp $sp 4
   subu $sp $sp 8
   addu $fp $sp 16
   #... Function body ...
   lw $ra, 0($fp)
   move $t0, $fp
   lw $fp, -4($fp)
   move $sp, $t0
   jr $ra
```

Function Body

- Obviously, quite different based on content
  - Higher-level data constructs
    - Loading parameters, setting return
    - Evaluating expressions
  - Higher-level control constructs
    - Performing a call
    - Loops
    - Ifs

Function Locals

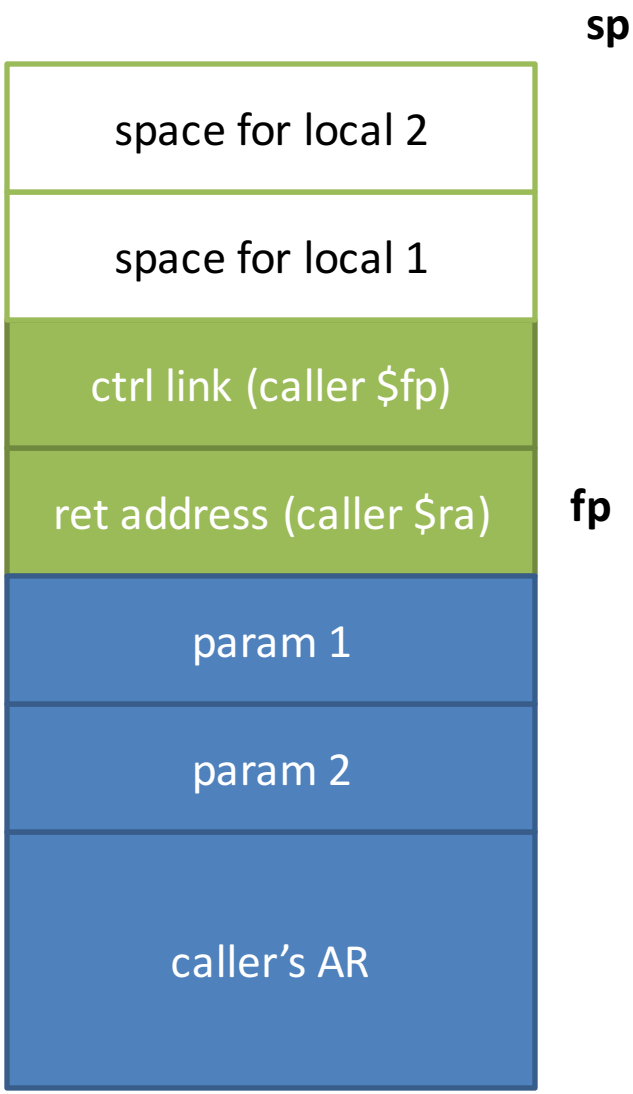



```
.text
f:
    # … prologue … #
    lw $t0, -8($fp)
    lw $t1, -12($fp)



    # … epilogue … #
```

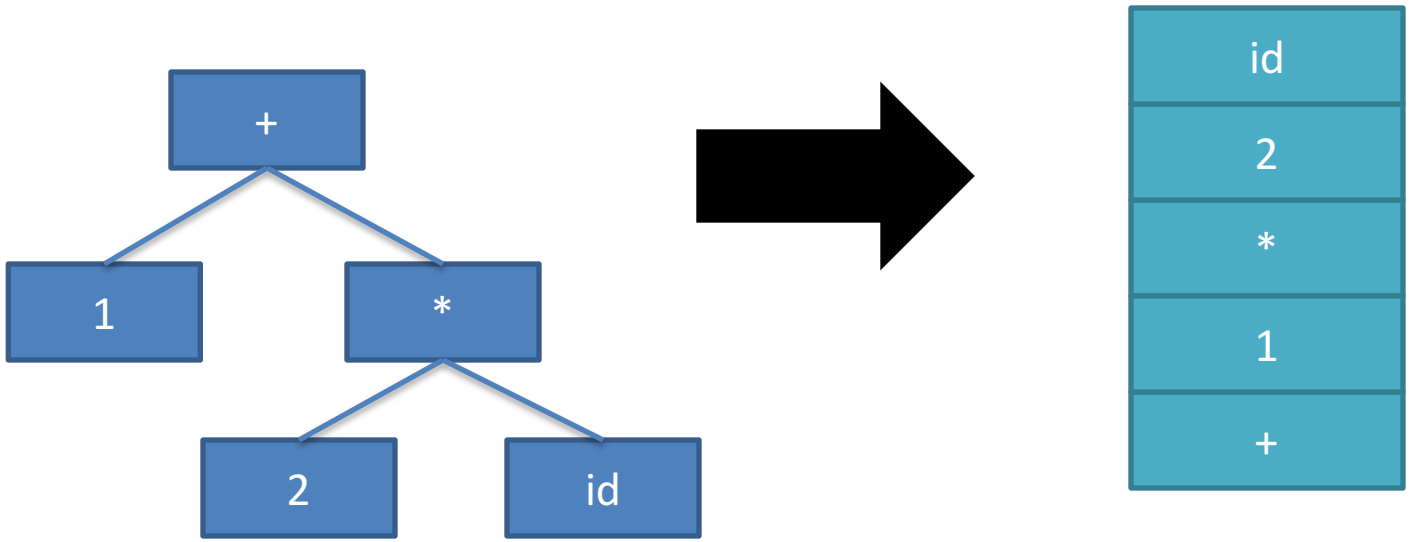
Function Returns




```
.text
f:
    # … prologue … #
    lw $t0, -8($fp)
    lw $t1, -12($fp)
    lw $v0, -8($fp)
    j f_exit
f_exit:
    # … epilogue … #
```

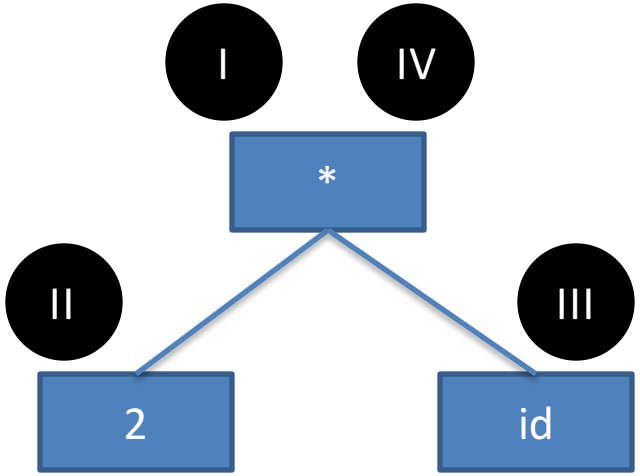
Function Body: Expressions

- Goal
  - Serialize ("flatten") an expression tree
- Use the same insight as the parser
  - Use a work stack and a post-order traversal



Serialized Psuedocode

- Key insight
  - Use the stack pointer location as “scratch space”
  - At operands: push value onto the stack
  - At operators: pop source values from stack, push result




```
push 2
push id
pop id into t1
pop 2 into t0
mult t0 * t1 into t0
push t0
```

$t1 = id

$t0 = ~~2~~ 2 * id

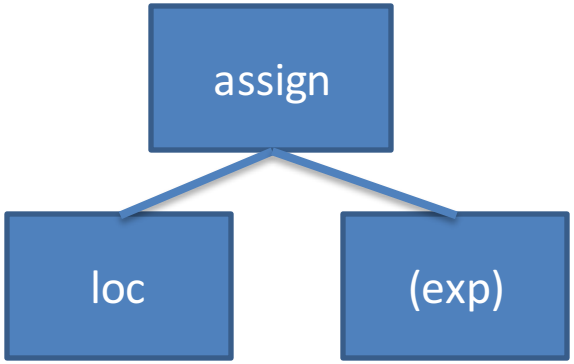
Serialized MIPS

L1: push 2
L2: push id
L3: pop id into t1
L4: pop 2 into t0
L5: mult t0 * t1 into t0
L6: push t0

```
L1: li $t0 2
    sw $t0 0($sp)
    subu $sp $sp 4
L2: lw $t0 id
    sw $t0 0($sp)
    subu $sp $sp 4
L3: lw $t1 4($sp)
    addu $sp $sp 4
L4: lw $t0 4($sp)
    addu $sp $sp 4
L5: mult $t0 $t0 $t1
L6: sw $t0 0($sp)
    subu $sp $sp 4
```

Stmts

- By the end of the expression, our stack isn't exactly as we left it
  - Contains the result of the expression
  - This is by design

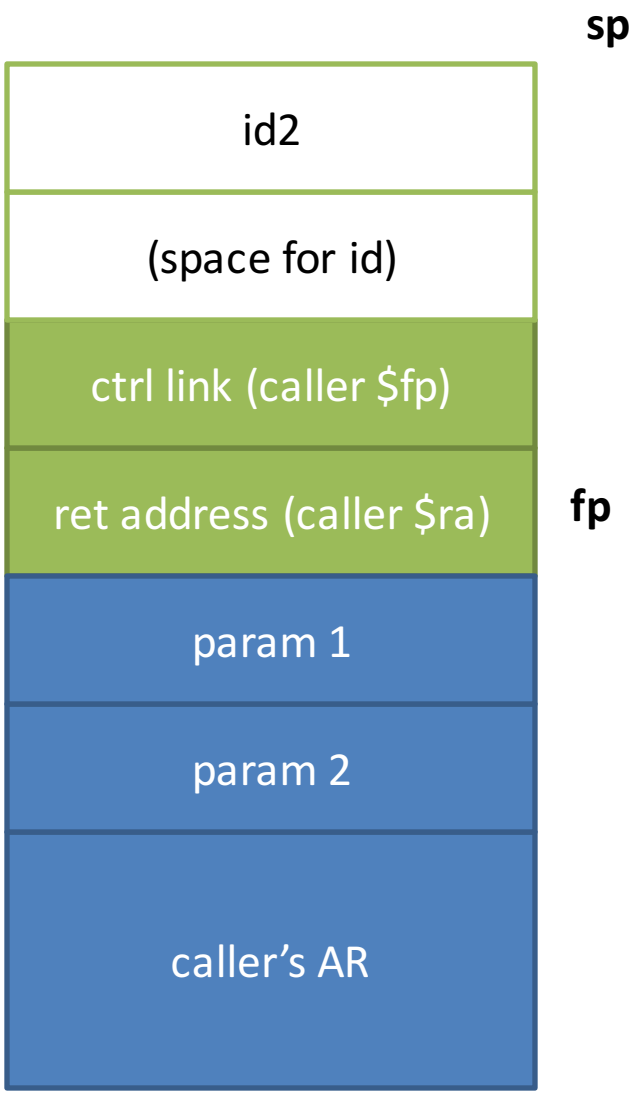


1) Compute RHS expr on stack
2) Compute LHS *location* on stack
3) Pop LHS into $t1
4) Pop RHS into $t0
5) Store value $t0 at address $t1

Simple Assign, You Try

- Generate stack-machine style MIPS code for

  id = 1 + 2;



Algorithm

1) Compute RHS expr on stack
2) Compute LHS *location* on stack
3) Pop LHS into $t1
4) Pop RHS into $t0
5) Store value $t1 at address $t0

Dot Access

- Fortunately, we know the offset from the base of a struct to a certain field statically
  - The compiler can do the math for the slot address
  - This isn't true for languages with pointers!

```
struct Demo inst;
struct Demo inst2;
inst.b.c = inst2.b.c + 1;
```

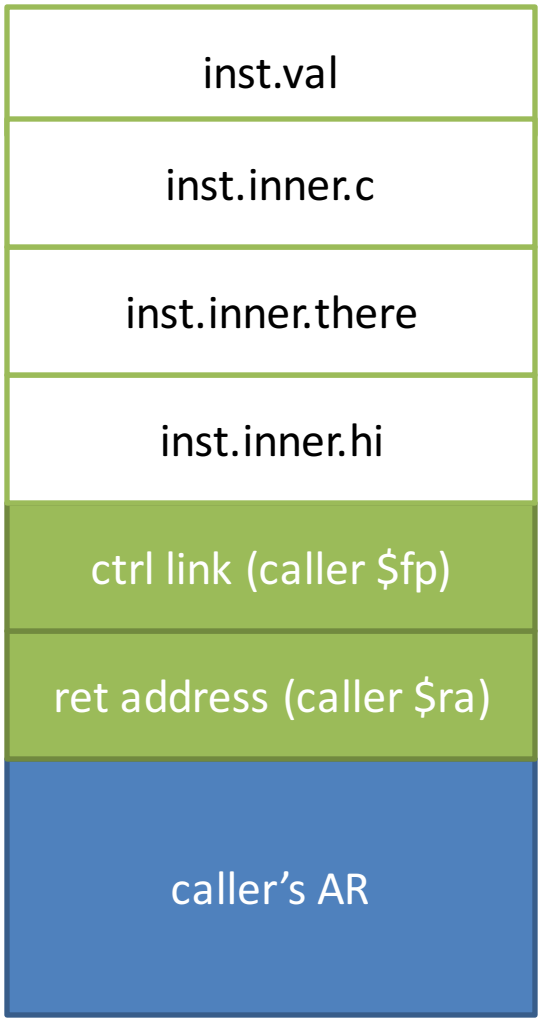
load this address load this value

Dot Access Example

```
void v(){
    struct Inner{
      bool hi;
      int there;
      int c;
    };
    struct Demo{
      struct Inner b;
      int val;
    };
    struct Demo inst;
    inst.b.c = inst.b.c;
}
```

inst is based at -8($fp)

field b.c is -8 off the base



LHS

```
subu $t0 $fp 16
sw $t0 0($sp)
```

RHS

```
lw $t0 -16($fp)
sw $t0 0($sp)
subu $sp $sp 4
```

Control Flow Constructs

- Function Calls
- Loops
- Ifs

Function Call

- Two tasks:
  - Put argument *values* on the stack (pass-by-value semantics)
  - Jump to the callee preamble label
  - Bonus 3rd task: save *live* registers
    - (We don't have any in a stack machine)
  - Semi-bonus 4th task: retrieve result value

Function Call Example

```
int f(int arg1, int arg2){
  return 2;
}
int main(){
  int a;
  a = f(a,4);
}
```

```
li $t0 4          # push arg 2
sw $t0 0($sp)     #
subu $sp $sp 4    #
lw $t0 -8($fp)    # push arg 1
sw $t0 0($sp)     #
subu $sp $sp 4    #
jal f             # goto f
addu $sp $sp 8    # tear down params
sw $v0 -8($fp)    # retrieve result
```

Generating If-then Stmts

- First, get names for the true and false, and successor labels
- Generate the head of the loop
  - Make calls to the (not-yet placed!) true and false labels
- Generate the true branch
  - Place the true label
  - Write the body of the branch
  - Jump to the (not-yet placed!) successor label
- Generate the false branch (just like the true branch)
- Place the successor label

If-then Stmts

```
…
if (val == 1){
   val = 2;
}
…
```

```
  lw $t0 val        # evaluate condition LHS
  sw $t0 0($sp)     # push onto stack
  subu $sp $sp 4    #
  li $t0 1          # evaluate condition RHS
  sw $t0 0($sp)     # push onto stack
  subu $sp $sp 4    #
  lw $t1 4($sp)     # pop RHS into $t1
  addu $sp $sp 4    #
  lw $t0 4($sp)     # pop LHS into $t0
  addu $sp $sp 4    #
  bne $t0 $t1 L_0   # skip if condition false
  li $t0 2          # Loop true branch
  sw $t0 val
  j L_0             # end true branch
L_0:                # branch successor
  …
```

If-then-else Stmts

```
…
if (val == 1){
   val = 2;
} else {
   val = 3;
}
…
```

```
   lw $t0 val          # evaluate condition LHS
   sw $t0 0($sp)       # push onto stack
   subu $sp $sp 4      #
   li $t0 1            # evaluate condition RHS
   sw $t0 0($sp)       # push onto stack
   subu $sp $sp 4      #
   lw $t1 4($sp)       # pop RHS into $t1
   addu $sp $sp 4      #
   lw $t0 4($sp)       # pop LHS into $t0
   addu $sp $sp 4      #
   bne $t0 $t1 L_1     # branch if condition false
   li $t0 2            # Loop true branch
   sw $t0 val
   j L_0               # end true branch
L_1:                   # false branch
   …
L_0:                   # branch successor
```

Generating While Loops

- Very similar to if-then stmts
  - Generate a bunch of labels
  - Label for the head of the loop
  - Label for the successor of the loop
- At the end of the loop body
  - Unconditionally jump back to the head

While Loop

```
while (val == 1){
    val = 2;
}
```

```
L_0:
  lw $t0 val          # evaluate condition LHS
  sw $t0 0($sp)       # push onto stack
  subu $sp $sp 4      #
  li $t0 1            # evaluate condition RHS
  sw $t0 0($sp)       # push onto stack
  subu $sp $sp 4      #
  lw $t1 4($sp)       # pop RHS into $t1
  addu $sp $sp 4      #
  lw $t0 4($sp)       # pop LHS into $t0
  addu $sp $sp 4      #
  bne $t0 $t1 L_1     # branch loop end
  li $t0 2            # Loop body
  sw $t0 val
  j L_0               # jump to loop head
L_1:                  # Loop successor
  …
```

P6 Helper Functions

- Generate (opcode, …args…)
  - Generate(“add”, “T0”, “T0”, “T1”)
    - writes out `add $t0, $t0, $t1`
  - Versions for fewer args as well
- Generate indexed (opcode, “Reg1”, “Reg2”, offset)
- GenPush(reg) / GenPop(reg)
- NextLabel() – Gets you a unique label
- GenLabel(L) –Places a label

QtSpim