CS 536

Code Generation, Continued

Announcements

No Discussion Section

- Not enough interest

P6 is Posted

- Consider at least looking at the project as soon as possible
- We'll go through *basically* everything you need to know today

MIPS Screencasts are (Almost) Up

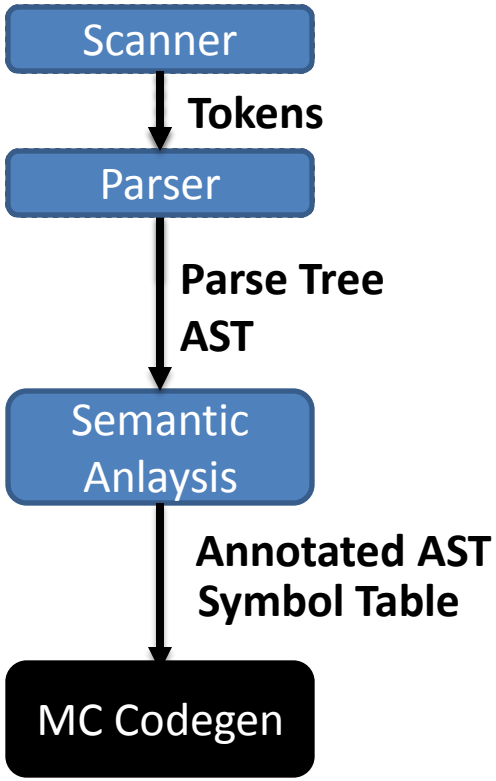
- Broken into several subsections
  - Setting up QtSpim
  - Global data
  - Stack
  - AR code

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
  - Ask me
  - Consult the (nearly-operational)

Roadmap

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



Outline

- Talk about evaluating different node types
- Discuss some useful helper functions
  - Available in Project 6
- We have time to discuss CodeGen
  - Ask questions or we'll blaze through it

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;
}
```

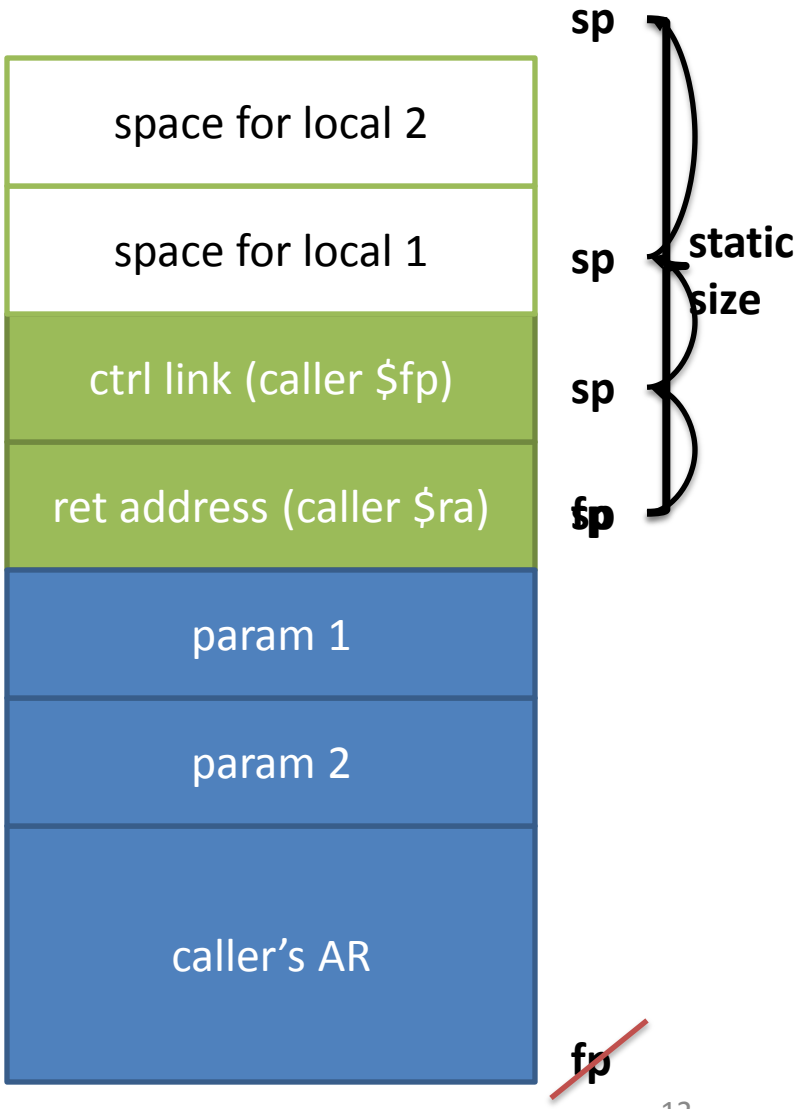
```
.text
f:
#... Function body ...
```

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



low mem

high mem

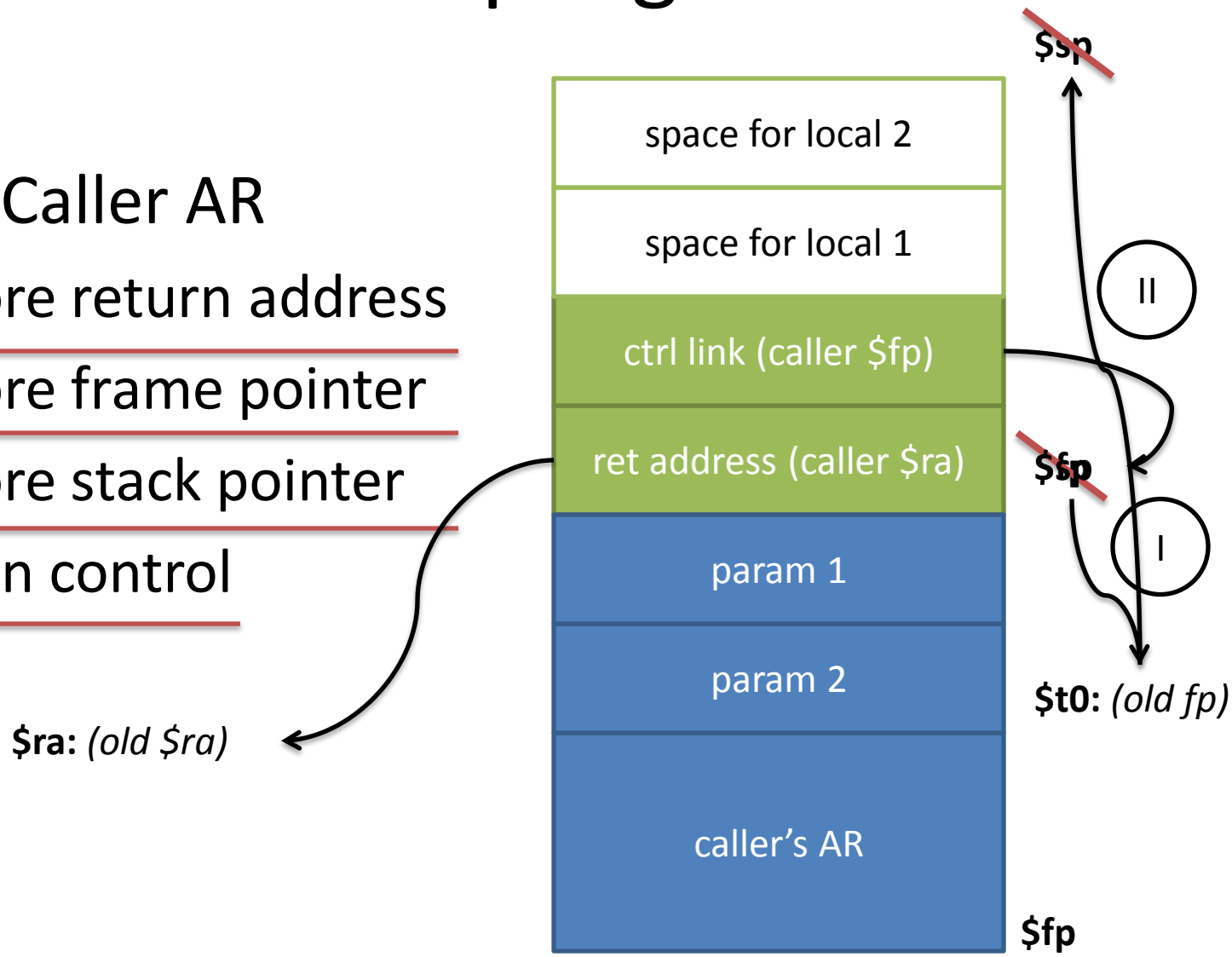
Function Prologue: MIPS

- 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

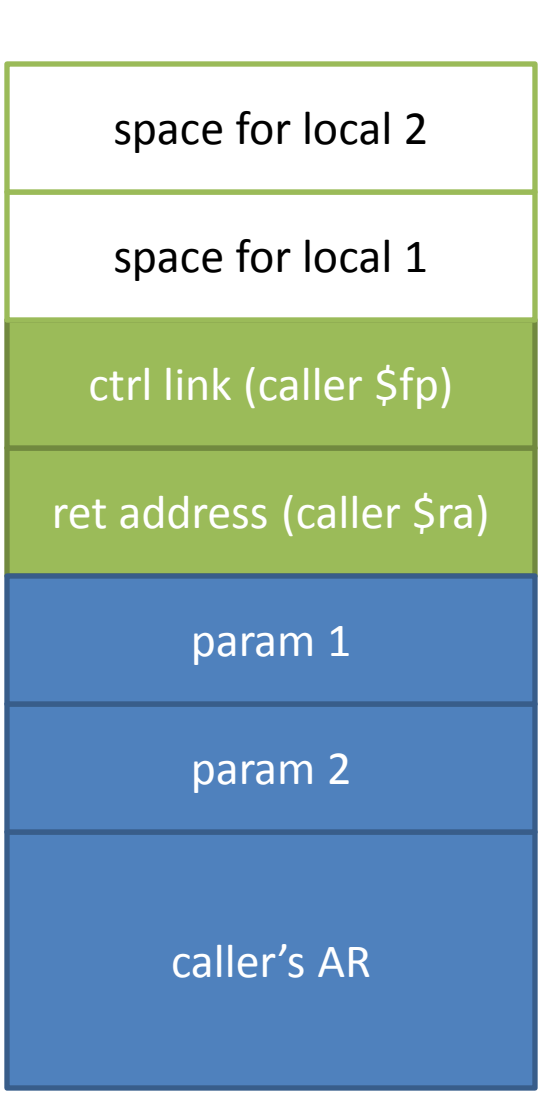
- Restore Caller AR
  1. restore return address
  2. restore frame pointer
  3. restore stack pointer
  4. return control

```
.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

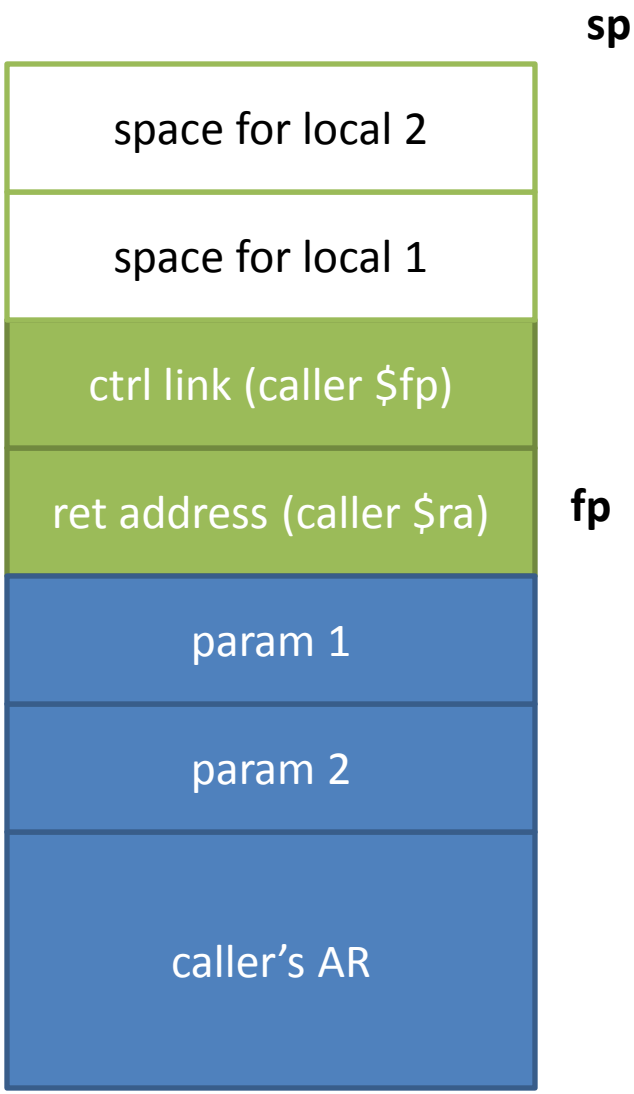
Function Locals




```
.text
f:
    # … prologue … #
    lw $t0, 4($fp)
    lw $t1, -4($fp)


    # … epilogue … #
```

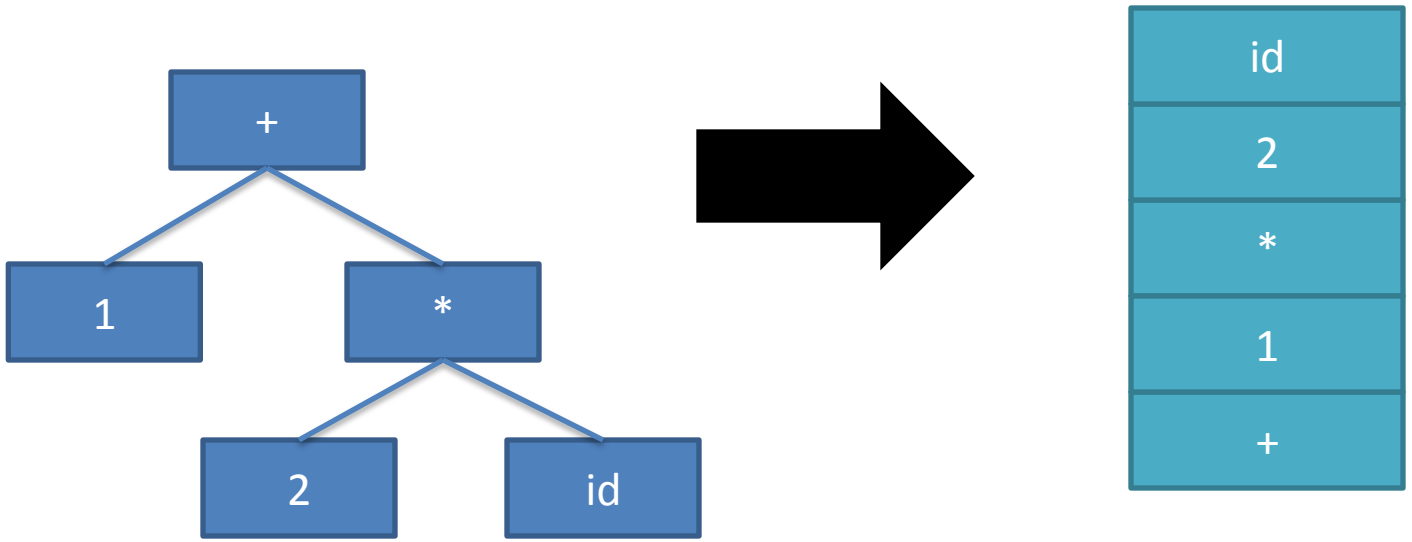
Function Returns




```
.text
f:
    # … prologue … #
    lw $t0, 4($fp)
    lw $t1, -4($fp)
    lw $v0, 8($fp)
    j f_exit
f_exit:
    # … epilogue … #
```

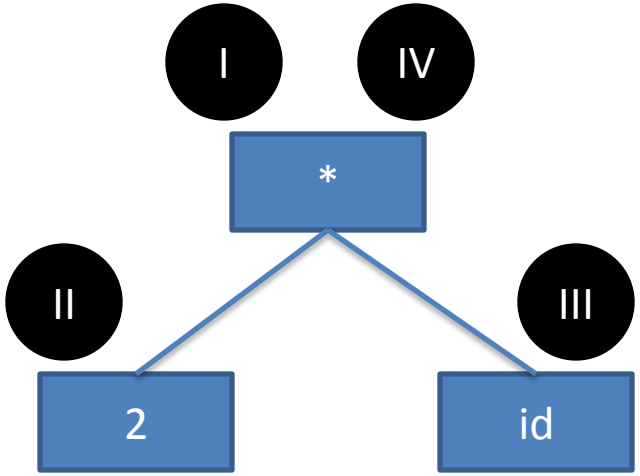
Function Body: Expressions

- 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~~ 2 * id

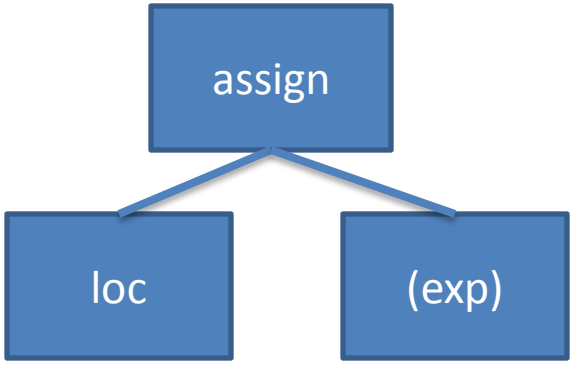
Serialized MIPS

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 have the result of the expression
  - This is by design

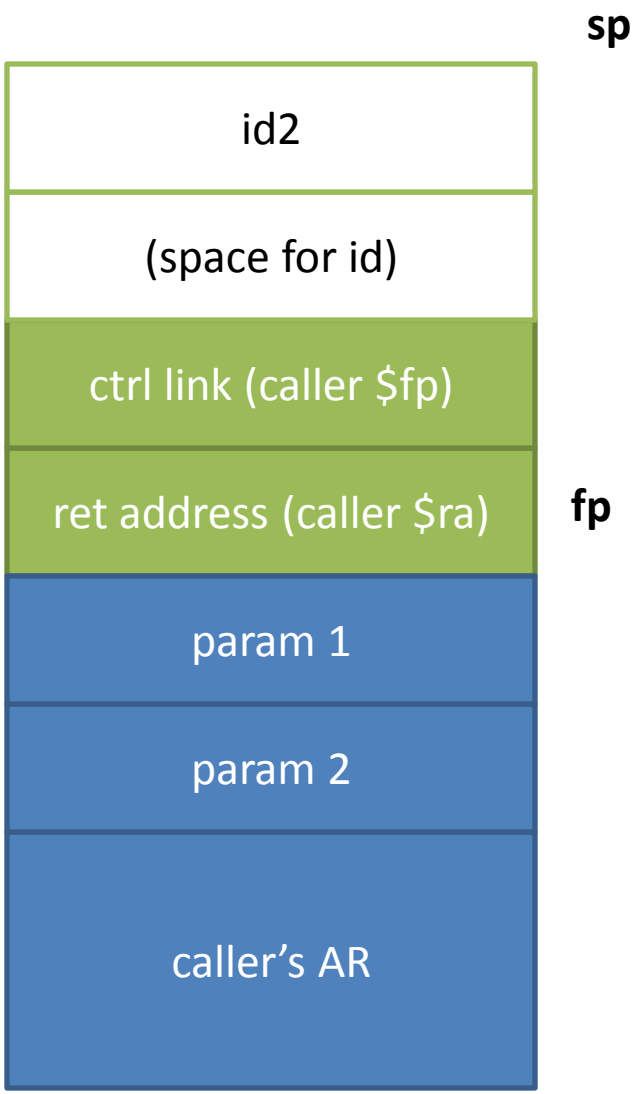


1) Compute RHS expr on stack
2) Compute LHS *location* on stack
3) Pop LHS into $t1
4) Pop RHS into $t0
5) Store value $t0 at address $t1

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;
```

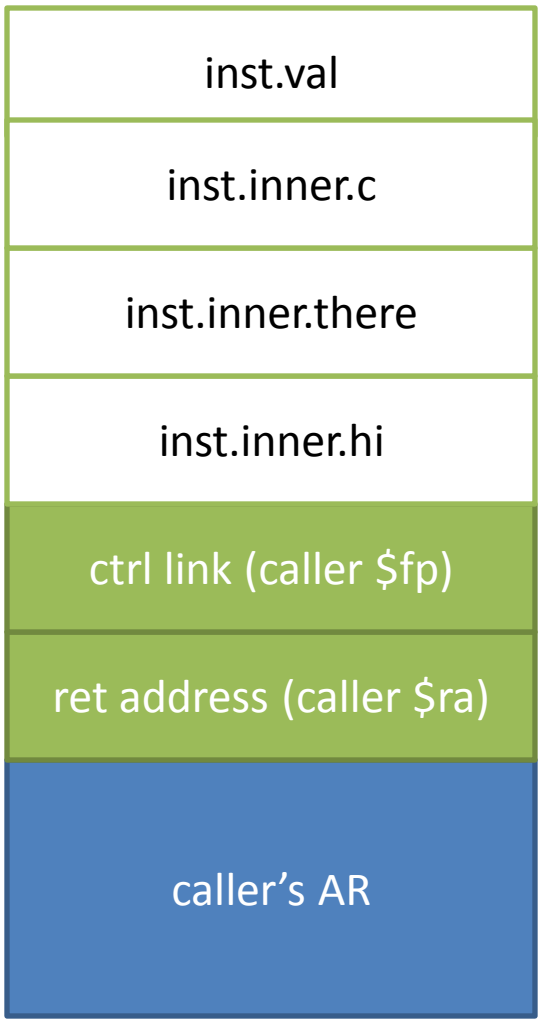
load this address load this value

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 of the base



LHS

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

RHS

```
lw $t0 -16($sp)
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 Tutorial