Code Generation, Continued

Code generation for function definition, expressions and statements.

1. MIPS for function
preamble + prologue + body + epilogue.
Preamble: create the label;
Prologue: save caller's $ra, save control link, make space for locals, update $fp.
Note that updated $fp points **to** the caller's $ra.
Body: details later.
Epilogue: restore caller's $ra, restore caller's $fp, restore $sp, return control.

2. Statements
Idea: post-order traversal of AST, using the stack.
At operands: push value onto stack;
At operators: pop source values from stack, compute result, push result onto stack.
Assignment: (1) compute RHS **expression** on stack; (2) compute LHS **location** on stack; (3) pop LHS into $t1; (4) pop RHS into $t0; (5) store $t0 at address $t1.
Dot access: use offset from the base of the struct.

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

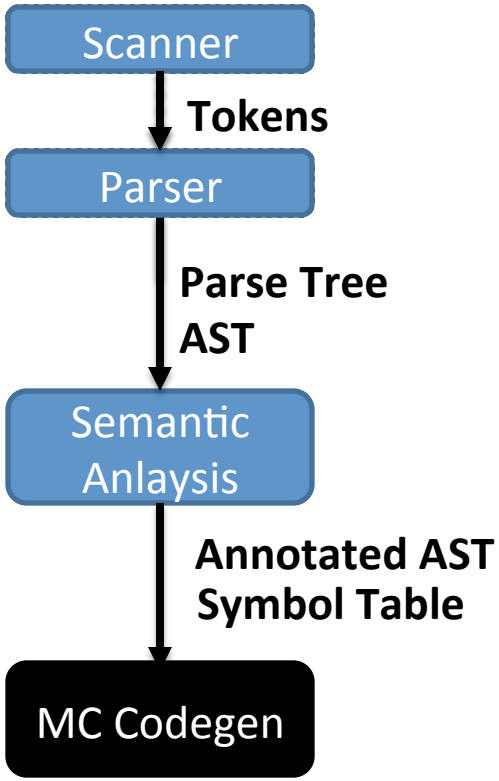
Roadmap

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

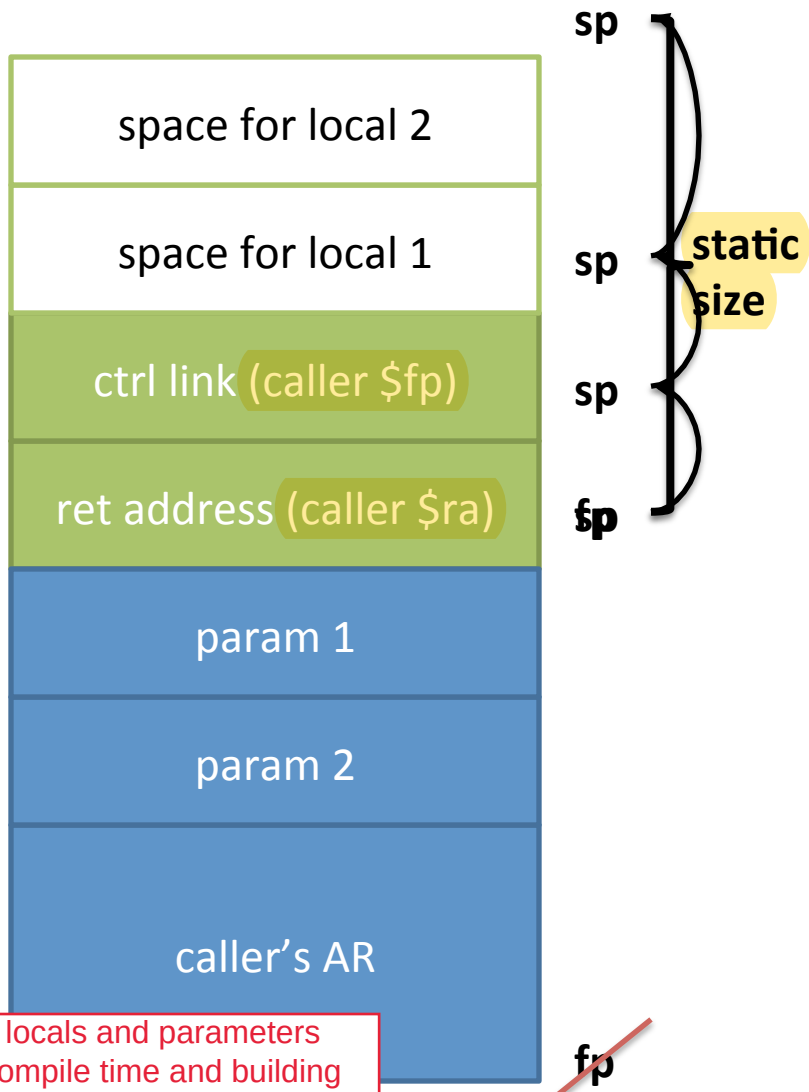
```
jal f
```

jal: jump-and-link. Put the original $ip in the $ra and set the $ip to the new value.

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

The number of locals and parameters are known at compile time and building the symbol table.

Function Prologue: MIPS

Before this line is executed, $ra stores the return address to the caller.

Remember the format of instruction: operator register memAddr

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
```

16 = 4 + 4 + 8

Just reserving space, not writing actual data.

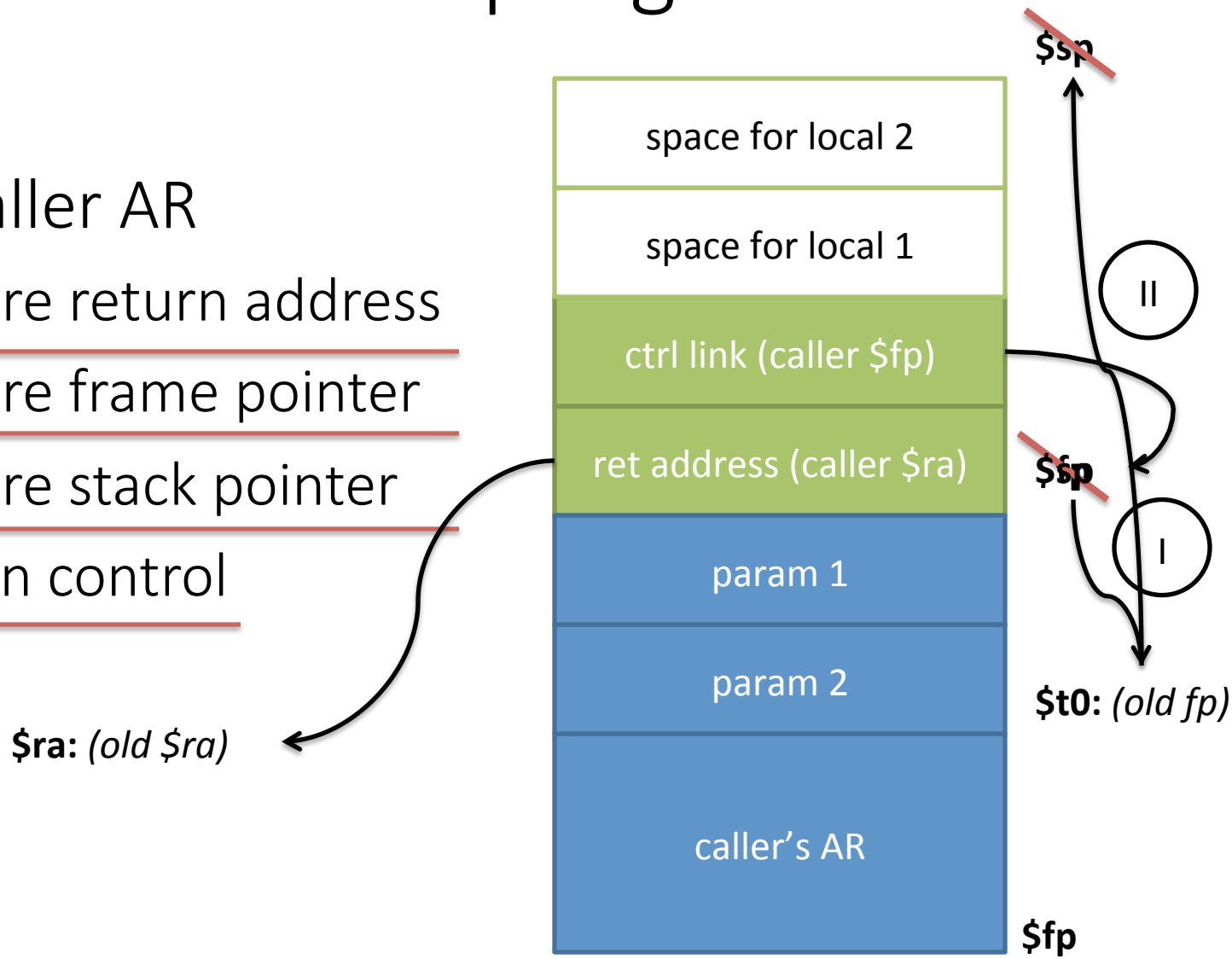
Question: Here the callee saves the caller's $ra on the stack. Can we have caller saving its own $ra before calling the function?

Answer: Yes, but having callee do the saving is better. Consider a function that can be called by many callers. If we let caller save the $ra, the code for pushing $ra onto the stack would be duplicated in all callers, whereas if we let the callee do this, we only have one such instruction in the callee. This reduces duplicated code and compiled binary size.

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

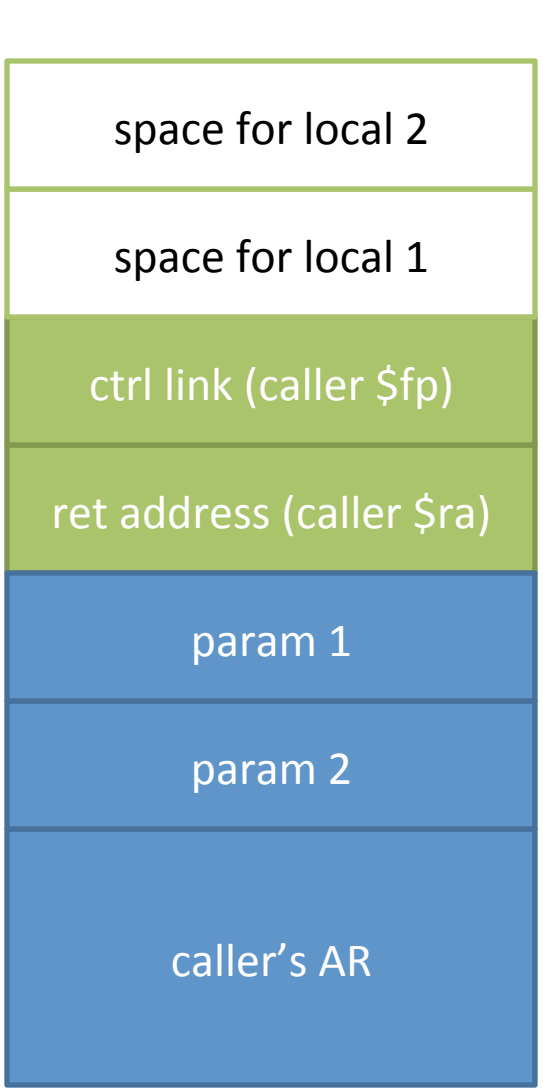
```
.text
f:
   sw $ra 0($sp)
   subu $sp $sp 4
   sw $fp 0($sp)
   subu $sp $sp 4
   subu $sp $sp 8
   addu $fp $sp 16
   #... Function body ...
   lw $ra, 0($fp)
   move $t0, $fp
   lw $fp, -4($fp)
   move $sp, $t0
   jr $ra
```

Function Body

Obviously, quite different based on content

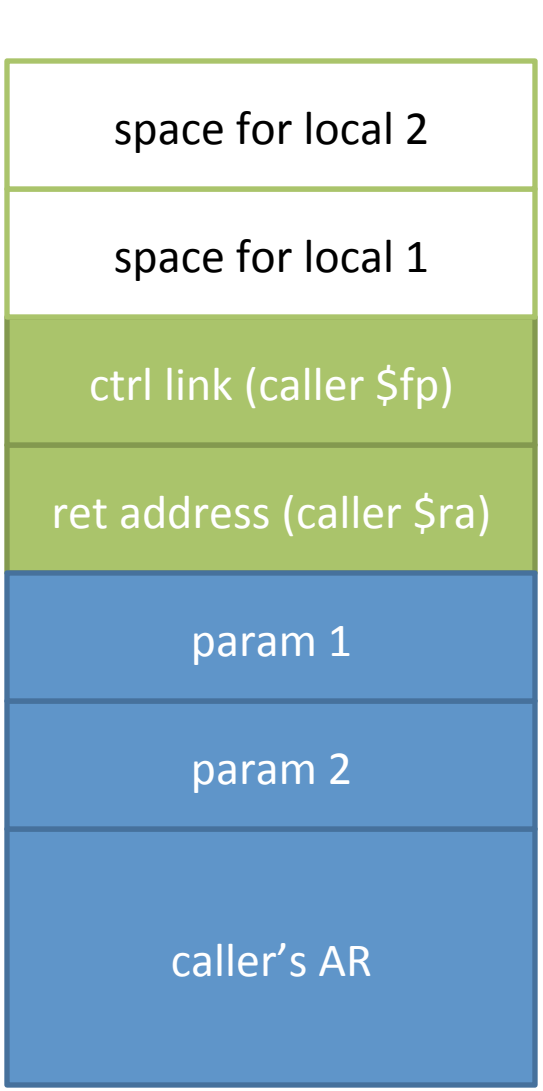
- Higher-level data constructs
  - Loading parameters, setting return
  - Evaluating expressions
- Higher-level control constructs
  - Performing a call
  - Loops
  - Ifs

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 … #
```

Using label for function epilogue to help multiple returns.

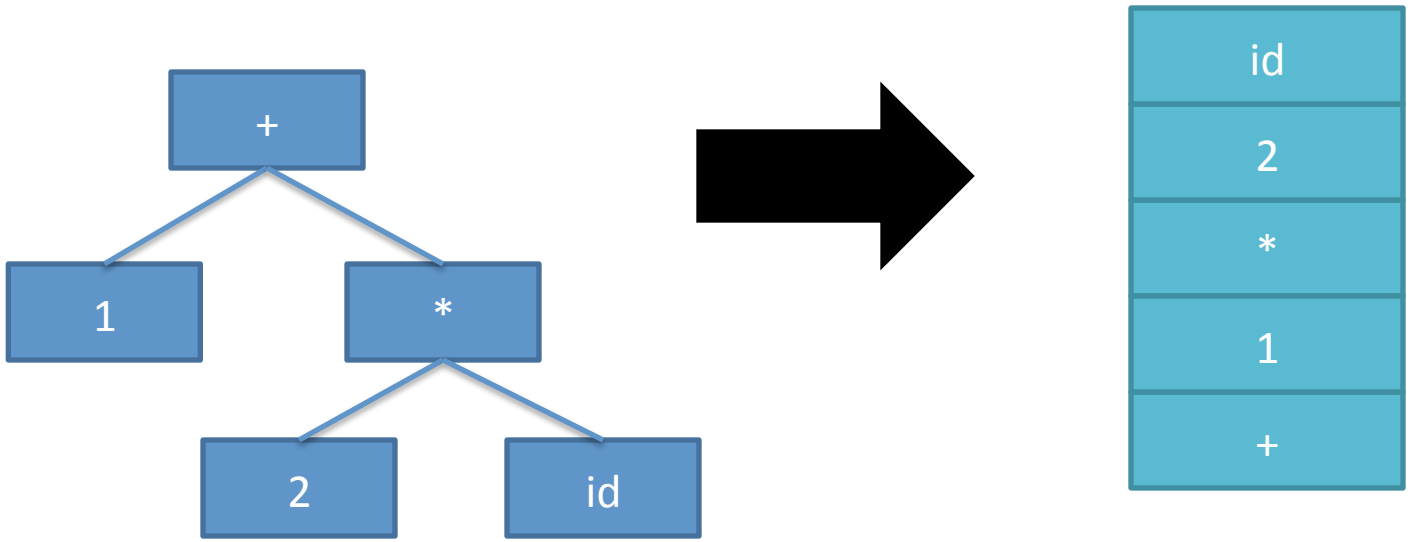
Function Body: Expressions

Goal

– Serialize (“flatten”) an expression tree

Use the same insight as the parser

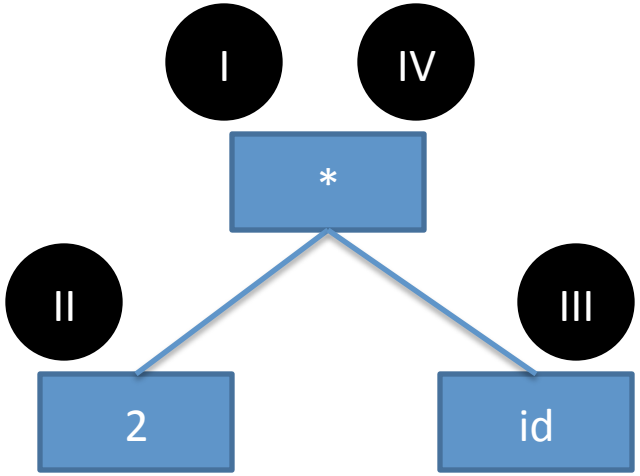
– Use a work stack and a post-order traversal



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

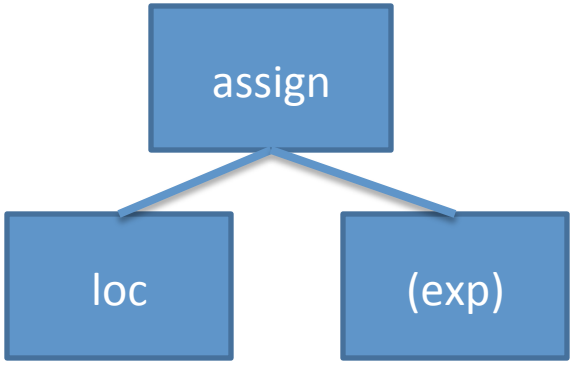
L1: push 2
L2: push id
L3: pop id into t1
L4: pop 2 into t0
L5: mult t0 * t1 into t0
L6: push t0

```
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

The formal solution in lec21 start.

Simple Assign, You Try

Generate stack-machine style MIPS code for

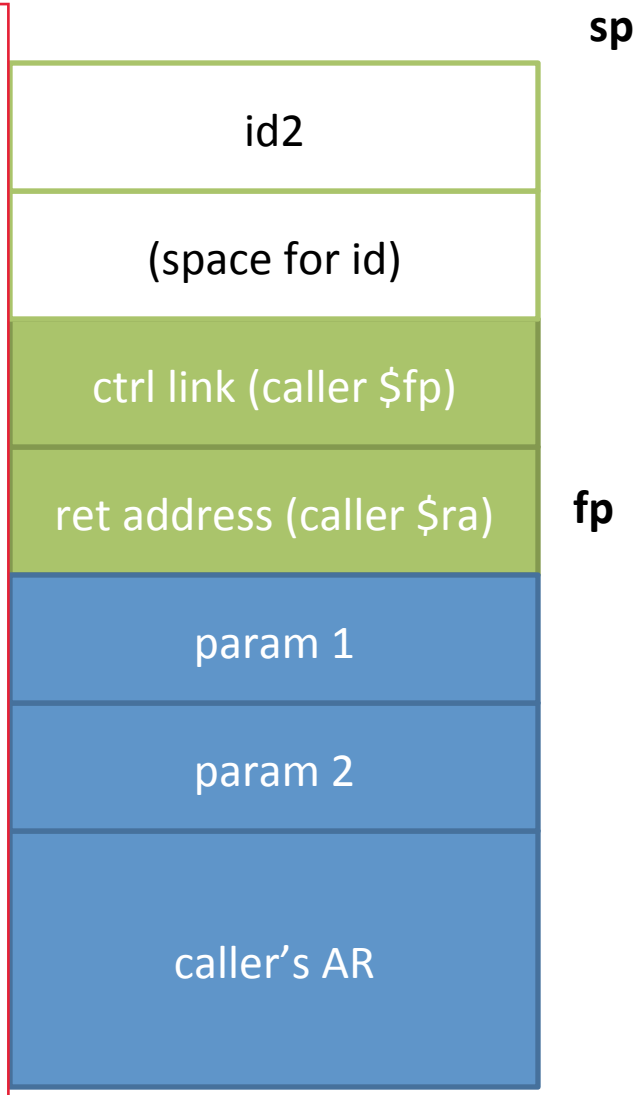
id = 1 + 2;

```
# Step 2
subu $t0 $fp 8 # address of id
sw $t0 ($sp)
subu $sp $sp 4
```

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 $t0 at address $t1

```
# Step 1
# push 1 onto stack
li $t0 1
sw $t0 0($sp)
addu $sp $sp 4

# push 2 onto stack
li $t0 2
sw $t0 0($sp)
addu $sp $sp 4

# pop into $t0
lw $t0 4($sp)
addu $sp $sp 4

# pop into $t1
lw $t1 4($sp)
addu $sp $sp 4

# put result into $to
add $t0 $t0 $t1

# push result onto stack
sw $t0 0($sp)
addu $sp $sp 4

# step 2, 3, 4

# step 5
sw $t0 0($t1)
```



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;
```

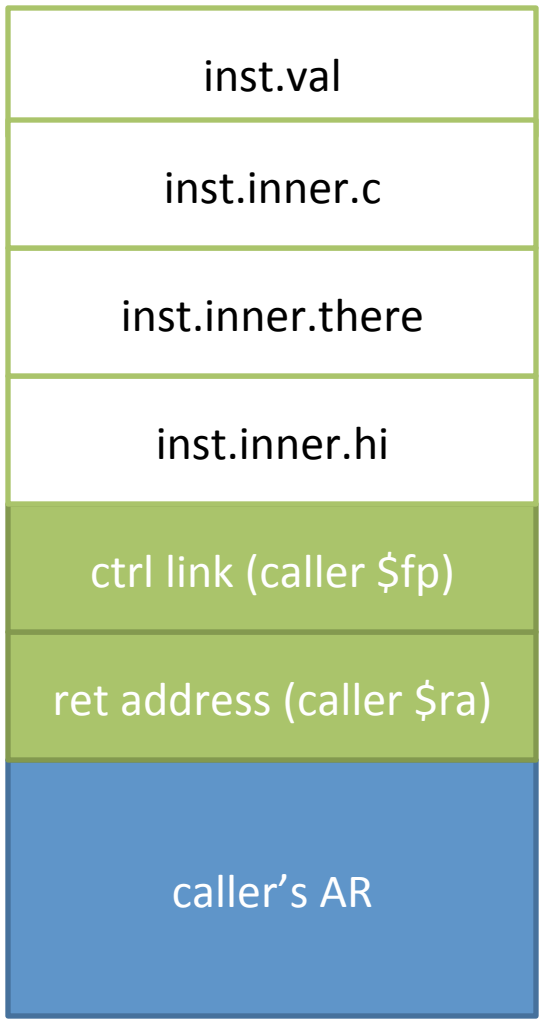
load this address load this value

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



Load the address

LHS

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

Load the value

RHS

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

Control Flow Constructs

Function Calls

Loops

Ifs

We do these next time

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
```

Push args onto stack;
Jump to function;
tear down parameters;
retrieve result.

Summary

Today:

- Got the basics of MIPS
- CodeGen for *some* AST node types

Next time:

- Do the rest of the AST nodes
- Introduce control flow graphs

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