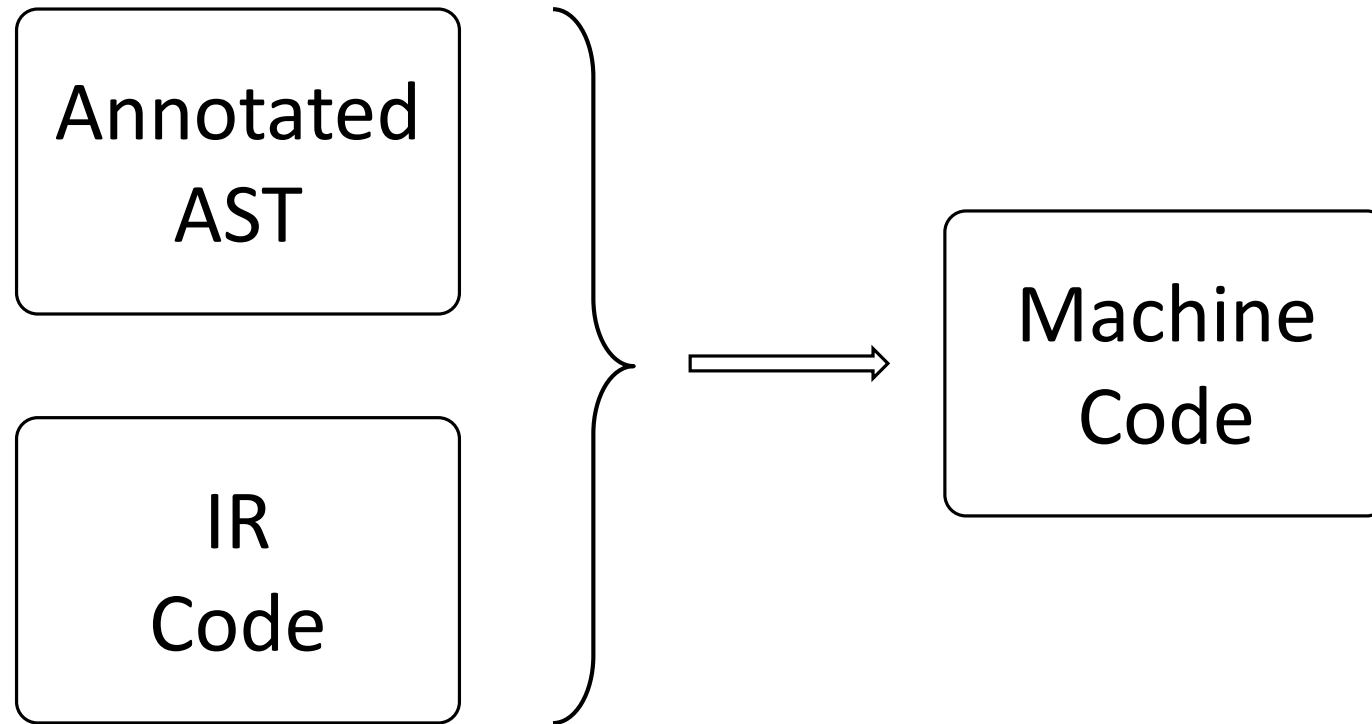# Code Generation

TEACHING ASSISTANT: DAVID TRABISH

Code Generation

MIPS Architecture

- MIPS has 32 registers:
  - t0, …, t9
    - general purpose
  - a0, a1, a2, a3
    - arguments (in some compilers)
  - v0, v1
    - return value, system calls
  - sp, fp
    - stack pointer, frame pointer
  - ra
    - return address

MIPS Architecture

- Labels

```
data_label_1: .word 17

data_label_2: .asciiz "abc"

code_label:
li $t0, 3
...
```

MIPS Architecture

- Basic assignments

```
li $t0, 3
move $t1, $t2
```

MIPS Architecture

- Arithmetic instructions operate on registers and constants:
  - add, sub, mul, div, and, or, xor, …

```
add $t2, $t0, $t1
mul $t3, t1, 7
```

MIPS Architecture

- Read from memory:

```
lw $t0,4($t1)
lw $t0,label
lw $t0,label+4
lw $t0,label+8($t1)
```

MIPS Architecture

- Write to memory:

```
sw $t0,2($t1)
sw $t0,label
sw $t0,label+4
sw $t0,label+8($t1)
```

MIPS Architecture

- Branches and Jumps:

```
beq $t1, $t2, label
bne $t1, 7, label
j label
jal label
jalr $t1
```

MIPS Architecture

- System calls:
  - Syscall number passed via v0
  - Arguments are passed via a0, a1, a2, a3
- For example, calling PrintInt(3):

```
li $v0, 1
li $a0, 3
syscall
```

SPIM

```
.data
g_foo:  .word 17
g_str:  .asciiz "hello"
…
```
} global data

```
.text
li $v0, 1
lw $a0, g_foo
syscall
li $v0, 4
la $a0, g_str
syscall
```
} code

SPIM

```
            .data
            g_foo: .word 17                    }  global data
            g_str: .asciiz "hello"
            …


            .text
            li $v0, 1
PrintInt(17) { lw $a0, g_foo
            syscall
            li $v0, 4                           }  code
PrintStr("hello") { la $a0, g_str
            syscall
```
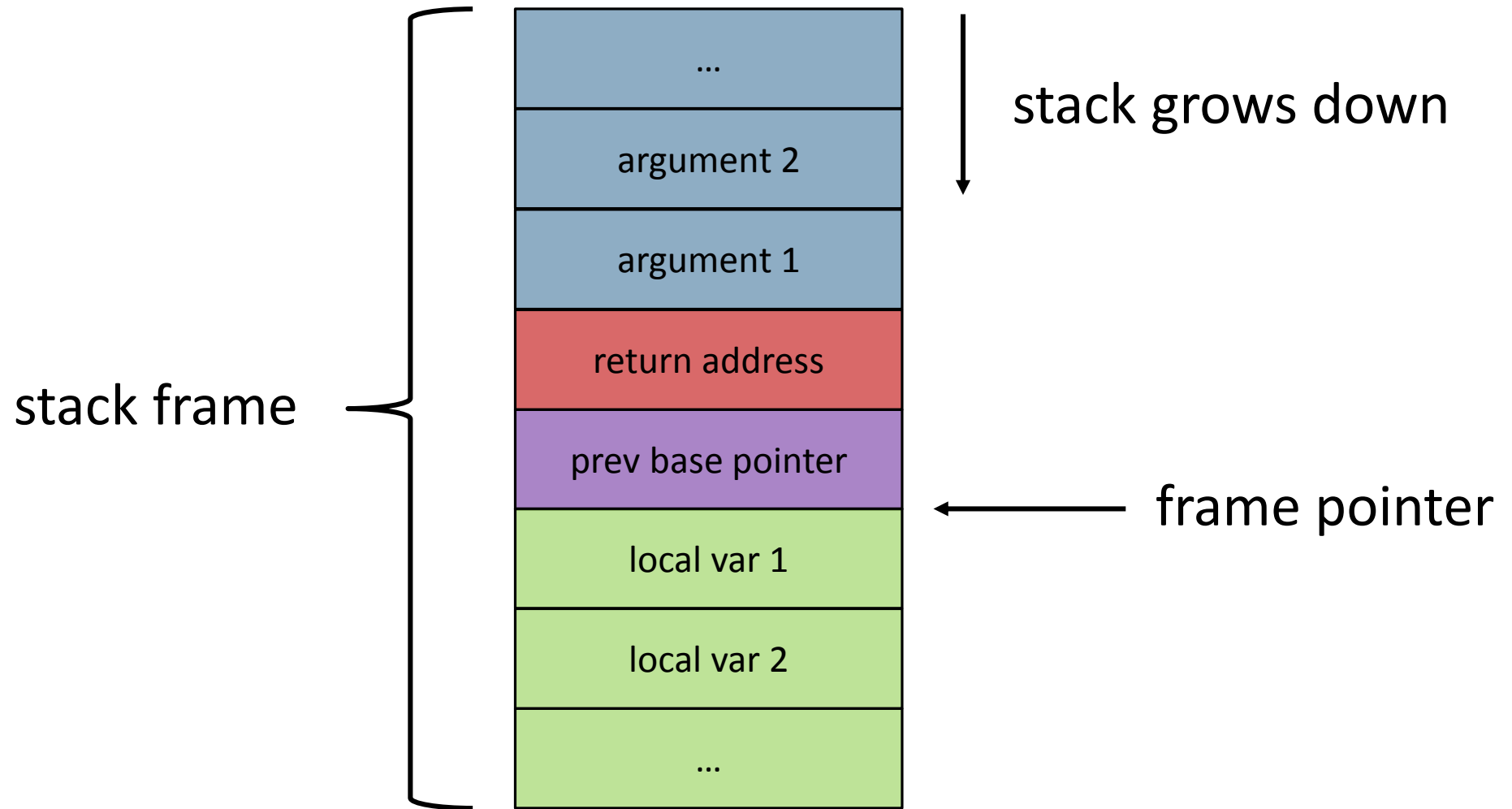
SPIM

- Running SPIM:
  - spim –f *input_file*
- Interactive debugging:
  - xspim
- Tutorials:
  - https://courses.cs.washington.edu/courses/cse410/08sp/notes/spim/SpimTutorial.pdf
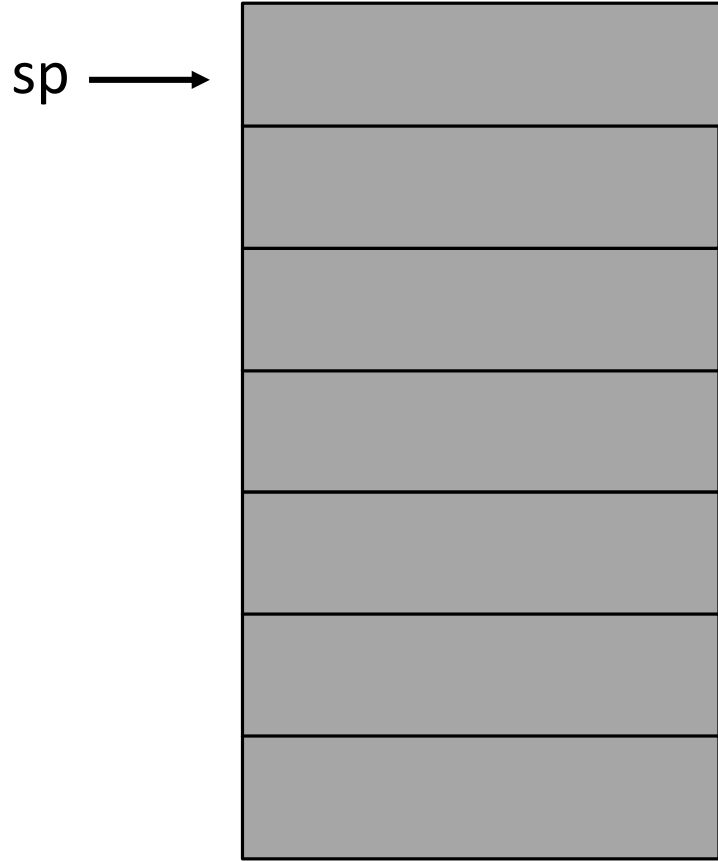 - https://web.stanford.edu/class/cs143/materials/SPIM_Manual.pdf

Stack

Stack

```
int f(int x, int y){
    int z = x + y;
    return z;
}
int g() {
    int x = f(10, 20)
}
```

```
f:
subu $sp, $sp, 4
sw $ra, 0($sp)
subu $sp, $sp, 4
sw $fp, 0($sp)
move $fp, $sp
sub $sp, $sp, 16
lw $t0, 8($fp)
lw $t1, 12($fp)
add $t2, $t0, $t1
sw $t2, -4($fp)
lw $v0, -4($fp)
move $sp, $fp
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```

```
g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
li $t0, 10
subu $sp, $sp, 4
sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```
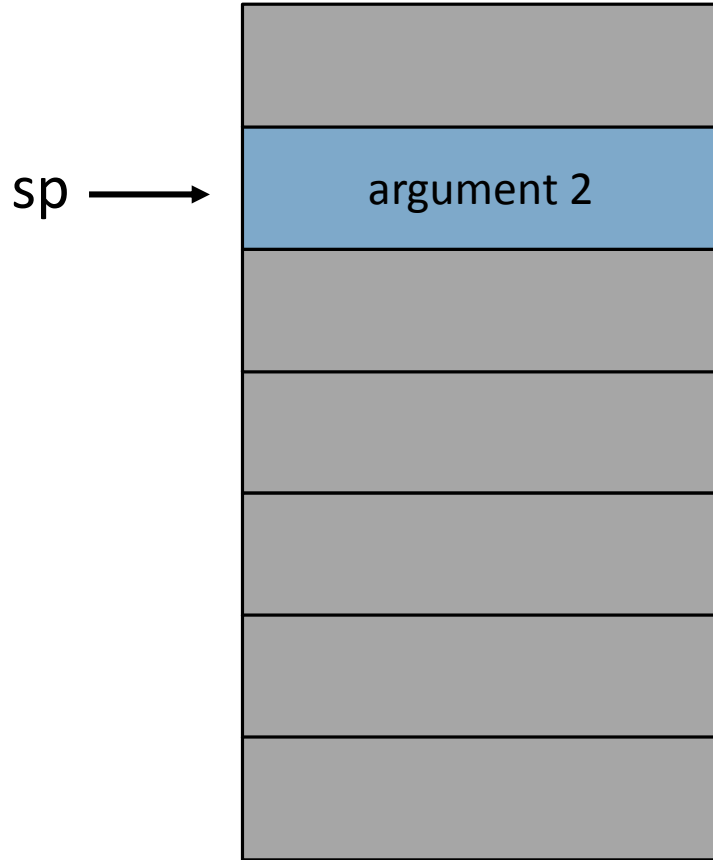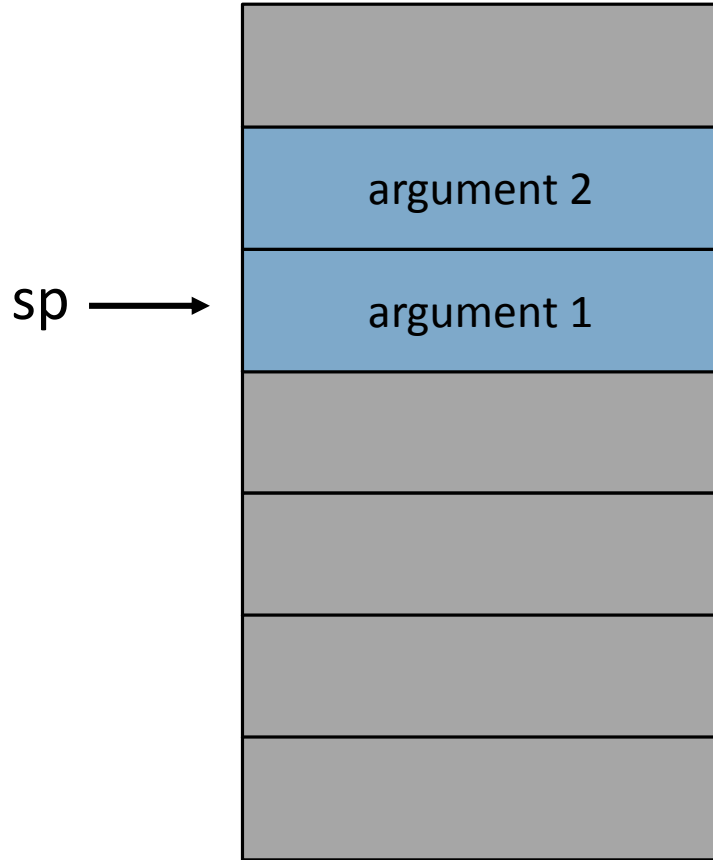
Stack

sp →

```
f:
subu $sp, $sp, 4
sw $ra, 0($sp)
subu $sp, $sp, 4
sw $fp, 0($sp)
move $fp, $sp
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lw $t0, 8($fp)
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add $t2, $t0, $t1
sw $t2, -4($fp)
lw $v0, -4($fp)
move $sp, $fp
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```

```
g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
li $t0, 10
subu $sp, $sp, 4
sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```
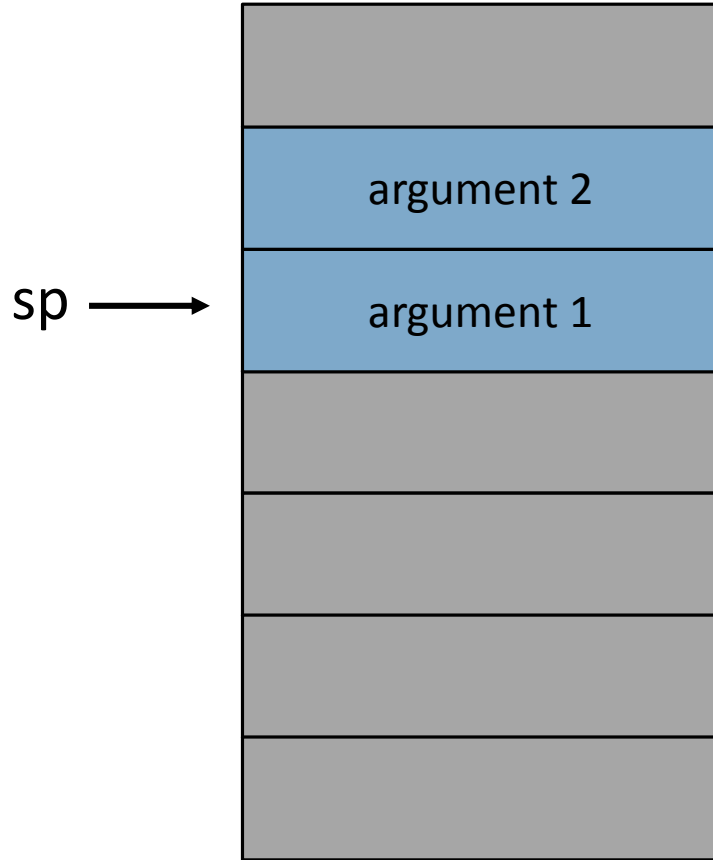
Stack

sp →

argument 2

```
f:
subu $sp, $sp, 4
sw $ra, 0($sp)
subu $sp, $sp, 4
sw $fp, 0($sp)
move $fp, $sp
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lw $t0, 8($fp)
lw $t1, 12($fp)
add $t2, $t0, $t1
sw $t2, -4($fp)
lw $v0, -4($fp)
move $sp, $fp
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```

```
g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
li $t0, 10
subu $sp, $sp, 4
sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```
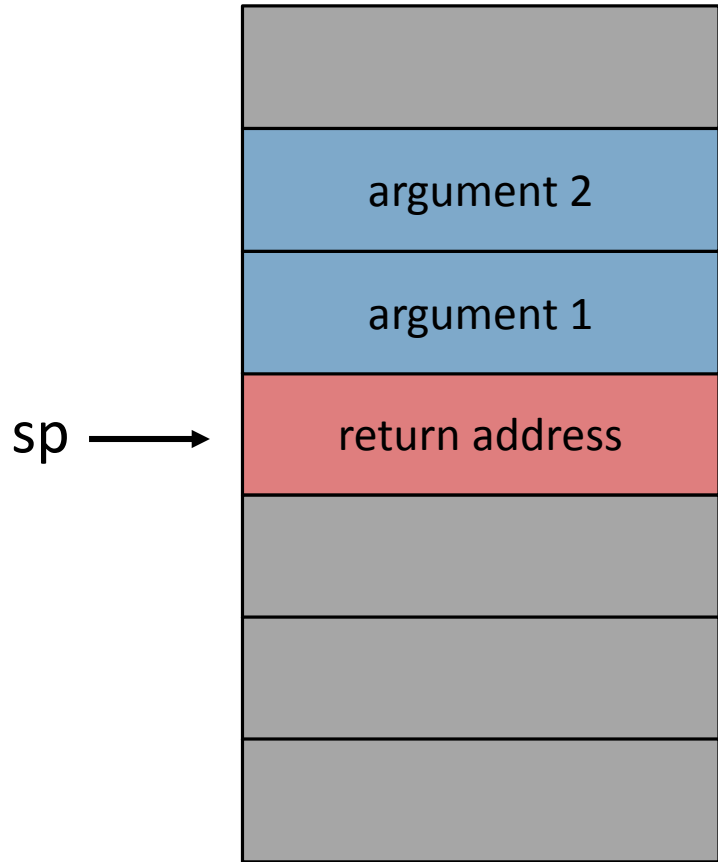
Stack


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f:
subu $sp, $sp, 4
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lw $v0, -4($fp)
move $sp, $fp
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```

```
g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
li $t0, 10
subu $sp, $sp, 4
sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```

Stack


```
f:
subu $sp, $sp, 4
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move $sp, $fp
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```

```
g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
li $t0, 10
subu $sp, $sp, 4
sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```
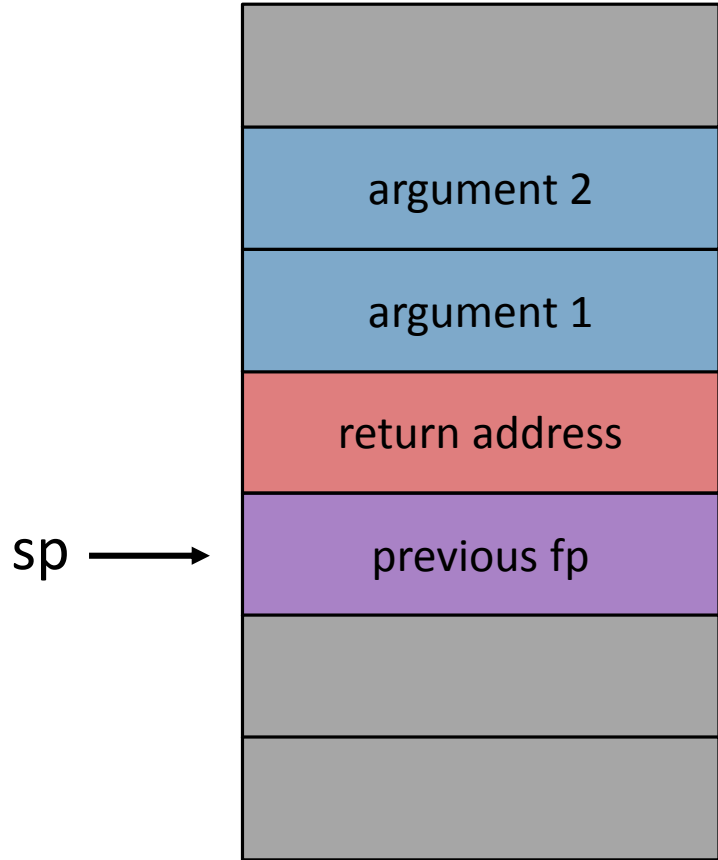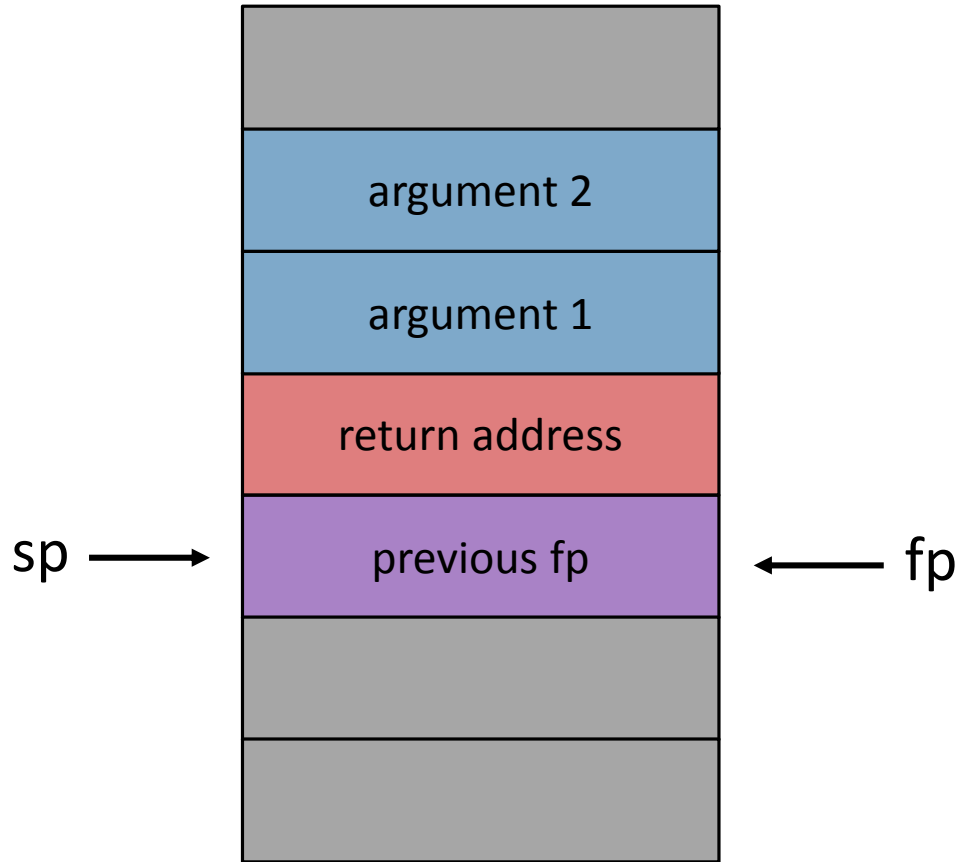
Stack


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lw $v0, -4($fp)
move $sp, $fp
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```

```
g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
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sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```
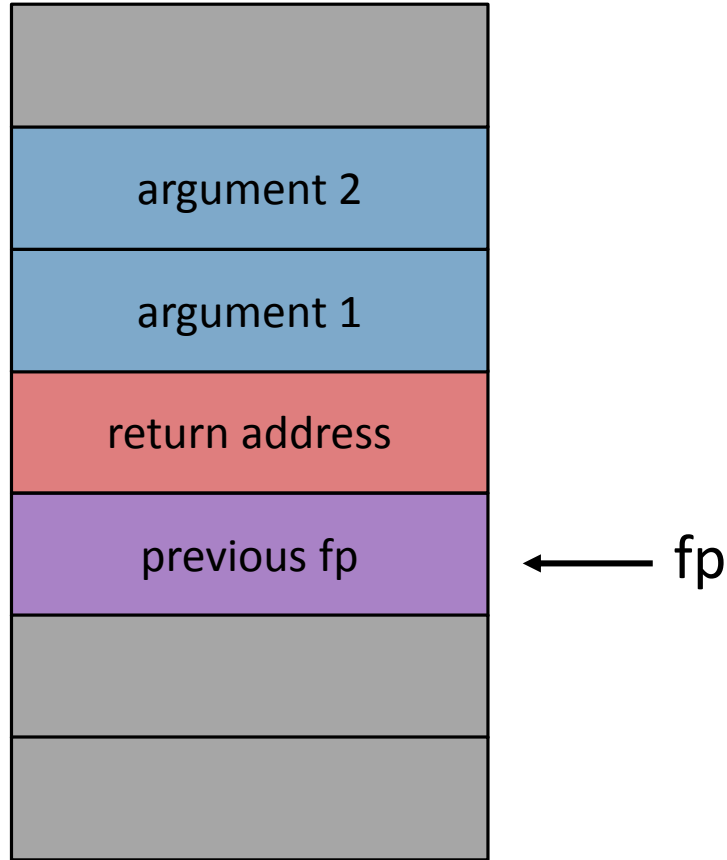
Stack


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add $t2, $t0, $t1
sw $t2, -4($fp)
lw $v0, -4($fp)
move $sp, $fp
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```

```
g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
li $t0, 10
subu $sp, $sp, 4
sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```
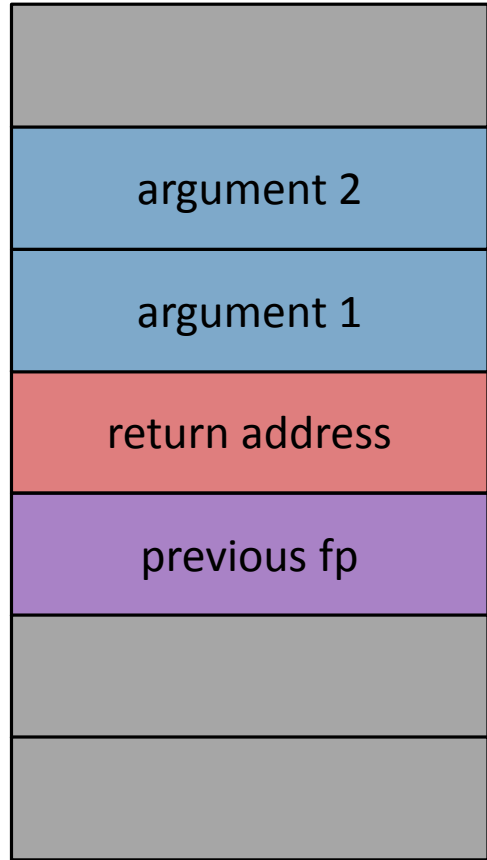
Stack


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```

```
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subu $sp, $sp, 4
sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```

Stack


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lw $fp, 0($sp)
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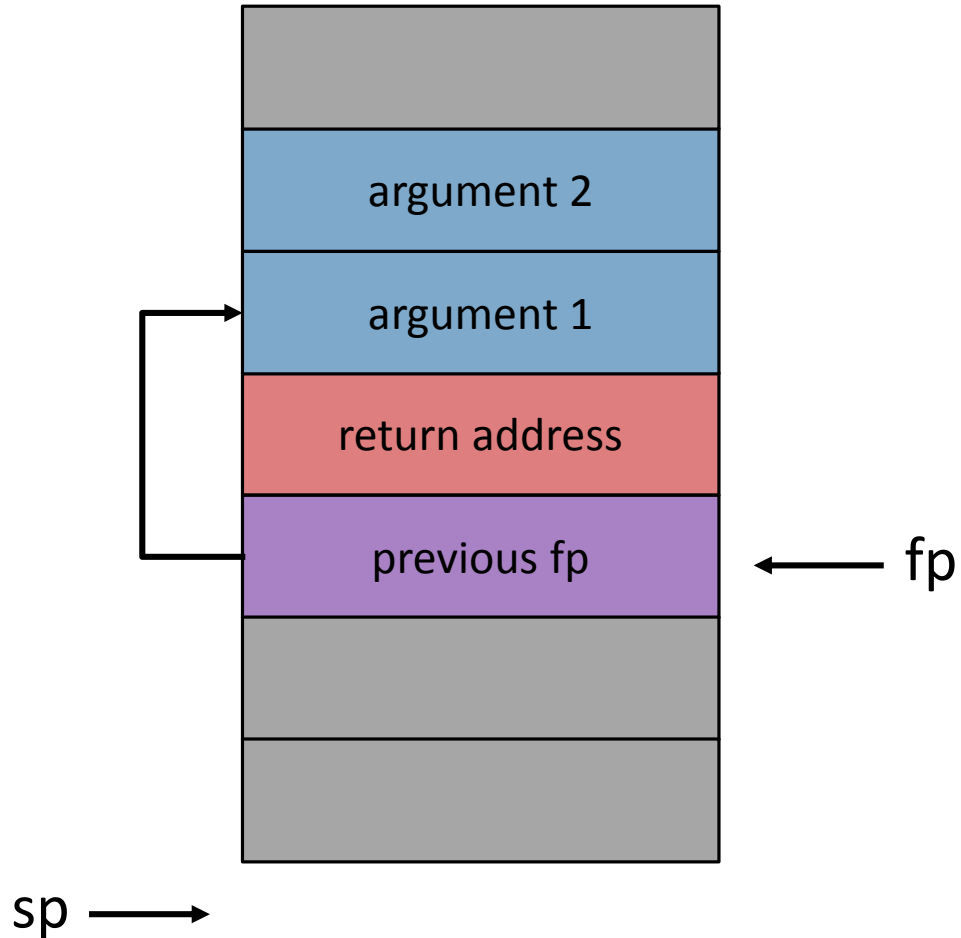
```
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li $t0, 20
subu $sp, $sp, 4
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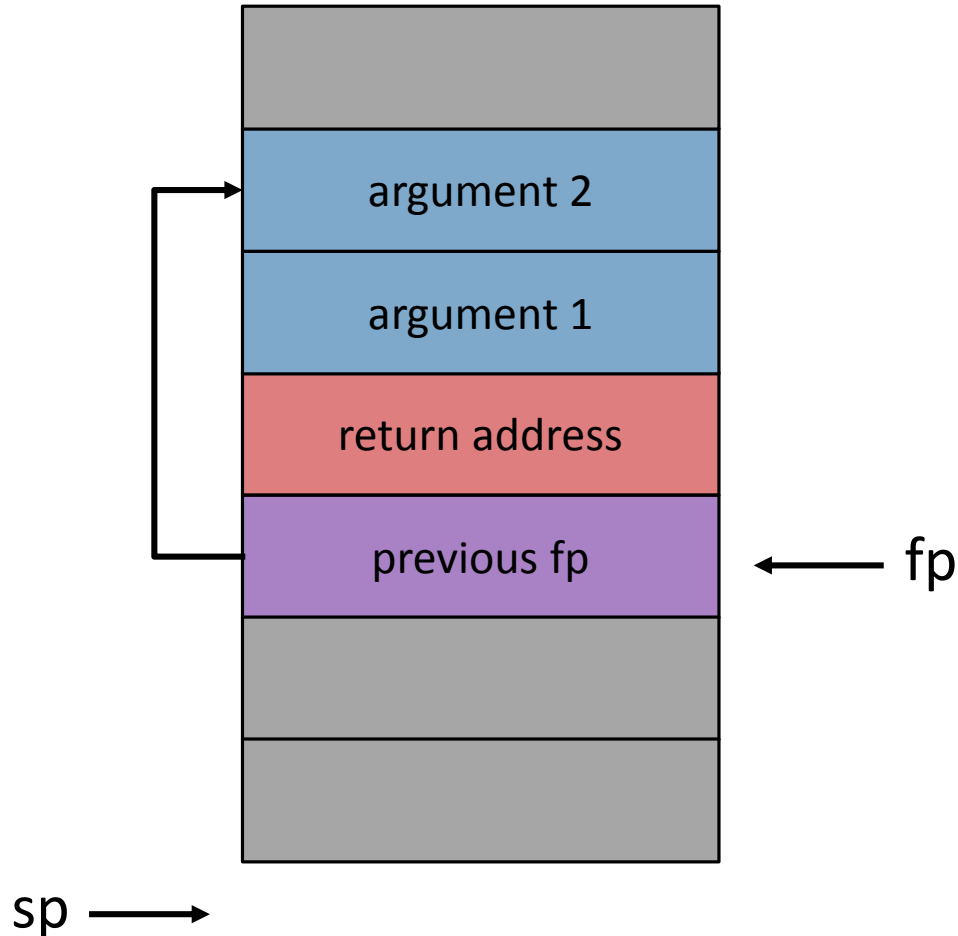
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```
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```
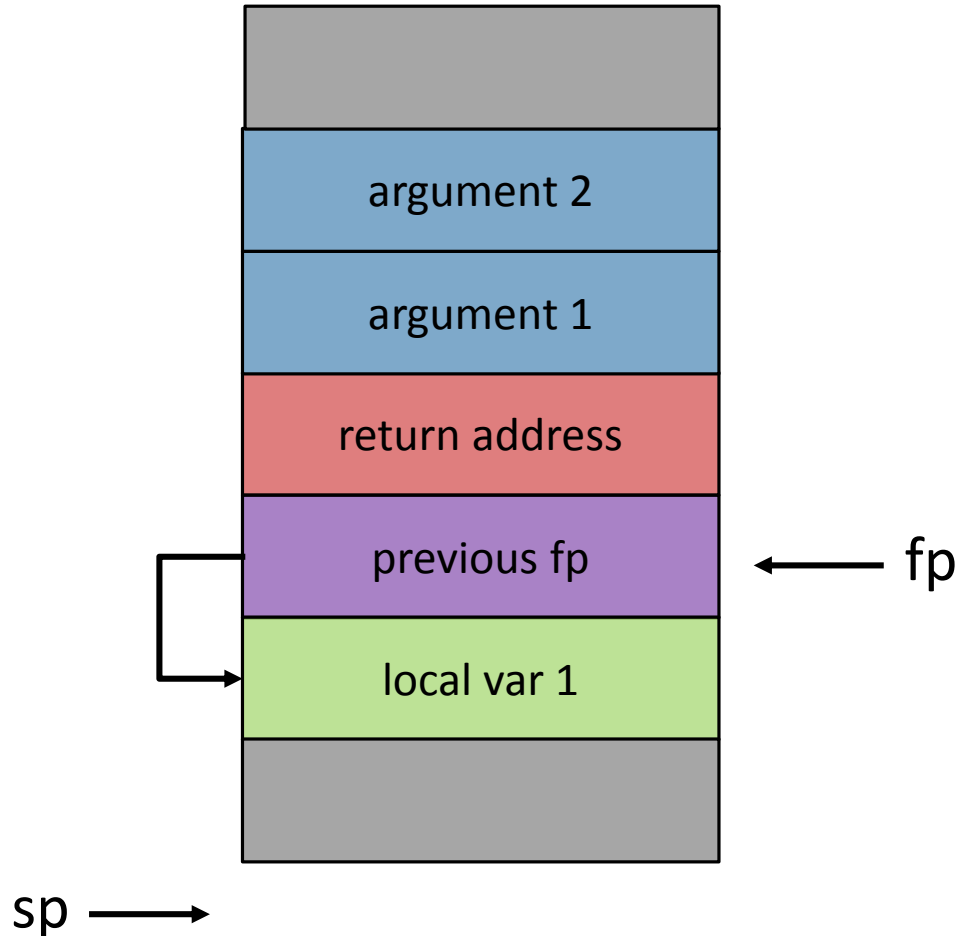
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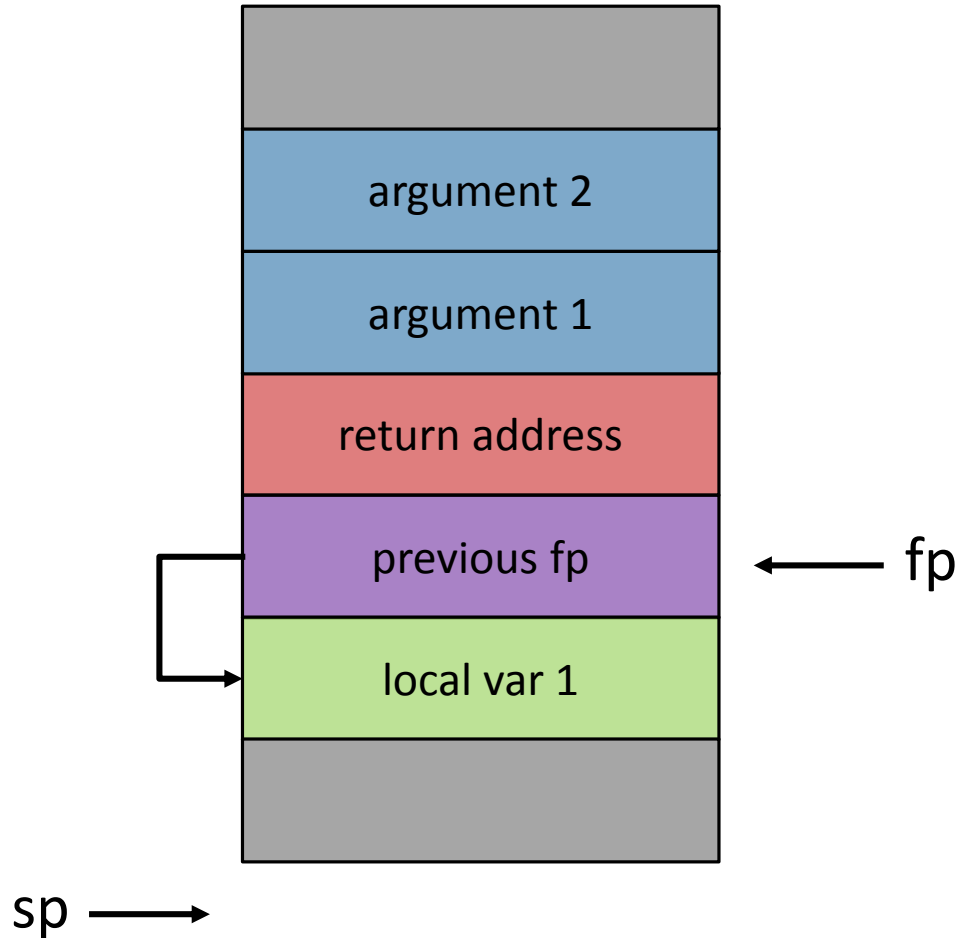
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```
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```
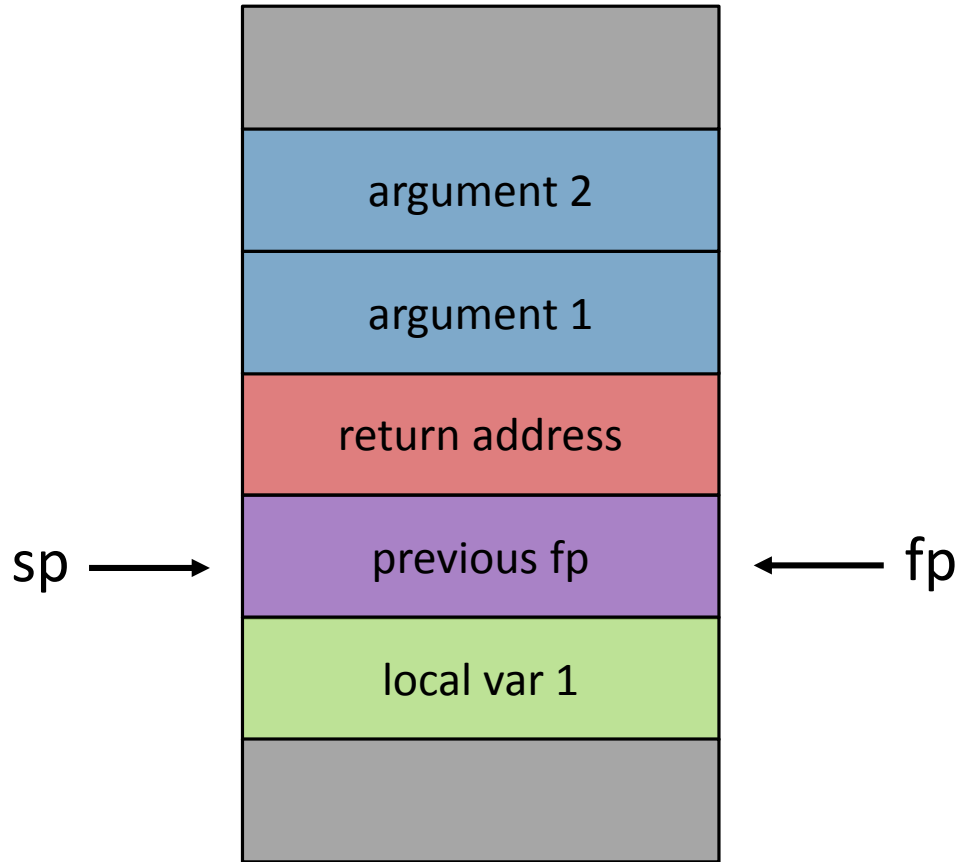
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Stack


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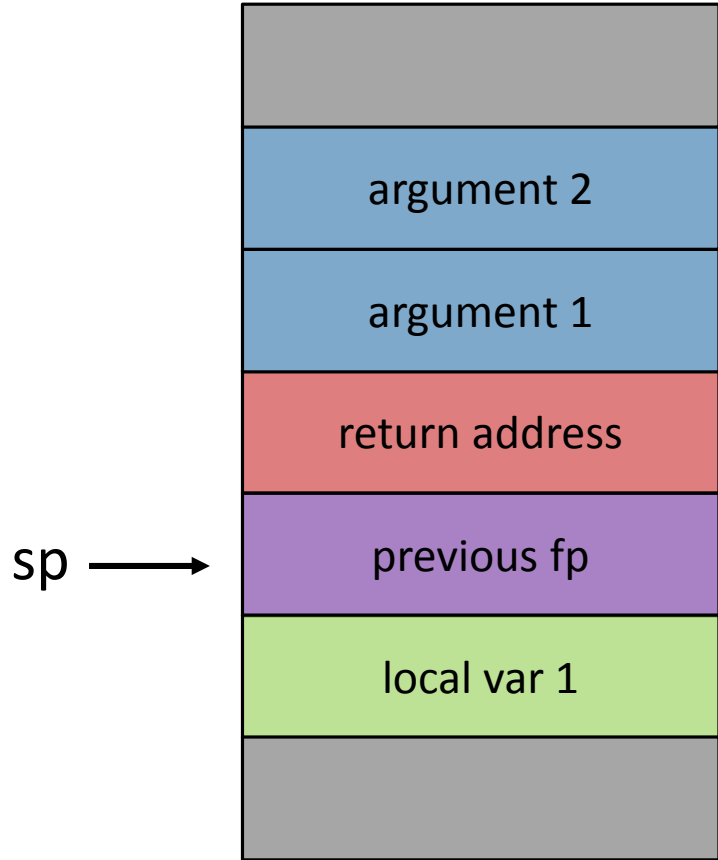
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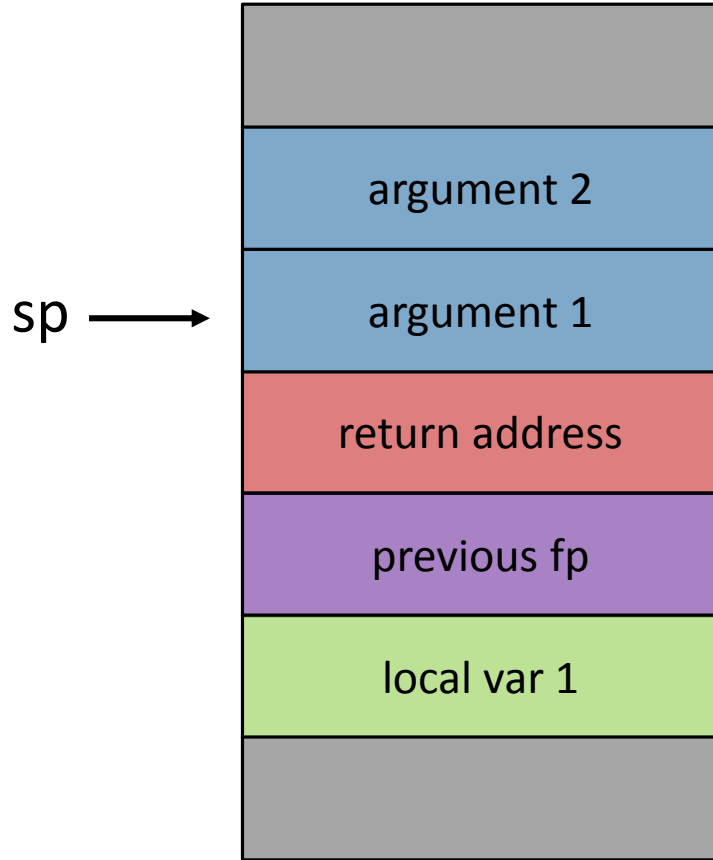
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```
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```
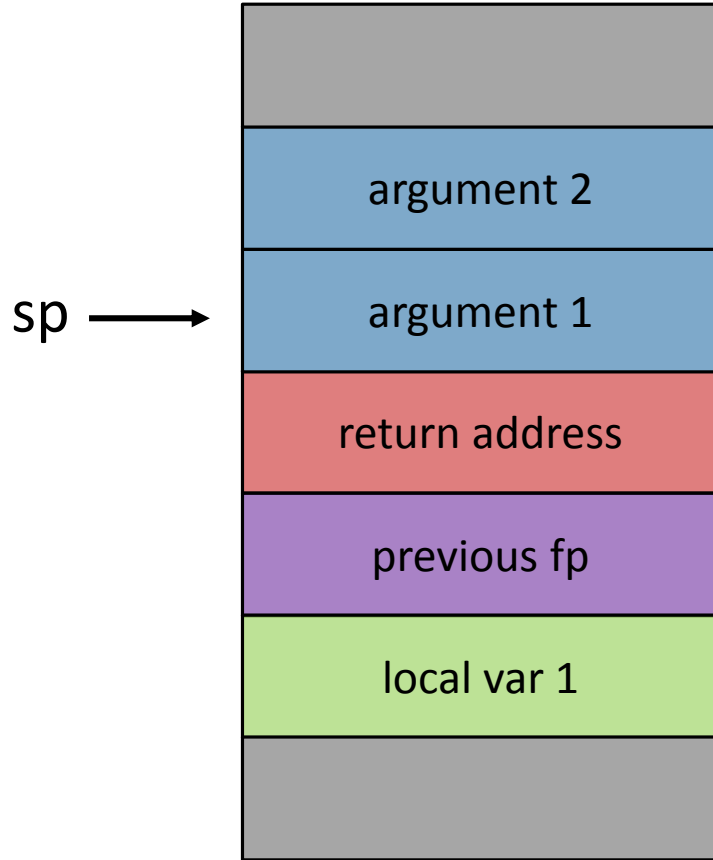
Stack


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lw $v0, -4($fp)
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lw $ra, 4($sp)
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```
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li $t0, 20
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...
```
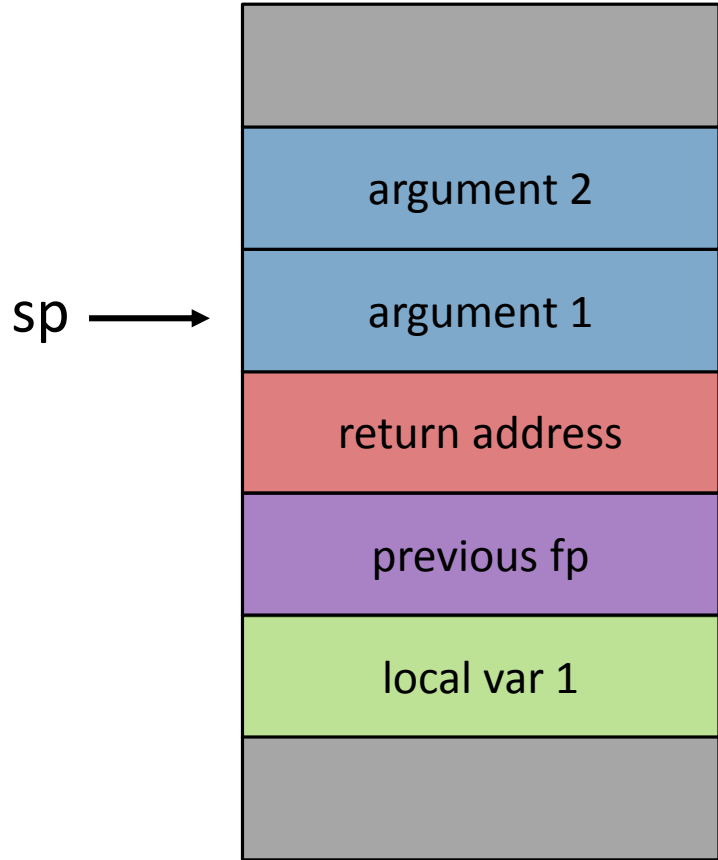
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```
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...
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Stack


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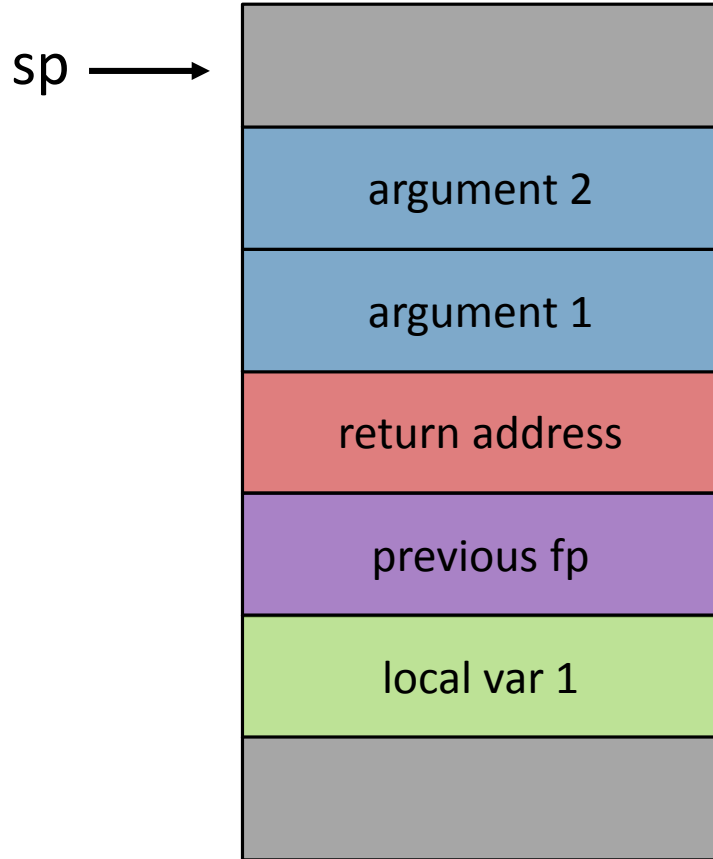
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...
```
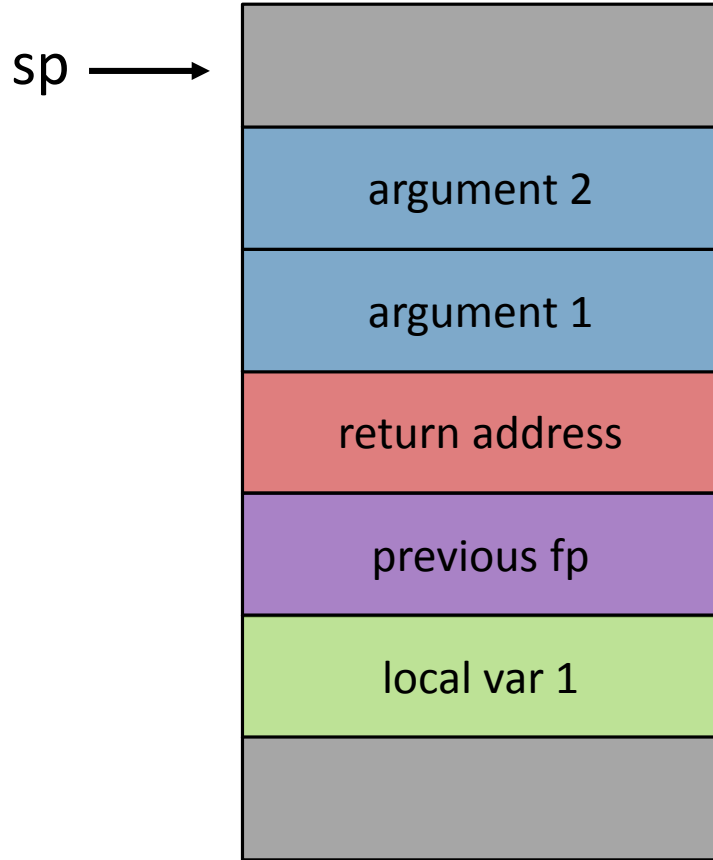
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```

```
g:
...
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jal f
addu $sp, $sp, 8
move $t0, $v0
...
```
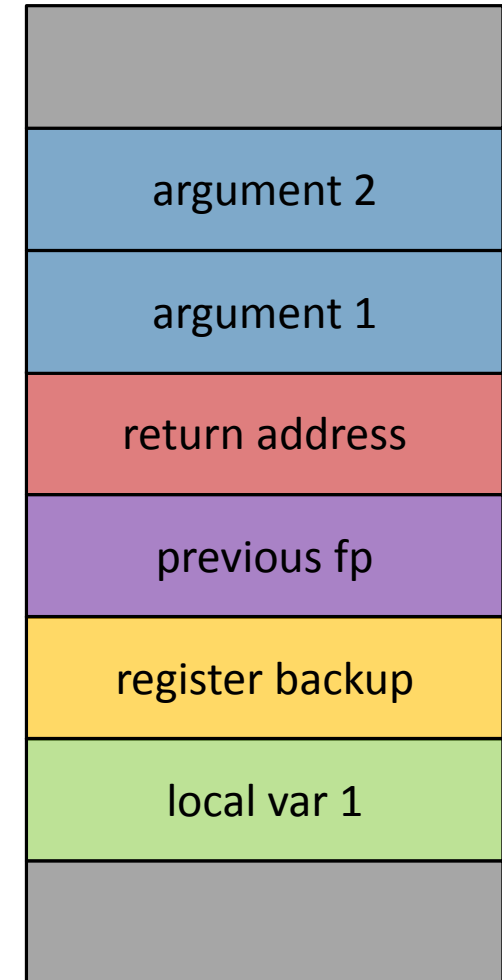
epilogue

Stack


```
f:
subu $sp, $sp, 4
sw $ra, 0($sp)
subu $sp, $sp, 4
sw $fp, 0($sp)
move $fp, $sp
sub $sp, $sp, 16
lw $t0, 8($fp)
lw $t1, 12($fp)
add $t2, $t0, $t1
sw $t2, -4($fp)
lw $v0, -4($fp)
move $sp, $fp
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```

```
g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
li $t0, 10
subu $sp, $sp, 4
sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```

Stack


```
f:
subu $sp, $sp, 4
sw $ra, 0($sp)
subu $sp, $sp, 4
sw $fp, 0($sp)
move $fp, $sp
sub $sp, $sp, 16
lw $t0, 8($fp)
lw $t1, 12($fp)
add $t2, $t0, $t1
sw $t2, -4($fp)
lw $v0, -4($fp)
move $sp, $fp
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```
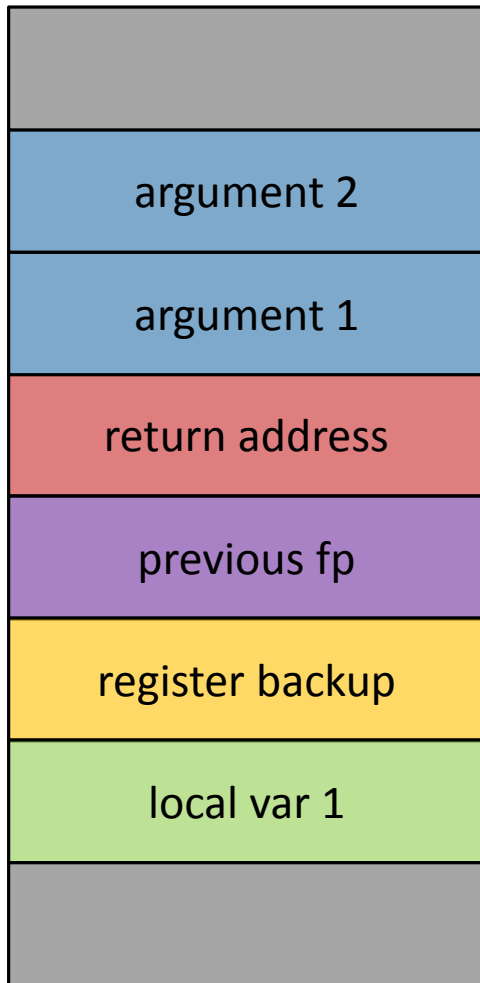
```
g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
li $t0, 10
subu $sp, $sp, 4
sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```

Register Backup

- Called functions may modify registers
- Backup at the **prologue**
- Restore at the **epilogue**

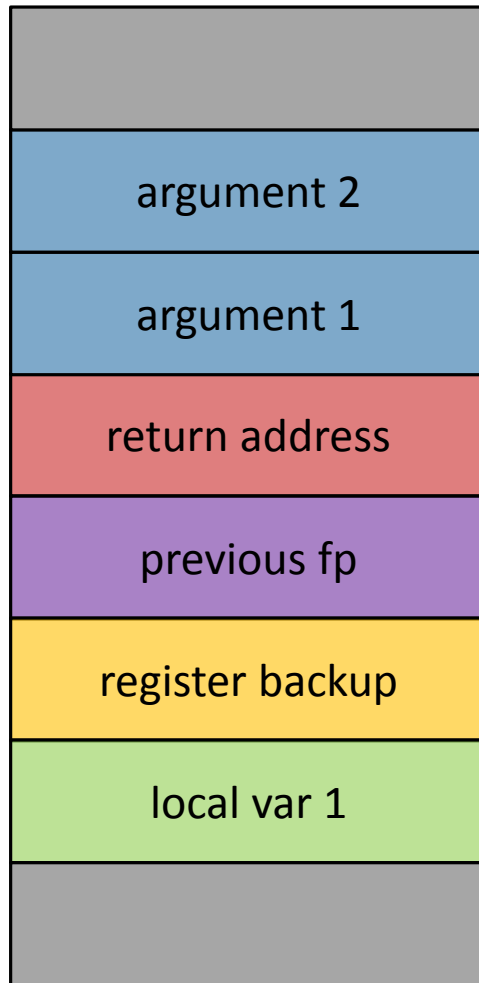| |
|---|
| |
| argument 2 |
| argument 1 |
| return address |
| previous fp |
| register backup |
| local var 1 |
| |

Register Backup: Prologue


```
f:
subu $sp, $sp, 4
sw $ra, 0($sp)
subu $sp, $sp, 4
sw $fp, 0($sp)
move $fp, $sp
subu $sp, $sp, 4
sw $t0, 0($sp)
…
subu $sp, $sp, 4
sw $t9, 0($sp)
sub $sp, $sp, 16
```

backup

argument 2

argument 1

return address

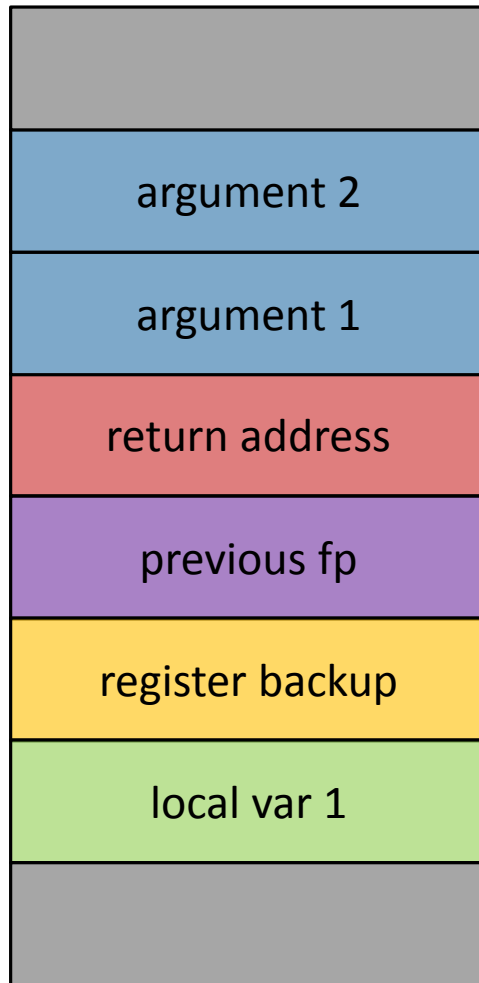previous fp

register backup

local var 1

Register Backup: Epilogue


```
f:
...

move $sp, $fp
lw $t0, -4($sp)
...
lw $t9, -40($sp)
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```

restore {

Stack diagram (top to bottom):
- argument 2
- argument 1
- return address
- previous fp
- register backup
- local var 1

Register Backup


```
f:
...
lw $t0, 8($fp)
lw $t1, 12($fp)
add $t2, $t0, $t1
sw $t2, -44($fp)
lw $v0, -44($fp)
...
```

Translating IR to MIPS

- Our IR is likely to use too many registers
- Assume for now, that the number of IR registers is reduced
  - Every **IR register** mapped to a **CPU register** (t0, ... t9)
- We will see later how to compute this **register allocation**
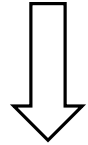
Translating IR to MIPS

- Translate global variable initializations
- Translate the IR instructions for each function
  - Implement a translation function for each IR instruction
  - If the translation requires additional registers:
    - Use registers s0, s1, …

IR command 1
IR command 2
…

MIPS command 1
MIPS command 2
MIPS command 3
…
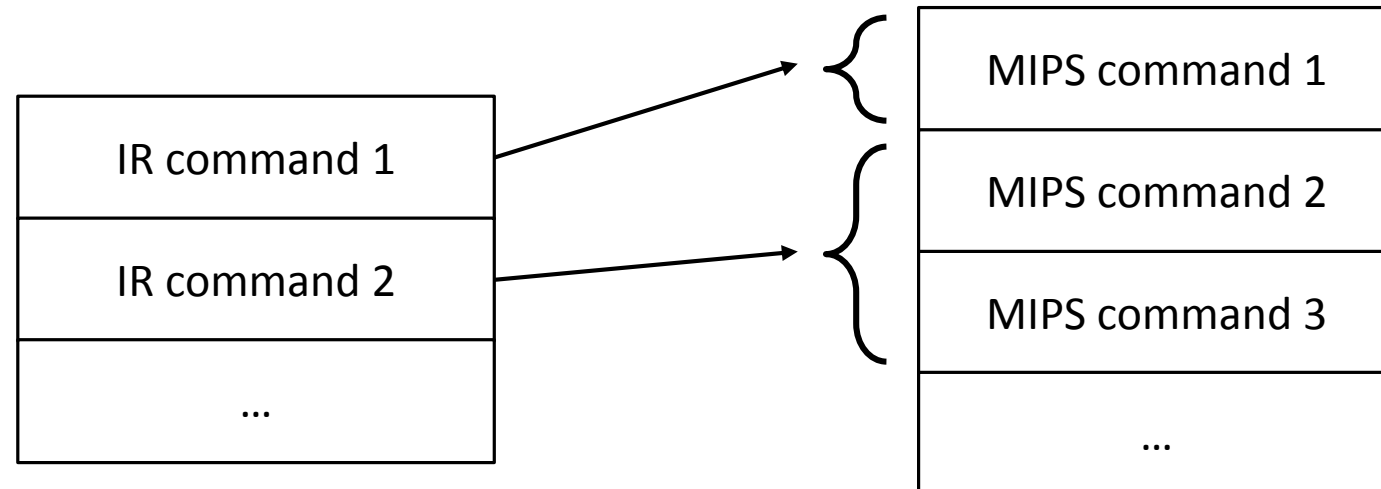
Translating IR

- Assignments (constant)

t1 = c

li $t1, c

Translating IR

- Assignments (read from memory)
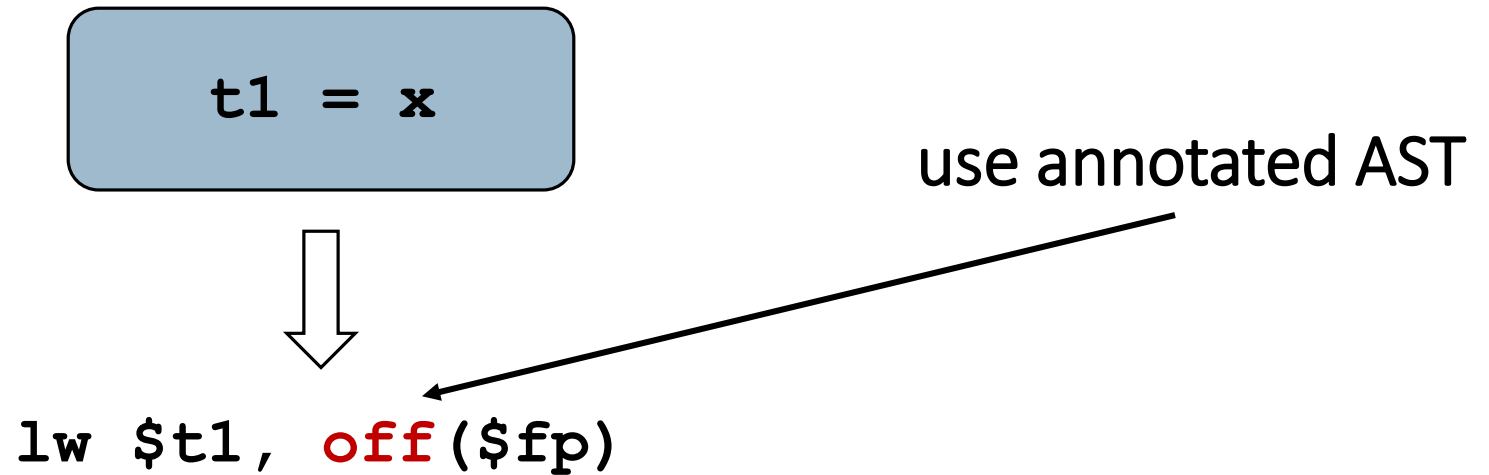- For local variables and parameters:
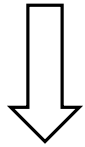
```
t1 = x
```

```
lw $t1, off($fp)
```

Translating IR

- Assignments (read from memory)
- For local variables and parameters:

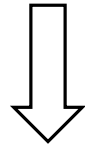t1 = x

use annotated AST

lw $t1, off($fp)

Translating IR

- Assignments (write to memory)
- For local variables and parameters:

```
x = t1
```

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

Translating IR

- Global initializations (integers)

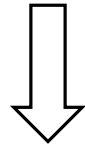```
int g_1 = 7;
```

$\Longrightarrow$
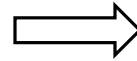
```
.data:
g_1:  .word 7
```

Translating IR

- Assignments (read from memory)
- For global variables:
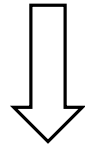
```
t1 = g_var
```

⬇

```
g_var: .word 17
...
lw $t1, g_var
```

Translating IR

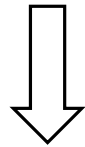- Assignments (write to memory)
- For global variables:


```
g_var = t1
```

```
g_var: .word 17
...
sw $t1, g_var
```

Translating IR

- Arithmetic operation
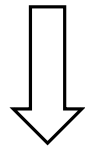
t0 = add t1, t2

add $t0, $t1, $t2

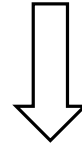# Translating IR

- Arithmetic operation

```
t0 = add t1, t2
```

```
add $t0, $t1, $t2
ble $t0, max, end
li $t0, max
end:
# more checks…
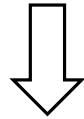```

# Translating IR

- Branch

**beq t1, t2, label**

**beq $t1, $t2, label**

# Translating IR
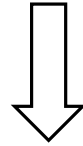
- Function call



```
t0 = call f(t1, t2)
```

```
subu $sp, $sp, 4
sw $t2, 0($sp)
subu $sp, $sp, 4
sw $t1, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
```

Translating IR

- Return (in a function f)
- Store result in **v0** and jump to f's **epilogue label** (f_epilogue)


```
return t1
```

```
move $v0, $t1
j f_epilogue
```

Translating IR

```
int g = 70;
int f(int x){
   int z = x;
   if (z) {
      z = g
   }
   return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

Translating IR

```
int g = 70;
int f(int x){
    int z = x;
    if (z) {
        z = g
    }
    return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

Translating IR

```
int g = 70;
int f(int x){
    int z = x;
    if (z) {
        z = g
    }
    return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g:  .word 70
.text
f:
```

Translating IR

```
int g = 70;
int f(int x){
   int z = x;
   if (z) {
      z = g
   }
   return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g:  .word 70
.text
f:
# prologue here
...
```

Translating IR

```
int g = 70;
int f(int x){
    int z = x;
    if (z) {
        z = g
    }
    return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g:  .word 70
.text
f:
# prologue here
...
lw $t1, 8($fp)
```

Translating IR

```
int g = 70;
int f(int x){
   int z = x;
   if (z) {
      z = g
   }
   return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g: .word 70
.text
f:
# prologue here
...
lw $t1, 8($fp)
sw $t1, -44($fp)
```

Translating IR

```
int g = 70;
int f(int x){
   int z = x;
   if (z) {
      z = g
   }
   return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g:  .word 70
.text
f:
# prologue here
...
lw $t1, 8($fp)
sw $t1, -44($fp)
lw $t2, -44($fp)
```

Translating IR

```
int g = 70;
int f(int x){
   int z = x;
   if (z) {
      z = g
   }
   return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g:  .word 70
.text
f:
# prologue here
...
lw $t1, 8($fp)
sw $t1, -44($fp)
lw $t2, -44($fp)
beq $t2, 0, end
```

Translating IR

```
int g = 70;
int f(int x){
    int z = x;
    if (z) {
        z = g
    }
    return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g:  .word 70
.text
f:
# prologue here
...
lw $t1, 8($fp)
sw $t1, -44($fp)
lw $t2, -44($fp)
beq $t2, 0, end
lw $t3, g
```

Translating IR

```
int g = 70;
int f(int x){
    int z = x;
    if (z) {
        z = g
    }
    return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g: .word 70
.text
f:
# prologue here
...
lw $t1, 8($fp)
sw $t1, -44($fp)
lw $t2, -44($fp)
beq $t2, 0, end
lw $t3, g
sw $t3, -44($fp)
```

Translating IR

```
int g = 70;
int f(int x){
    int z = x;
    if (z) {
        z = g
    }
    return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g:  .word 70
.text
f:
# prologue here
...
lw $t1, 8($fp)
sw $t1, -44($fp)
lw $t2, -44($fp)
beq $t2, 0, end
lw $t3, g
sw $t3, -44($fp)
end:
```
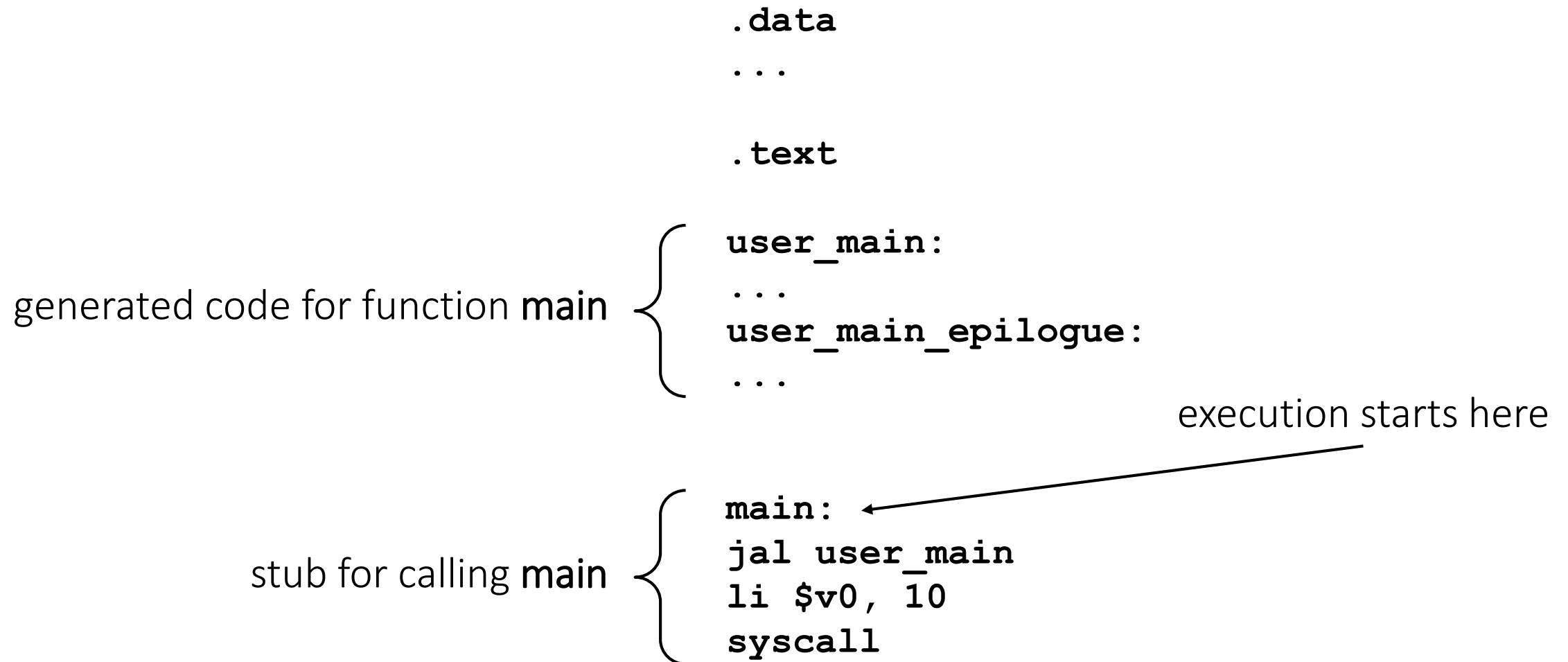
Translating IR

```
int g = 70;
int f(int x){
   int z = x;
   if (z) {
      z = g
   }
   return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g: .word 70
.text
f:
# prologue here
...
lw $t1, 8($fp)
sw $t1, -44($fp)
lw $t2, -44($fp)
beq $t2, 0, end
lw $t3, g
sw $t3, -44($fp)
end:
lw $t4, -44($fp)
```

Translating IR

```
int g = 70;
int f(int x){
    int z = x;
    if (z) {
        z = g
    }
    return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g: .word 70
.text
f:
# prologue here
...
lw $t1, 8($fp)
sw $t1, -44($fp)
lw $t2, -44($fp)
beq $t2, 0, end
lw $t3, g
sw $t3, -44($fp)
end:
lw $t4, -44($fp)
move $v0, $t4
j f_epilogue
```

Translating IR

```
int g = 70;
int f(int x){
  int z = x;
  if (z) {
    z = g
  }
  return z;
}
```

```
f:
t1 = x
z = t1
t2 = z
beq t2, 0, end
t3 = g
z = t3
end:
t4 = z
return t4
```

```
.data
g: .word 70
.text
f:
# prologue here
...
lw $t1, 8($fp)
sw $t1, -44($fp)
lw $t2, -44($fp)
beq $t2, 0, end
lw $t3, g
sw $t3, -44($fp)
end:
lw $t4, -44($fp)
move $v0, $t4
j f_epilogue
f_epilogue:
# epilogue here
...
```

Calling *main*

```
.data
...

.text
```

generated code for function **main**

```
user_main:
...
user_main_epilogue:
...
```

execution starts here

stub for calling **main**

```
main:
jal user_main
li $v0, 10
syscall
```

Strings

- We use null terminated strings
- Every character is one byte

```
string s1 = "1234";
string s2 = "a";
...
...
```

1	2	3	4	\0

a	\0
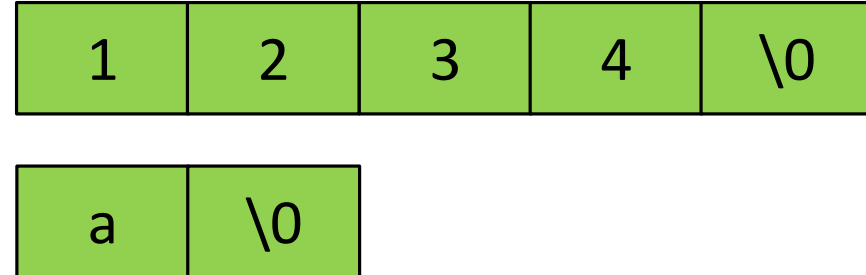
Strings

- Constant assignment

t0 = "1234"
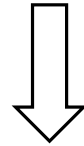
la $t0, str_const

.data
str_const: .asciiz "1234"

goes to **code section**

must be defined in **data section**

Strings

- Global variable initialization

```
string z := "1234";
```

```
.data
z_str: .asciiz "1234"
z: .word z_str
```

Strings

- Assume that *s1* and *s2* are strings

```
if (s1 == s2) {
  ...
}
```

```
t1 = s1;
t2 = s2;
t3 = str_eq t1, t2
beq t3, 0, label
...
```

Strings

- Inline string comparison

```
t1 = s1;
t2 = s2;
t3 = str_eq t1, t2
beq t3, 0, label
...
```

```
li $t3, 1 // result
move $s0, $t1
move $s1, $t2
str_eq_loop:
lb $s2, 0($s0)
lb $s3, 0($s1)
bne $s2, $s3, neq_label
beq $s2, 0, str_eq_end
addu $s0, $s0, 1
addu $s1, $s1, 1
j str_eq_loop
neq_label:
li $t3, 0
str_eq_end:
```

Strings

- Alternatively, create a function str_eq

```
t1 = s1;
t2 = s2;
t3 = str_eq t1, t2
beq t3, 0, label
...
```

```
subu $sp, $sp, 4
sw $t2, 0($sp)
subu $sp, $sp, 4
sw $t1, 0($sp)
jal str_eq
addu $sp, $sp, 8
move $t3, $v0
```

Arrays

- Each cell is 4 bytes (*int* or *pointer*)
- First cell is the **size** of the array
- The rest of the cells contain **data**
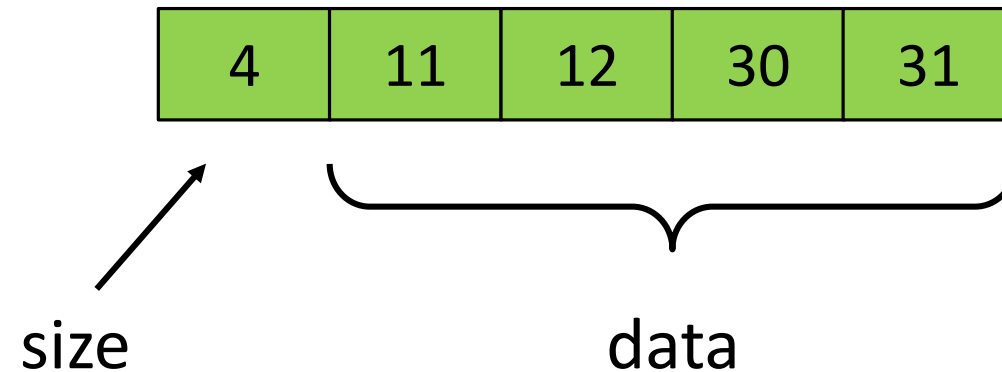
Arrays

- Creating arrays

t0 = new_array t1

```
li $v0, 9
move $a0, $t1
add $a0, $a0, 1
mul $a0, $a0, 4
syscall
move $t0, $v0
li $s0, $t1
sw $s0, 0($t0)
```

Arrays

- Array access

t0 = array_access t1, t2

```
move $s0, $t2
add $s0, $s0, 1
mul $s0, $s0, 4
addu $s0, $t1, $s0
lw $t0, 0($s0)
```

Arrays

- Checking access violation

t0 = array_access t1, t2

```
bltz $t2, abort
lw $s0, 0($t1)
bge $t2, $s0, abort
move $s0, $t2
add $s0, $s0, 1
mul $s0, $s0, 4
addu $s0, $t1, $s0
lw $t0, 0($s0)
...
abort:
li $v0, 10
syscall
```

Classes

Class Layout

```
class A {
  int x;
  string y;
  int f() { …
  int g() { …
}
```

Object

vt	x	y

f	g

virtual table
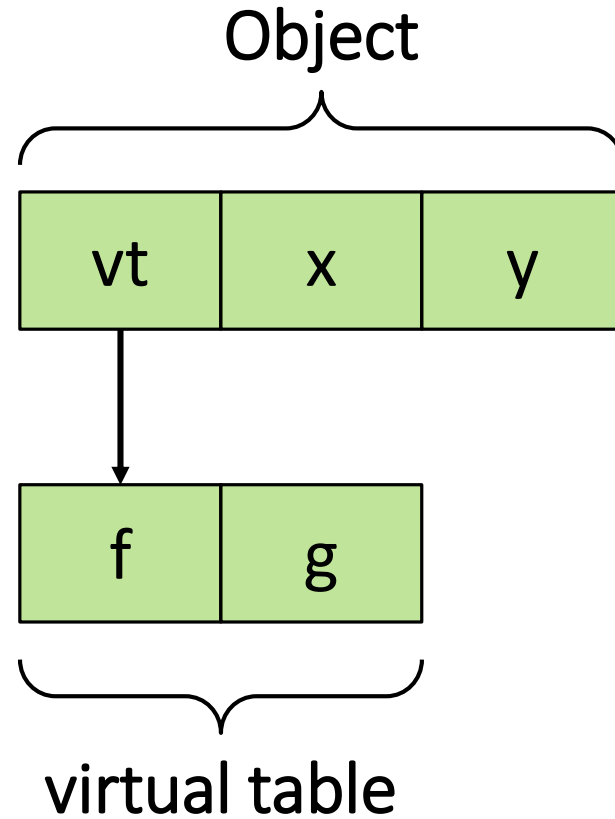
Class Layout

```
class A {
  int x;
  string y;
  int f() { …
  int g() { …
}
class B extends A {
  int z;
  int f() { …
  int h() { …
}
```


vt	x	y	z

f	g	h
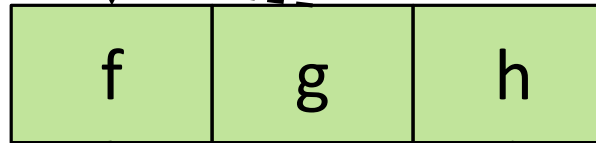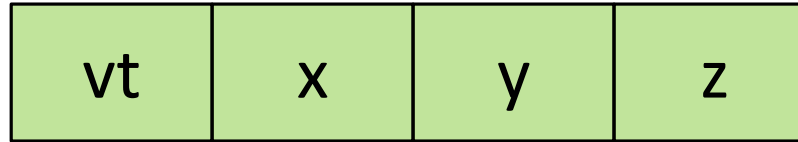
B's layout

Creating Objects

```
class A {
   int f1 = c;

   …
   int m1() { …

   …
}


A a = new A;
```
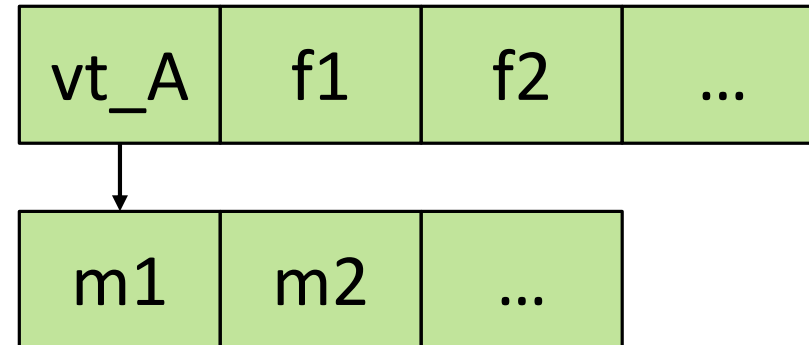
Creating Objects

```
class A {
    int f1 = c;
    …
    int m1() { …
    …
}


A a = new A;
```

```
t0 = new_class A
a = t0
```

IR

Creating Objects

```
t0 = new_class A
```


| vt_A | f1 | f2 | ... |

| m1 | m2 | ... |

virtual table

Creating Objects

t0 = new_class A

```
.data
vt_A:
.word m1
.word m2
...
```

| vt_A | f1 | f2 | ... |

| m1 | m2 | ... |

virtual table

Creating Objects

t0 = new_class A

| vt_A | f1 | f2 | … |

| m1 | m2 | … |

virtual table

```
.data
vt_A:
.word m1
.word m2
...
```

```
li $v0, 9
li $a0, size-of-A
syscall
move $t0, $v0
```

Creating Objects

t0 = new_class A

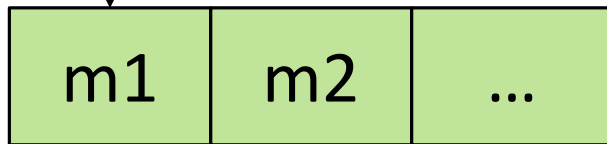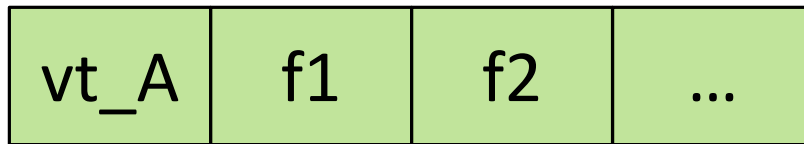| vt_A | f1 | f2 | ... |

| m1 | m2 | ... |

virtual table

```
.data
vt_A:
.word m1
.word m2
...
```

```
li $v0, 9
li $a0, size-of-A
syscall
move $t0, $v0
la $s0, vt_A
sw $s0, 0($t0)
```
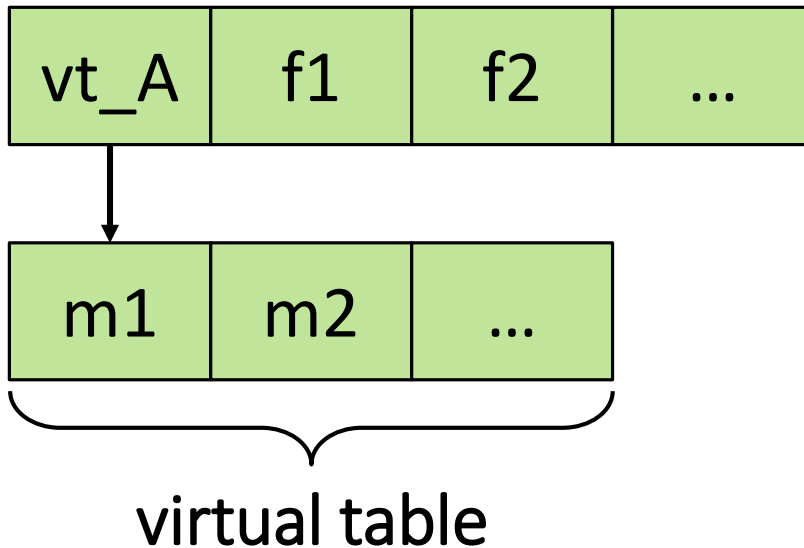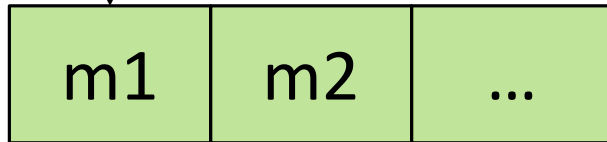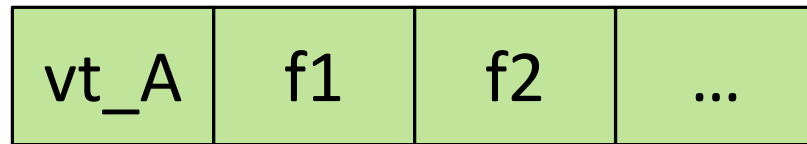
Creating Objects

t0 = new_class A

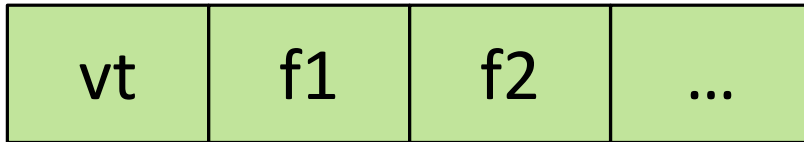

virtual table

```
.data
vt_A:
.word m1
.word m2
...
```

```
li $v0, 9
li $a0, size-of-A
syscall
move $t0, $v0
la $s0, vt_A
sw $s0, 0($t0)
li $s0, c
sw $s0, 4($t0)
...
```

Field Access

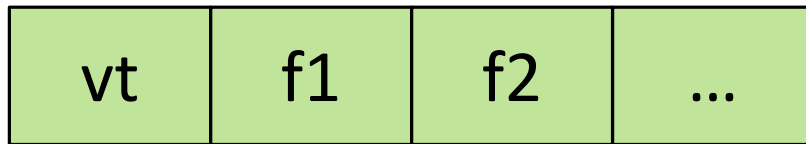t0 = field_access t1, f

lw $t0, off($t1)

use annotated AST

| vt | f1 | f2 | ... |

t1

Field Access

t0 = field_access t1, f

```
beq $t1, 0, abort
lw $t0, off($t1)
...
abort:
li $v0, 10
syscall
```

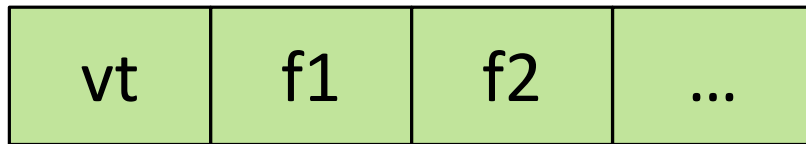| vt	f1	f2	…

t1

Field Access

field_set t1, f, t1

```
beq $t0, 0, abort
sw $t1, off($t0)
...
abort:
li $v0, 10
syscall
```

| vt | f1 | f2 | ... |

t1

Method Calls

```
t2 = virtual_call t0, m, t1
```
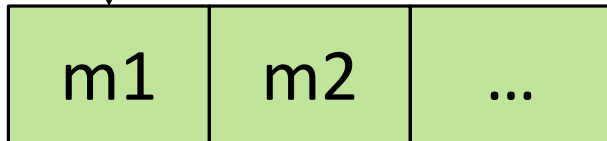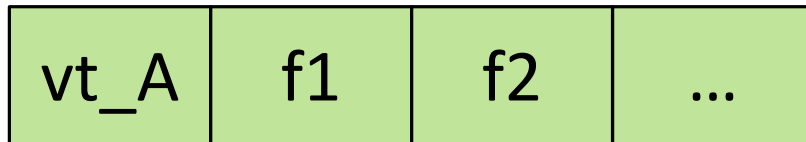
vt_A	f1	f2	...

m1	m2	...

virtual table

Method Calls

t2 = virtual_call t0, m, t1

```
subu $sp, $sp, 4
sw $t1, 0($sp)
```

vt_A	f1	f2	...

m1	m2	...

virtual table

Method Calls

t2 = **virtual_call** t0, m, t1

subu $sp, $sp, 4
sw $t1, 0($sp)
subu $sp, $sp, 4
sw $t0, 0($sp)

vt_A	f1	f2	...

m1	m2	...

virtual table

Method Calls

t2 = **virtual_call** t0, m, t1

vt_A	f1	f2	...

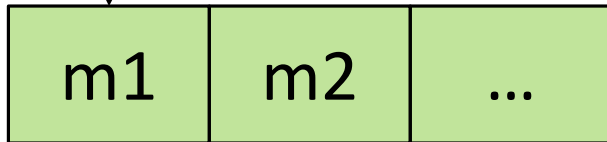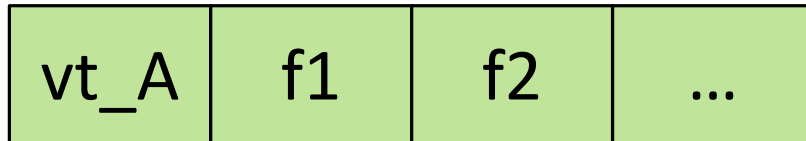| m1	m2	...
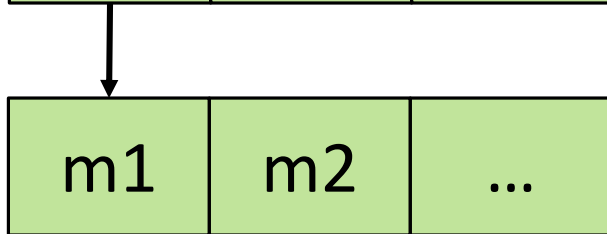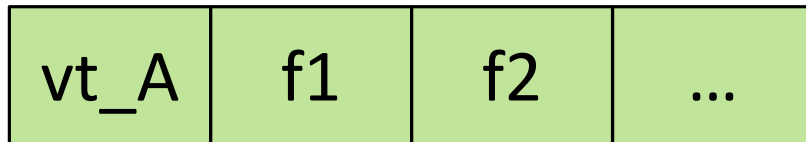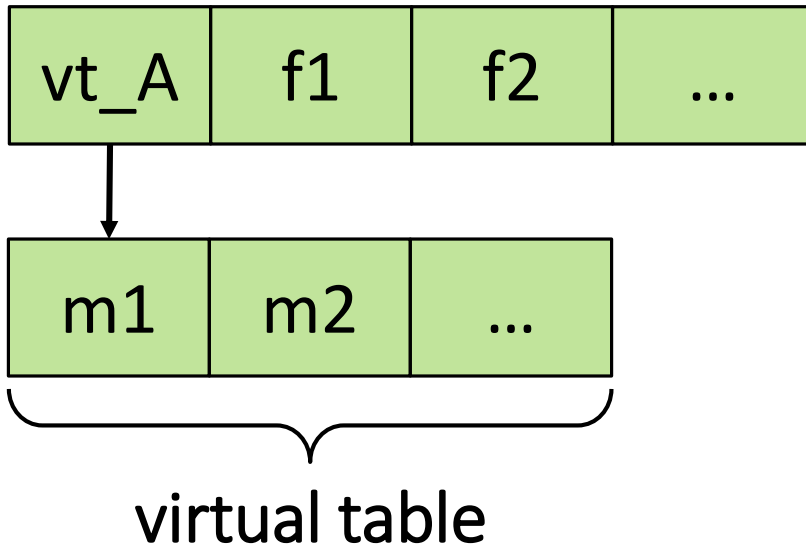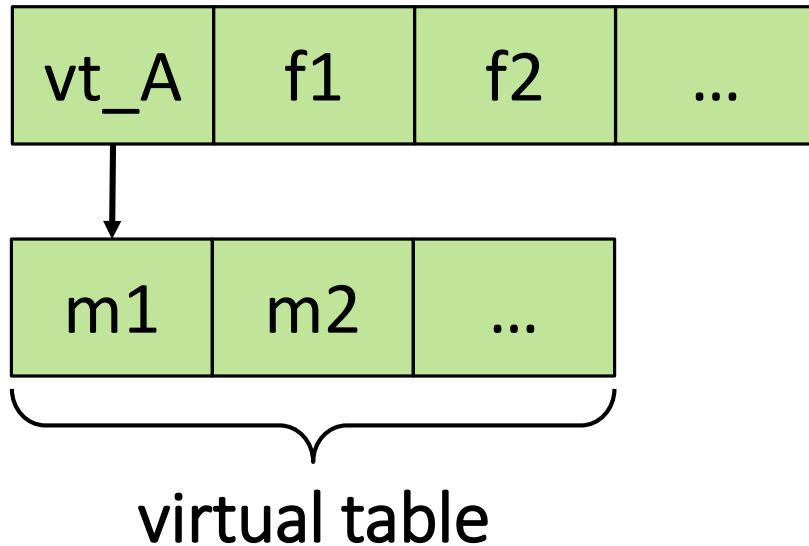
virtual table

```
subu $sp, $sp, 4
sw $t1, 0($sp)
subu $sp, $sp, 4
sw $t0, 0($sp)
lw $s0, 0($t0)
```

Method Calls

t2 = **virtual_call t0, m, t1**
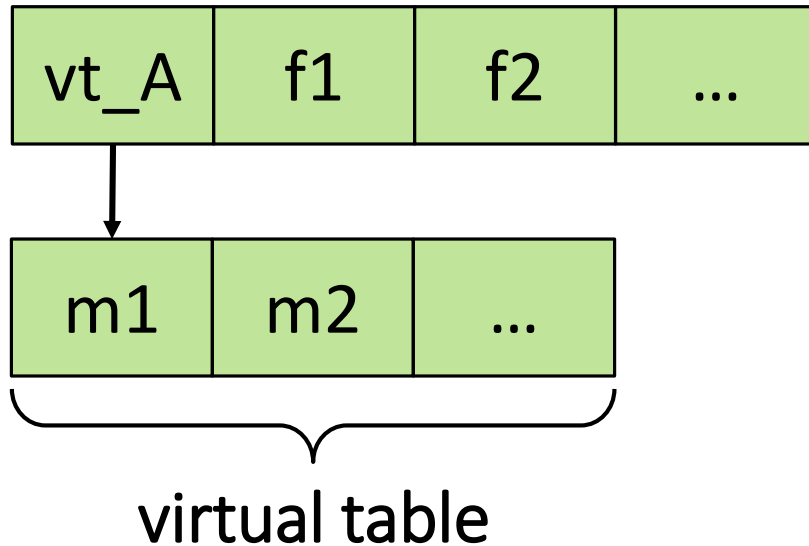

vt_A | f1 | f2 | …

m1 | m2 | …

virtual table

```
subu $sp, $sp, 4
sw $t1, 0($sp)
subu $sp, $sp, 4
sw $t0, 0($sp)
lw $s0, 0($t0)
lw $s1, off($s0)
```

use annotated AST

Method Calls

t2 = **virtual_call** t0, m, t1

virtual table

```
subu $sp, $sp, 4
sw $t1, 0($sp)
subu $sp, $sp, 4
sw $t0, 0($sp)
lw $s0, 0($t0)
lw $s1, off($s0)
jalr $s1
```

Method Calls

t2 = **virtual_call** t0, m, t1

virtual table

```
subu $sp, $sp, 4
sw $t1, 0($sp)
subu $sp, $sp, 4
sw $t0, 0($sp)
lw $s0, 0($t0)
lw $s1, off($s0)
jalr $s1
addu $sp, $sp, 8
```

Method Calls

t2 = **virtual_call** t0, m, t1

vt_A | f1 | f2 | …

m1 | m2 | …
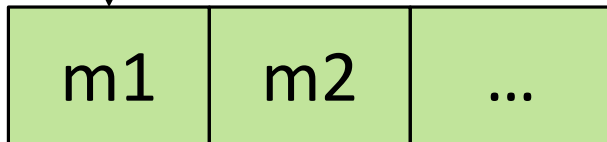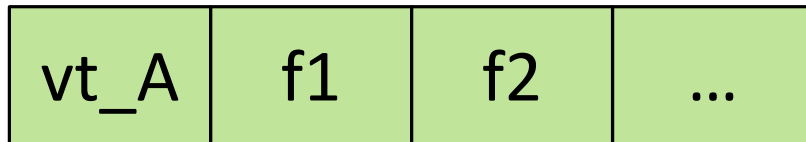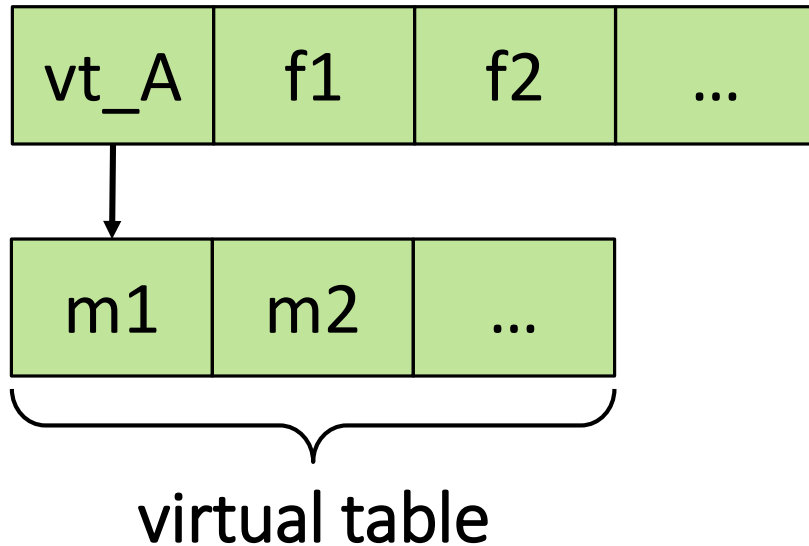
virtual table

```
subu $sp, $sp, 4
sw $t1, 0($sp)
subu $sp, $sp, 4
sw $t0, 0($sp)
lw $s0, 0($t0)
lw $s1, off($s0)
jalr $s1
addu $sp, $sp, 8
move $t2, $v0
```

Method Calls

```
class A {
  void m1(int x) {}
  void m2(int x) {}
}
class B extends A {
  void m2(int x) {}
}


B b = new B;
z = b.m2(7)
```

```
t0 = new_class B
b = t0
t1 = b
t2 = 7
t3 = virtual_call t1, m2, t2
z = t3
```

IR

Method Calls

```
t0 = new_class B
b = t0
t1 = b
t2 = 7
t3 = virtual_call t1, m2, t2
z = t3
```

```
.data
vt_B:
.word A_m1
.word B_m2
```

data section

Method Calls

```
t0 = new_class B
b = t0
t1 = b
t2 = 7
t3 = virtual_call t1, m2, t2
z = t3
```

```
li $v0, 9
li $a0, 4
syscall
move $t0, $v0
la $s0, vt_B
sw $s0, 0($t0)
```

```
.data
vt_B:
.word A_m1
.word B_m2
```
data section

Method Calls

```
t0 = new_class B
b = t0
t1 = b
t2 = 7
t3 = virtual_call t1, m2, t2
z = t3
```

```
li $v0, 9
li $a0, 4
syscall
move $t0, $v0
la $s0, vt_B
sw $s0, 0($t0)
sw $t0, off_b($fp)
```

```
.data
vt_B:
.word A_m1
.word B_m2
```
data section

Method Calls

```
t0 = new_class B
b = t0
t1 = b
t2 = 7
t3 = virtual_call t1, m2, t2
z = t3
```

```
li $v0, 9
li $a0, 4
syscall
move $t0, $v0
la $s0, vt_B
sw $s0, 0($t0)
sw $t0, off_b($fp)
lw $t1, off_b($fp)
```

```
.data
vt_B:
.word A_m1
.word B_m2
```
} data section

Method Calls

```
t0 = new_class B
b = t0
t1 = b
t2 = 7
t3 = virtual_call t1, m2, t2
z = t3
```

```
li $v0, 9
li $a0, 4
syscall
move $t0, $v0
la $s0, vt_B
sw $s0, 0($t0)
sw $t0, off_b($fp)
lw $t1, off_b($fp)
li $t2, 7
```

```
.data
vt_B:
.word A_m1
.word B_m2
```
data section

Method Calls

t0 = new_class B
b = t0
t1 = b
t2 = 7
t3 = virtual_call t1, m2, t2
z = t3

```
.data
vt_B:
.word A_m1
.word B_m2
```
data section

```
li $v0, 9
li $a0, 4
syscall
move $t0, $v0
la $s0, vt_B
sw $s0, 0($t0)
sw $t0, off_b($fp)
lw $t1, off_b($fp)
li $t2, 7
subu $sp, $sp, 4
sw $t2, 0($sp)
subu $sp, $sp, 4
sw $t1, 0($sp)
lw $s0, 0($t1)
lw $s1, 4($s0)
jalr $s1
addu $sp, $sp, 8
move $t3, $v0
```

Method Calls

```
t0 = new_class B
b = t0
t1 = b
t2 = 7
t3 = virtual_call t1, m2, t2
z = t3
```

```
.data
vt_B:
.word A_m1
.word B_m2
```
data section

```
li $v0, 9
li $a0, 4
syscall
move $t0, $v0
la $s0, vt_B
sw $s0, 0($t0)
sw $t0, off_b($fp)
lw $t1, off_b($fp)
li $t2, 7
subu $sp, $sp, 4
sw $t2, 0($sp)
subu $sp, $sp, 4
sw $t1, 0($sp)
lw $s0, 0($t1)
lw $s1, 4($s0)
jalr $s1
addu $sp, $sp, 8
move $t3, $v0
sw $t3, off_z($fp)
```