Code Generation

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MIPS Architecture

- MIPS has 32 registers:
  - t0, …, t9
  - a0, a1, a3, a4
  - v0, v1
  - sp, fp
  - ra
  - …
- We will work with MIPS32
  - 32-bit registers

MIPS Architecture

- Arithmetic instructions operate on registers and constants:
  - add, sub, and, mult, div, or, xor, nor, …

```
li $t0, 3
li $t1, 4
add $t2, $t0, $t1
mul $t3, t1, 7
```

MIPS Architecture

- Read from memory:

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

MIPS Architecture

- Write to memory:

```
sw $t0,$t1
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
...
label:
```

MIPS Architecture

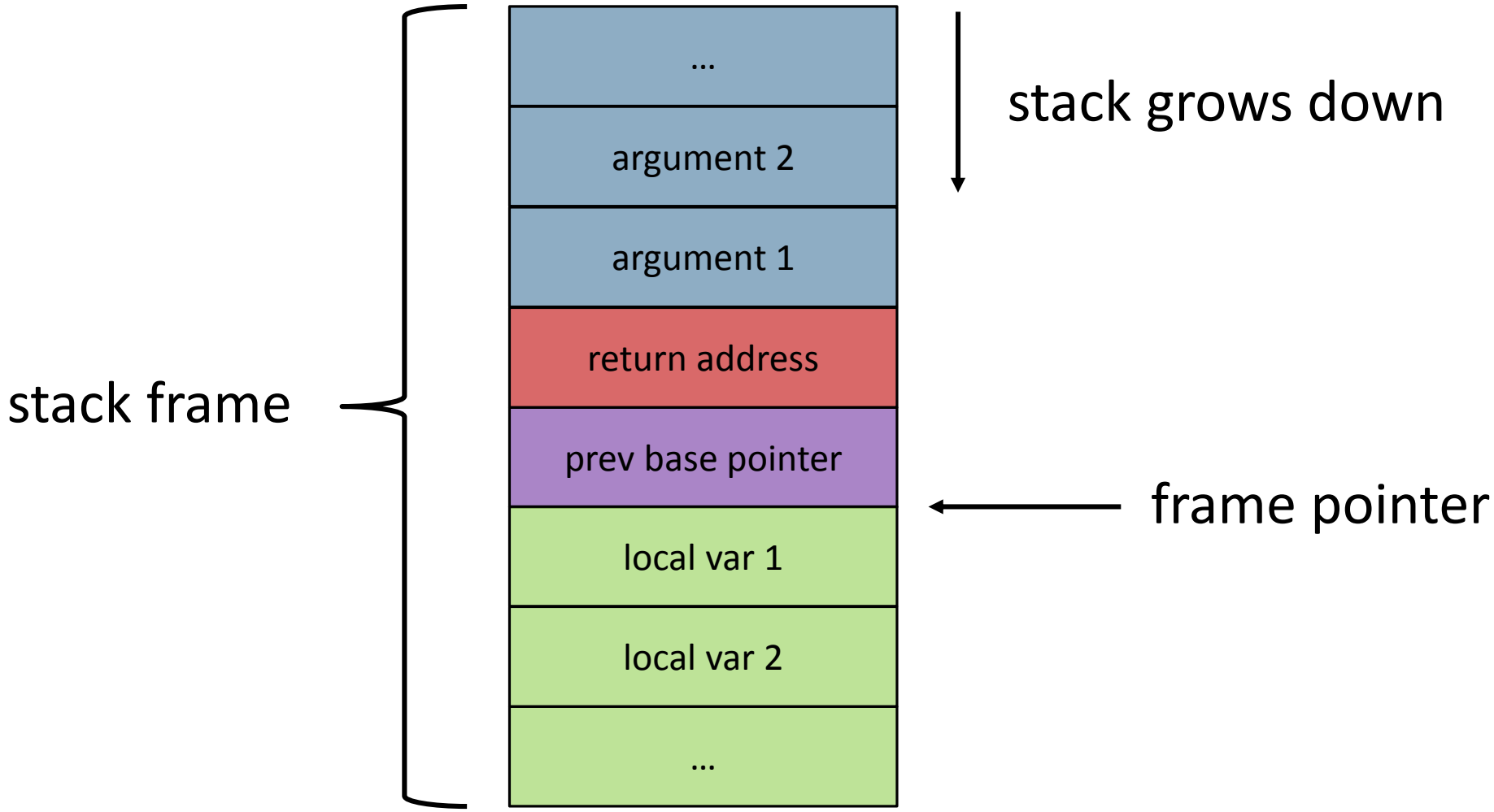
- System calls:
  - Syscall number passed via v0
  - Arguments are passed via a0, a1, a2, a3
- Calling PrintInt(17):

```
li $v0, 1
li $a0, 17
syscall
```

Stack Frames

- The stack consists of stack frame
- Each called function creates it’s stack frame

Stack


...
argument 2
argument 1
return address
prev base pointer
local var 1
local var 2
...
stack grows down
stack frame
frame pointer

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
```

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g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
li $t0, 10
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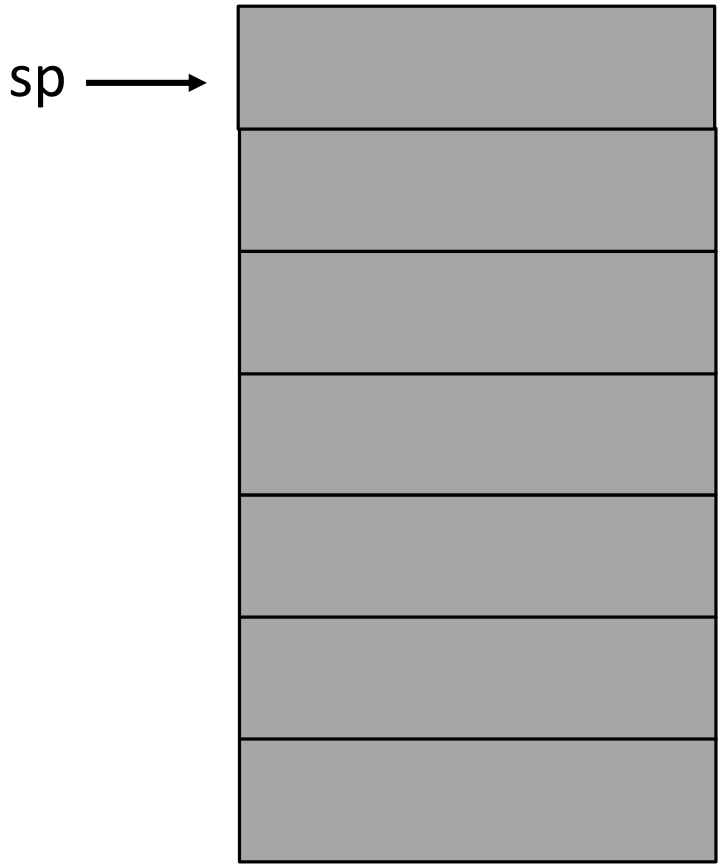
Stack

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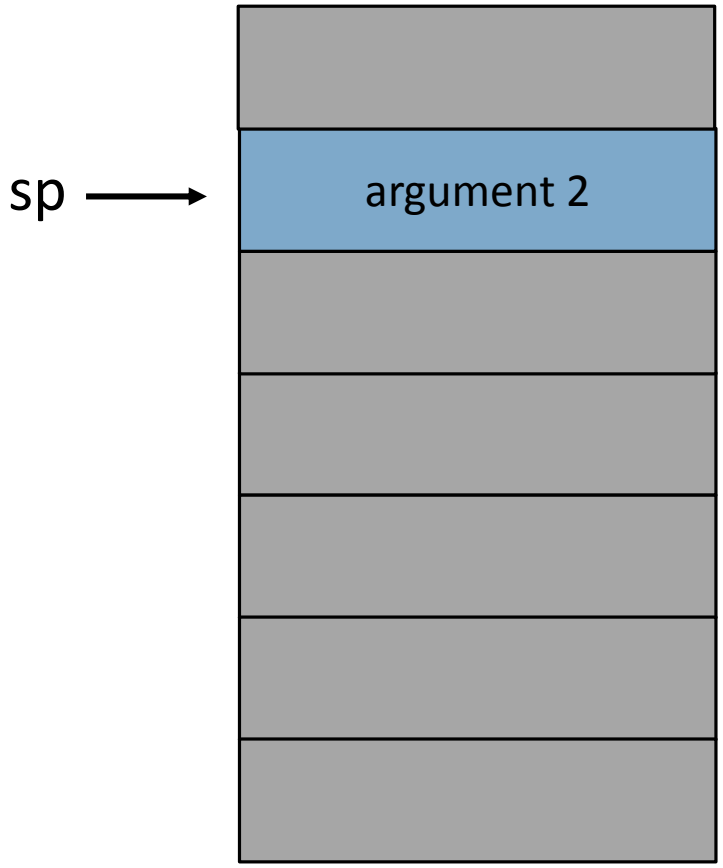


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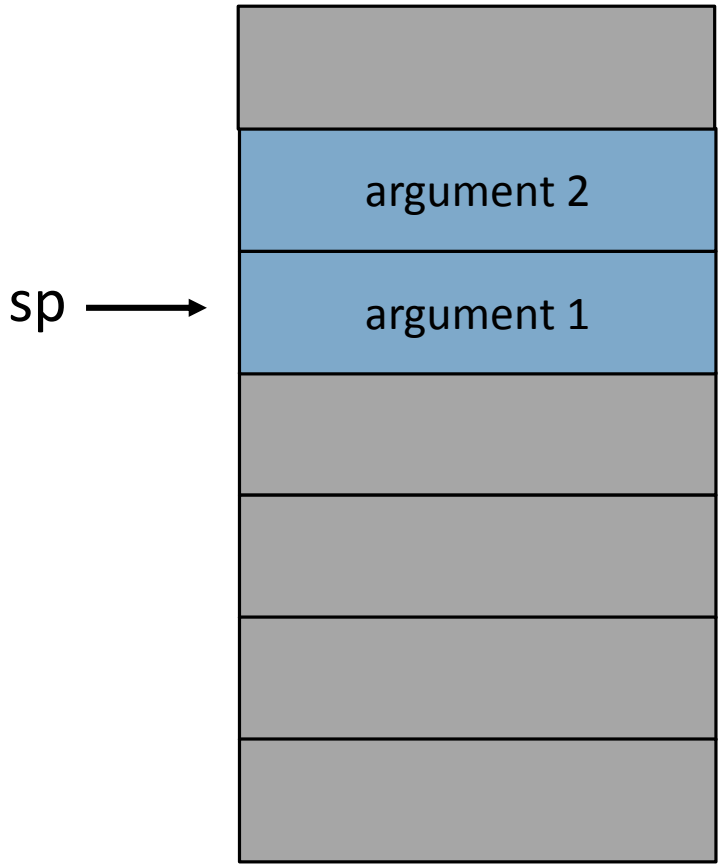


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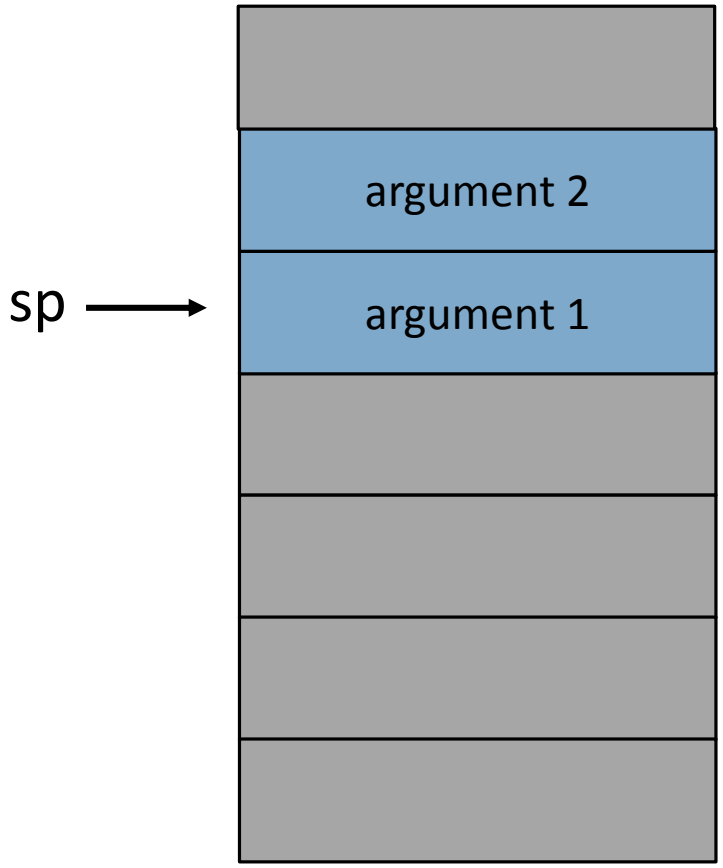


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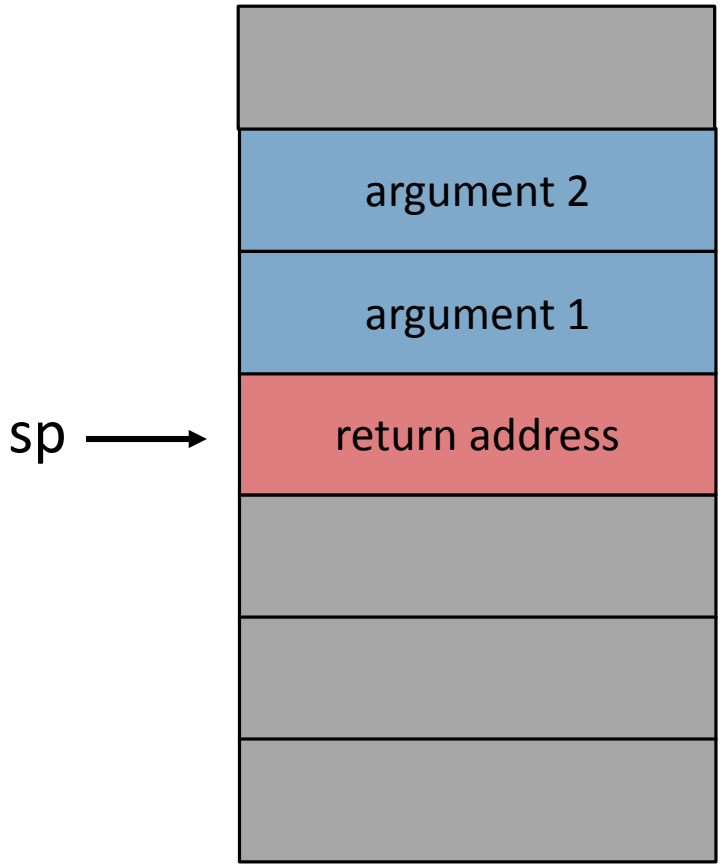


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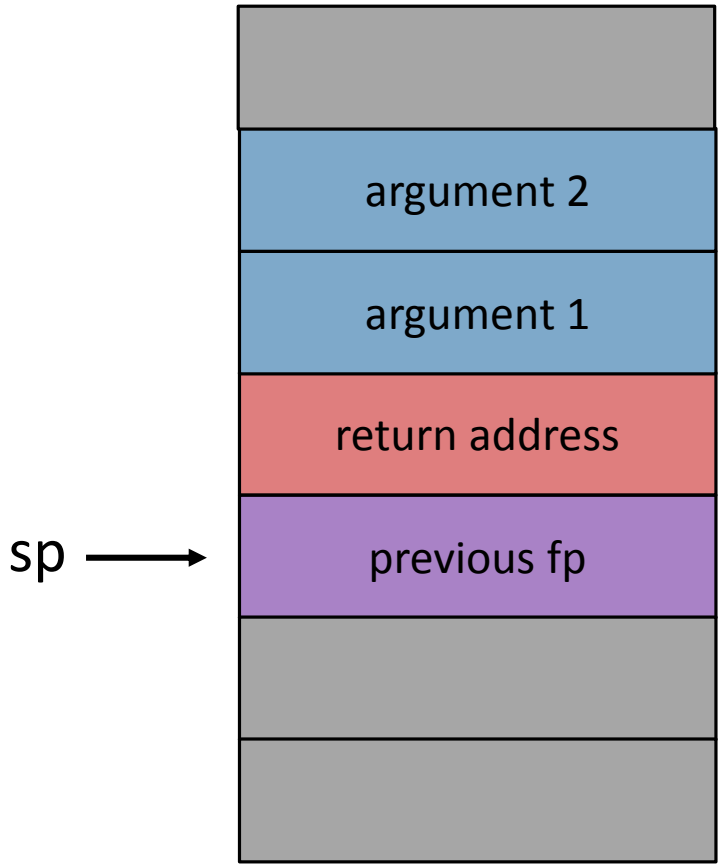
Stack

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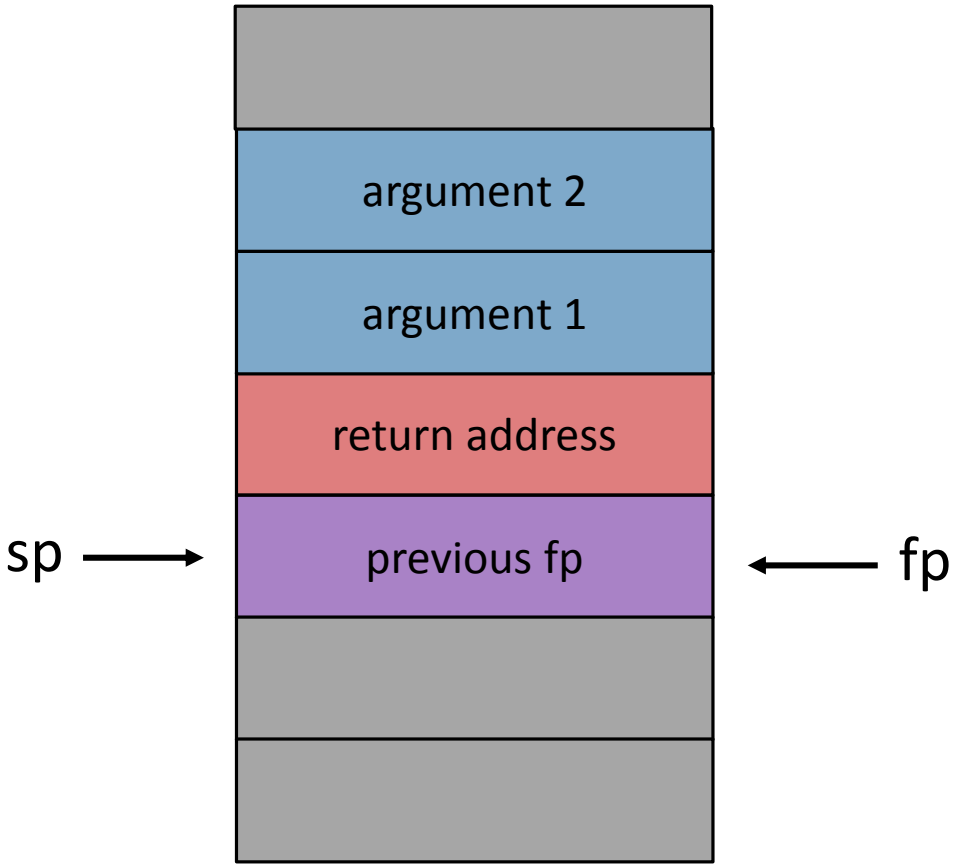


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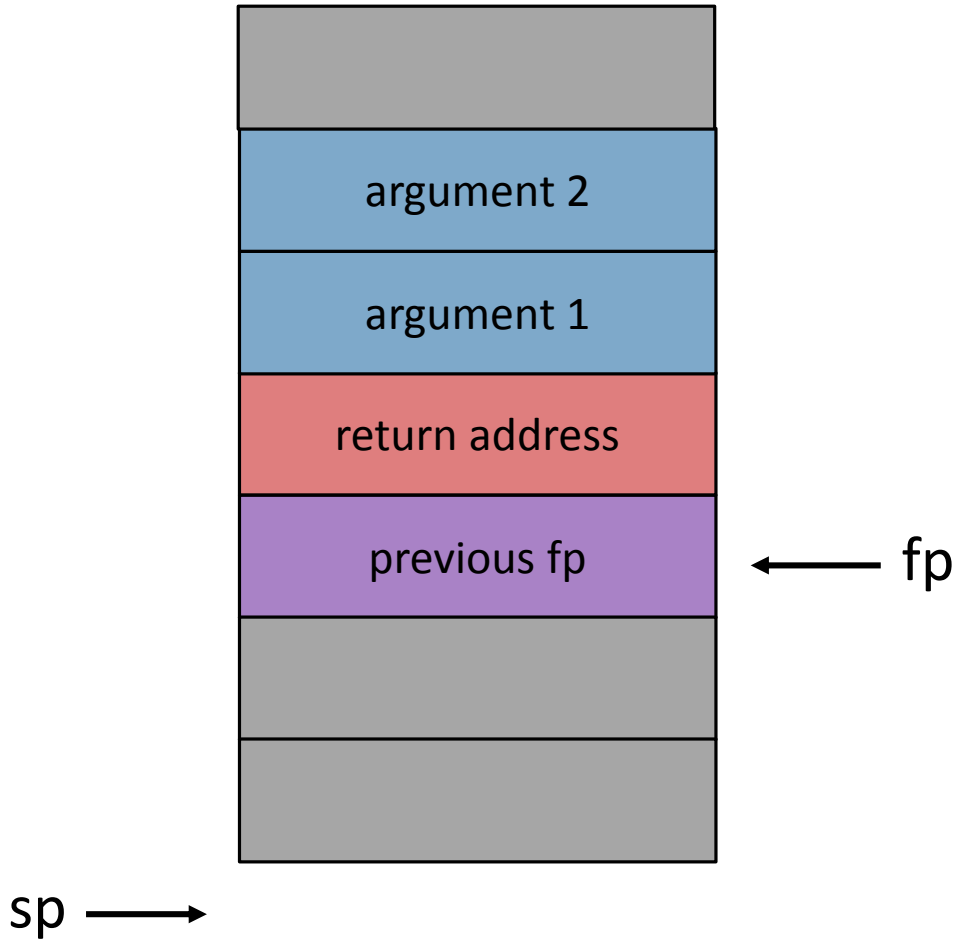


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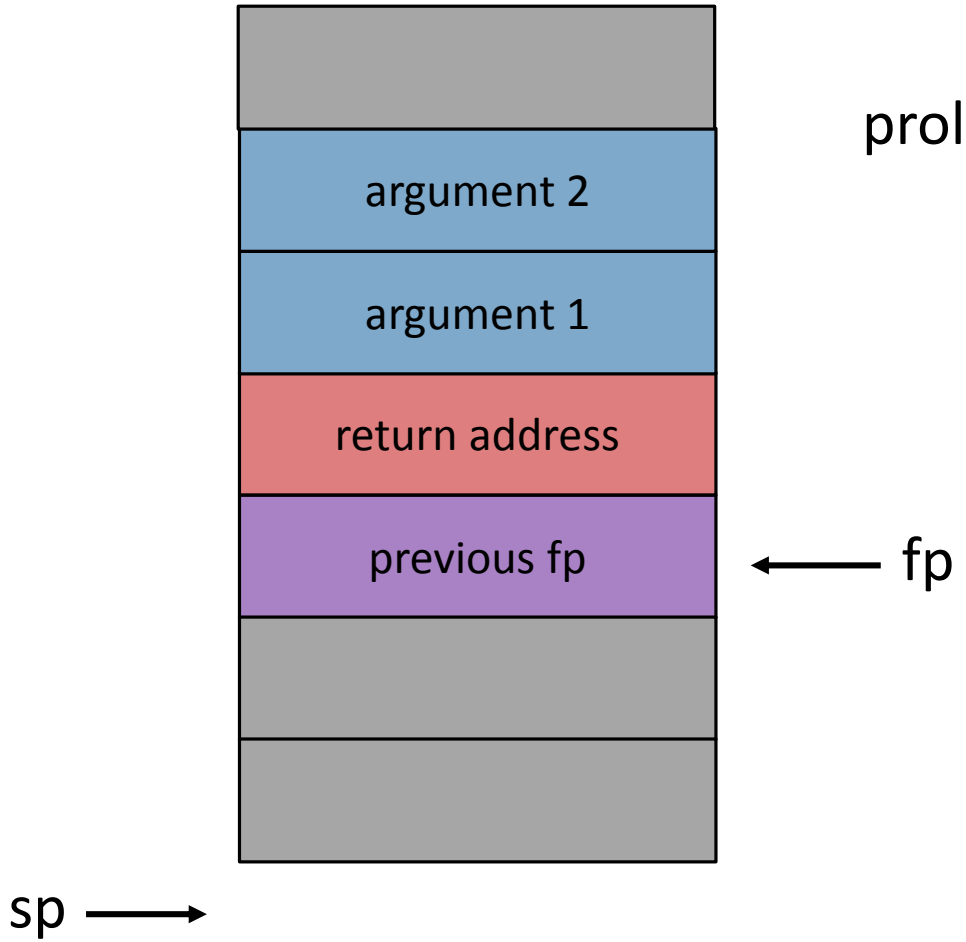

prologue

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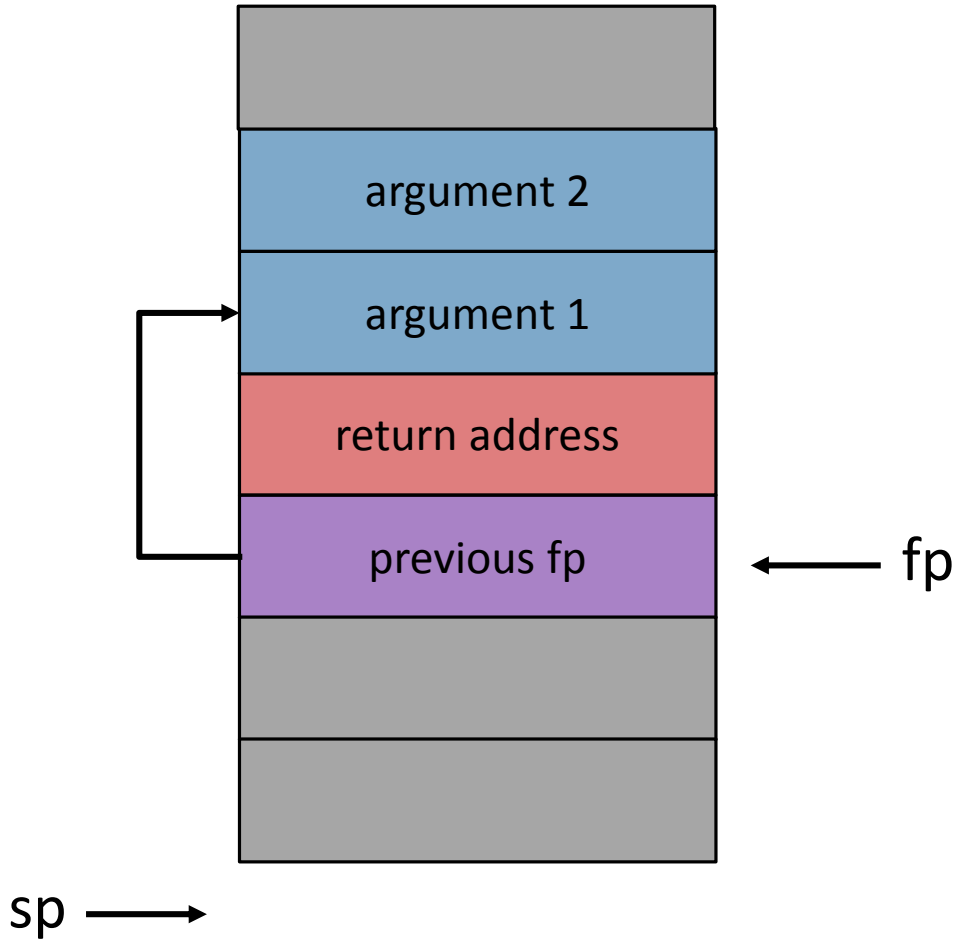


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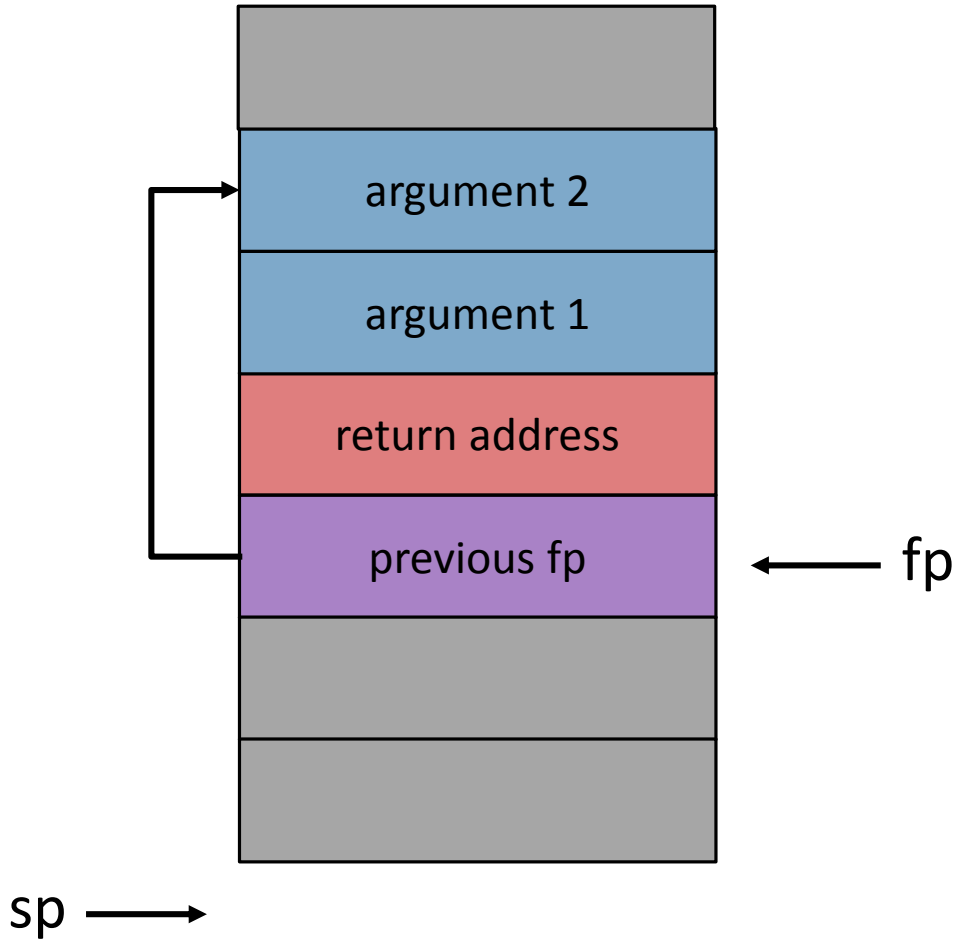


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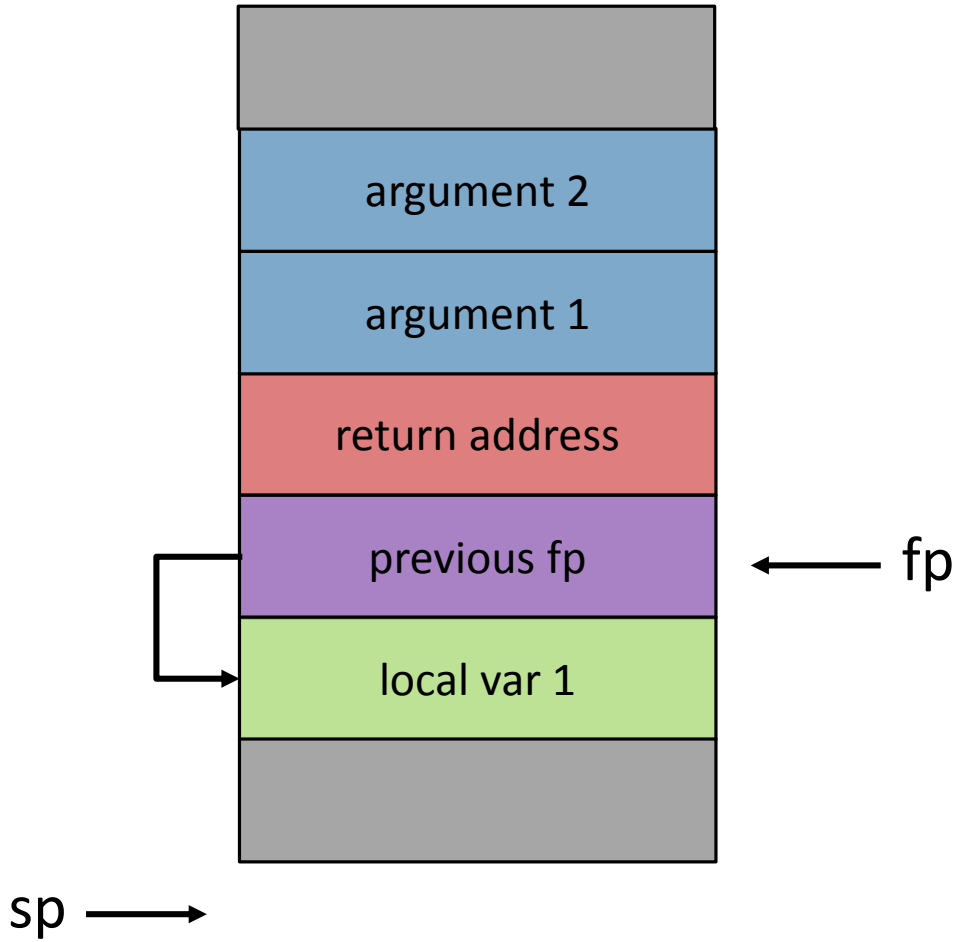


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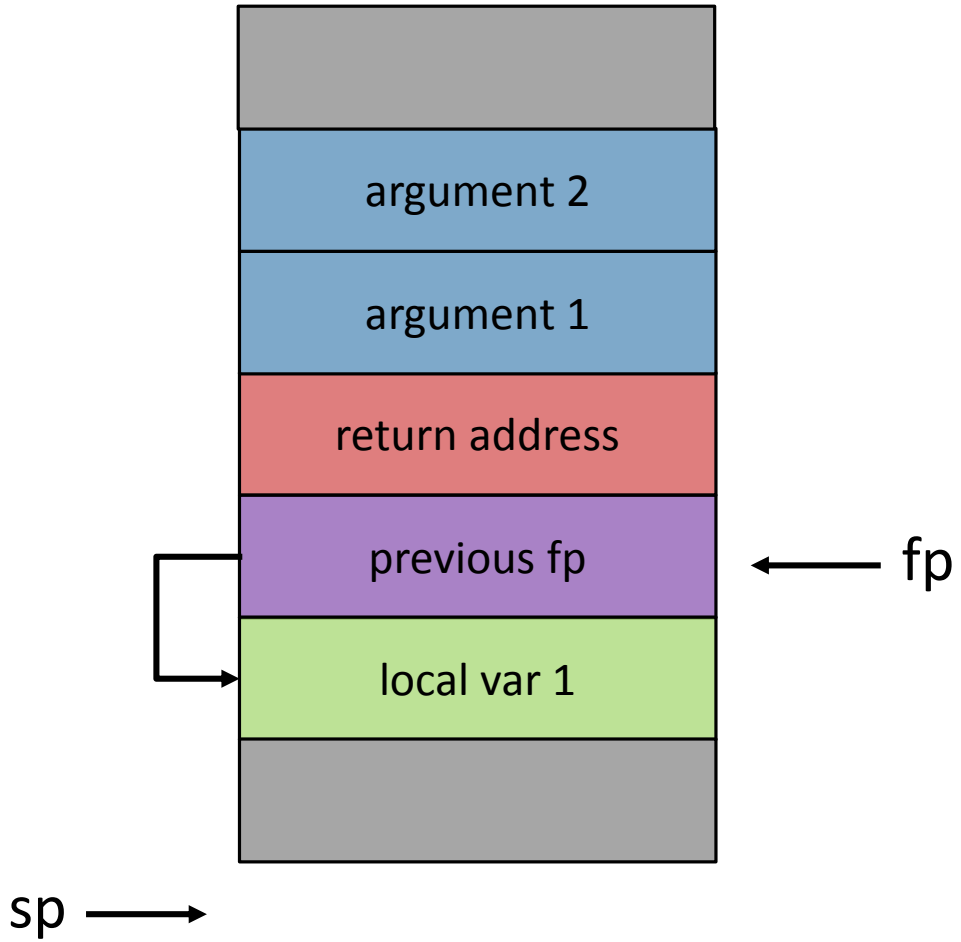


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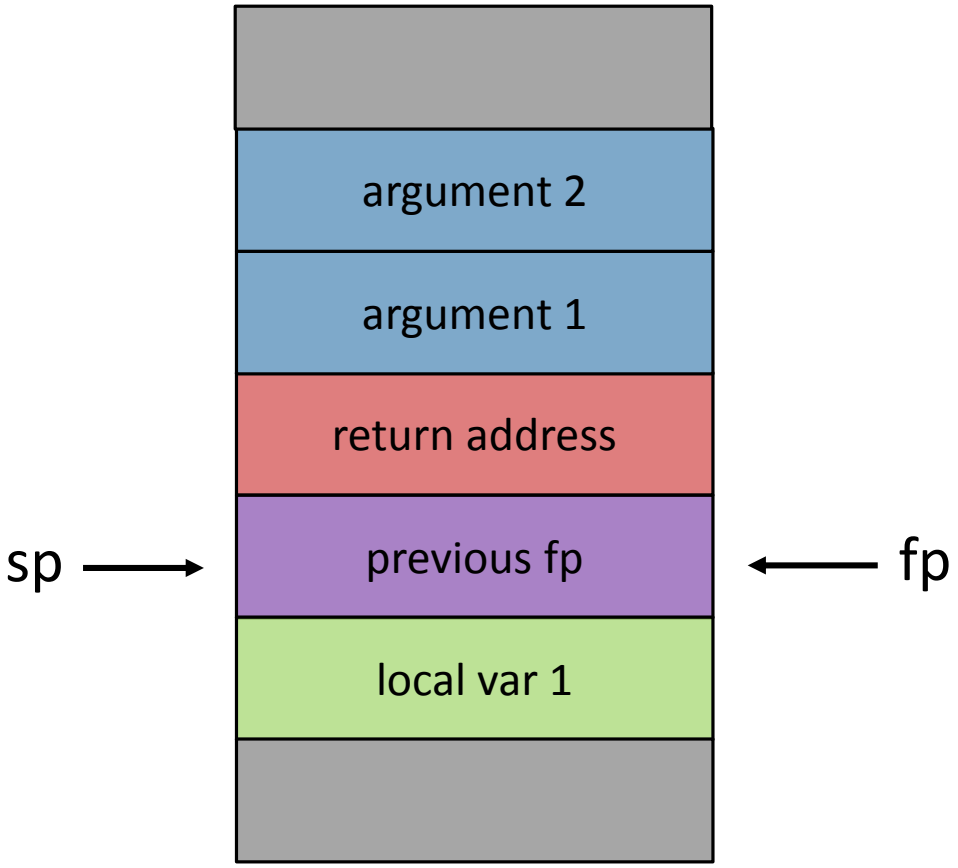


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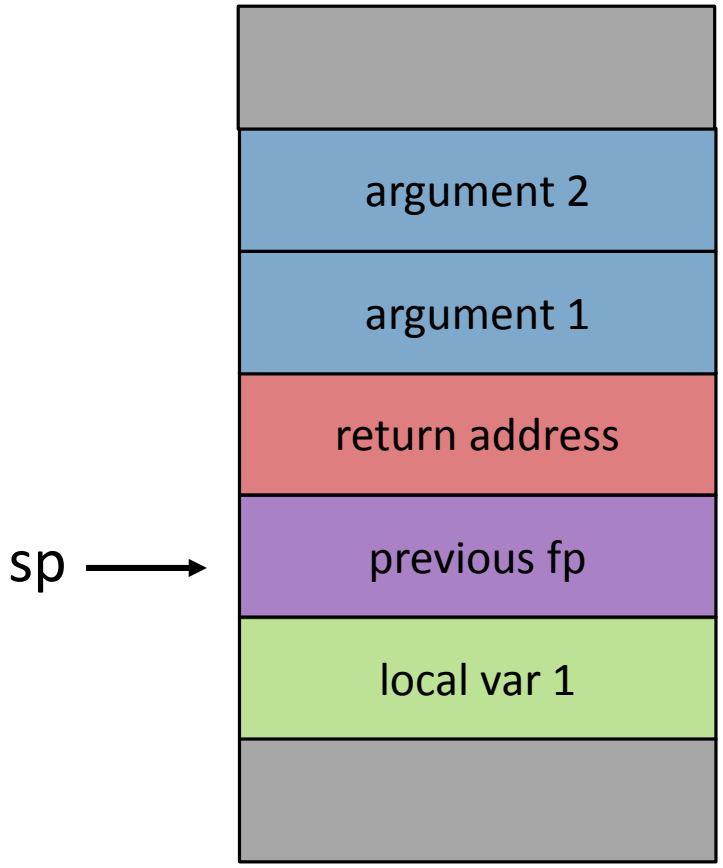


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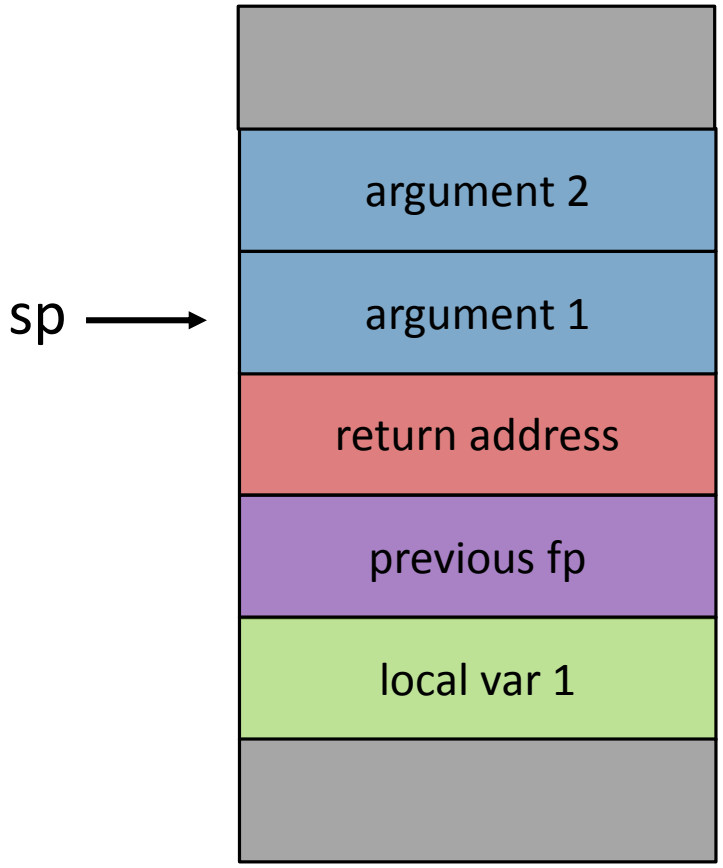


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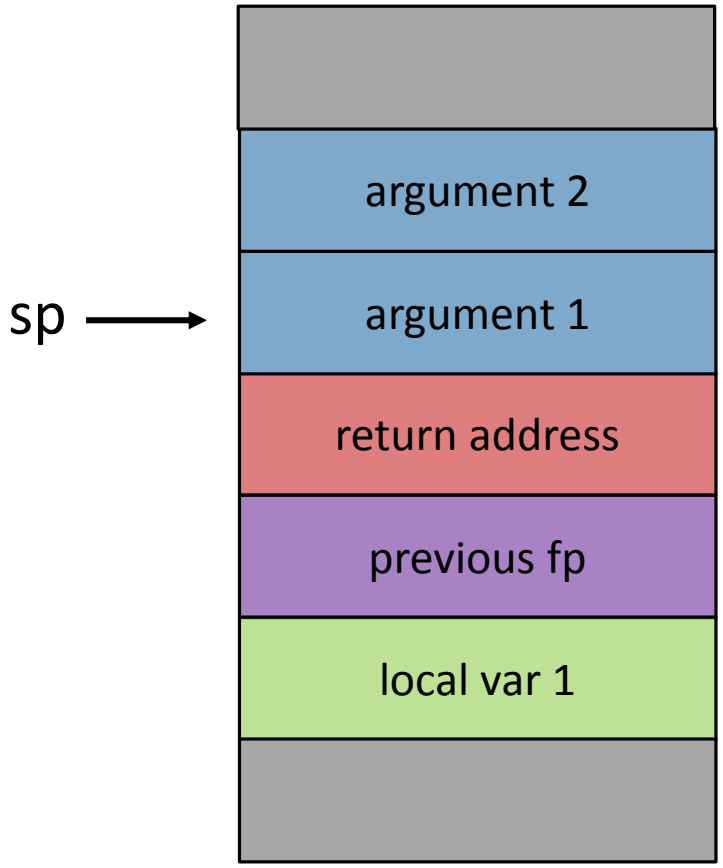


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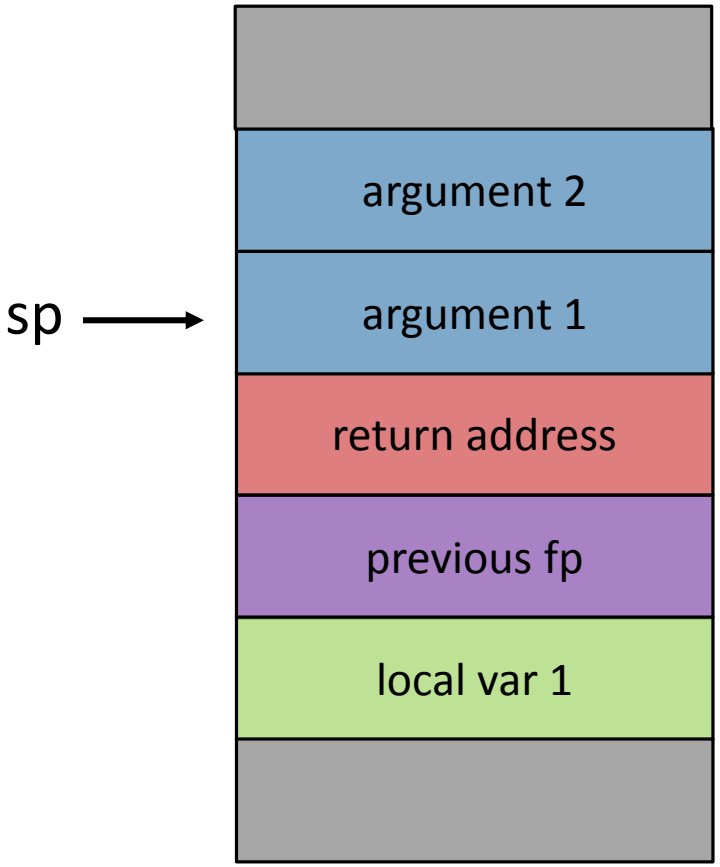


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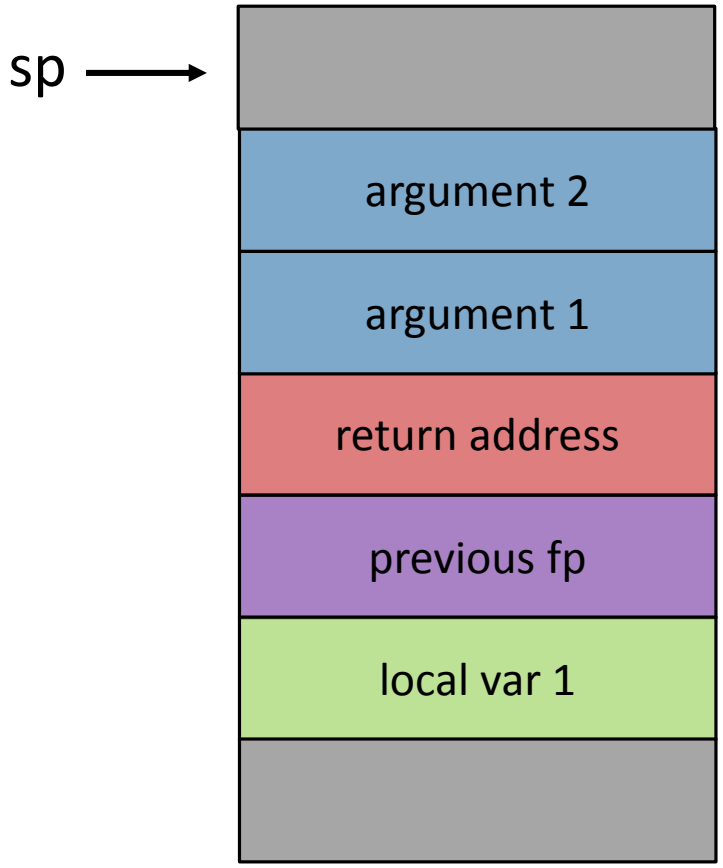
f:
subu $sp, $sp, 4
sw $ra, 0($sp)
subu $sp, $sp, 4
sw $fp, 0($sp)
move $fp, $sp
sub $sp, $sp, 16
lw $t0, 8($fp)
lw $t1, 12($fp)
add $t2, $t0, $t1
sw $t2, -4($fp)
lw $v0, -4($fp)
move $sp, $fp
lw $fp, 0($sp)
lw $ra, 4($sp)
addu $sp, $sp, 8
jr $ra
```

epilogue

```
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
...
```

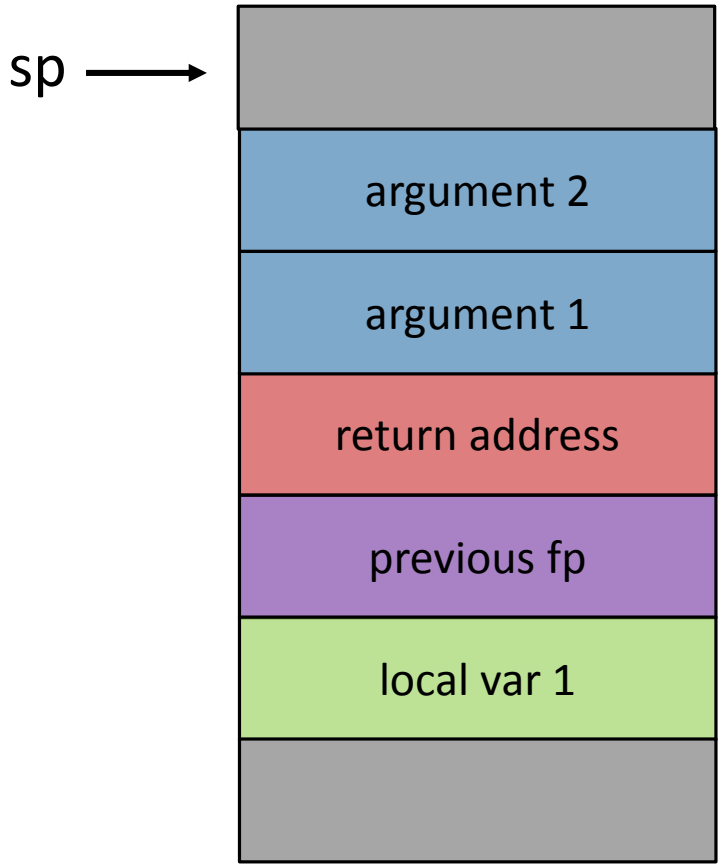
Stack




```
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
...
```

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
```

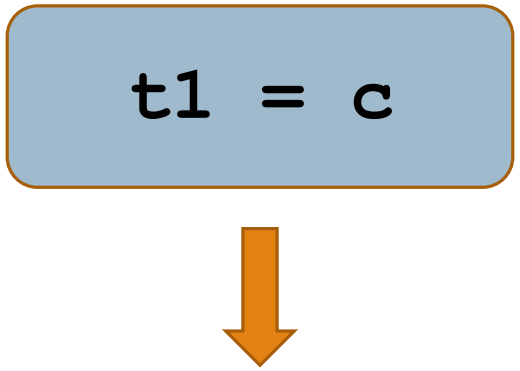
```
g:
...
li $t0, 20
subu $sp, $sp, 4
sw $t0, 0($sp)
li $t0, 10
subu $sp, $sp, 4
sw $t0, 0($sp)
jal f
addu $sp, $sp, 8
move $t0, $v0
...
```

Translating IR

- Our IR is likely to uses too many registers
- Assume for now, that the number of IR registers is reduced
  - Every IR register mapped to a CPU register
- We will see later how to compute this **register allocation**

Translating IR

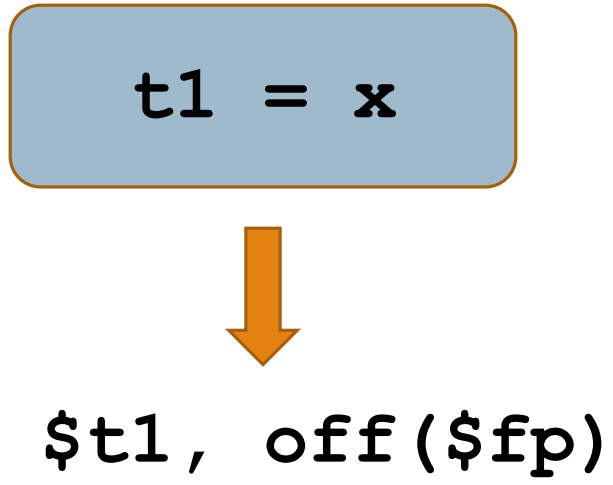
- Assignments (constant)




```
li $t1, c
```

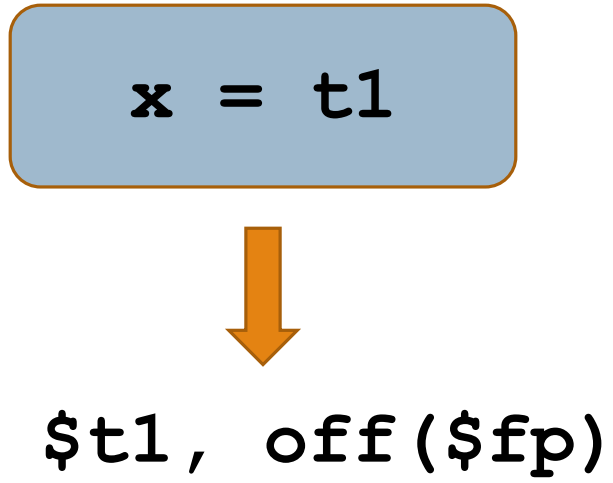
Translating IR

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



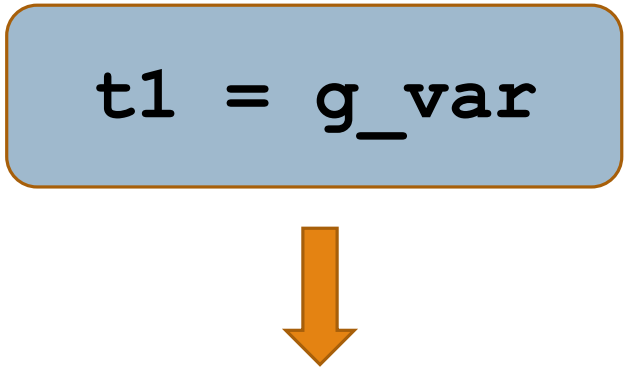
Translating IR

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



Translating IR

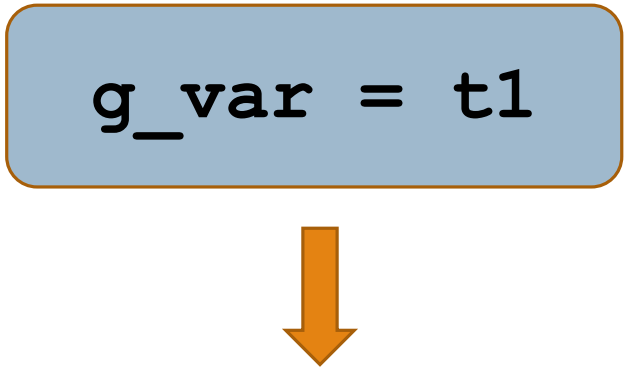
- Assignments (read from memory)
- For global variables:




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

Translating IR

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




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

Translating IR

- Arithmetic operation

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

```
add $t0, $t1, $t2
```

Translating IR

- Branch

```
compare t1, t2
branch_eq label
```

```
beq $t1, $t2, label
```

Translating IR

- Function call

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

```
sw $t1, 0($sp)
subu $sp, $sp, 4
sw $t2, 0($sp)
subu $sp, $sp, 4
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** (f_end)


```
move $v0, $t1
j f_end
```

Translating IR

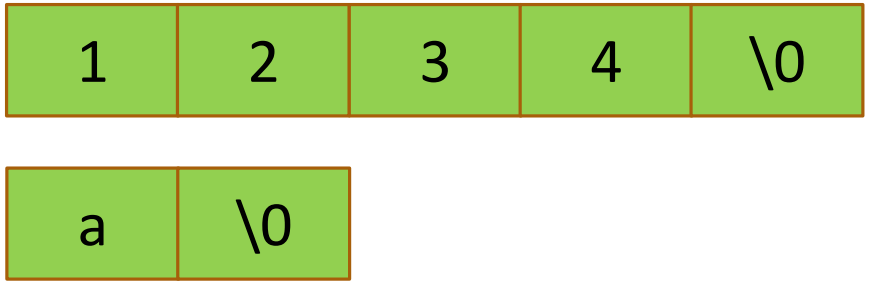
- Example…

```
int g = 1;
int f(int x){
  int z = x + 1;
  return a[z];
}
```

Strings

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

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



Strings

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

```
if (s1 == s2) {

}
```

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

Strings

- Inline string comparison

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

```
lw $t1, -4($fp) // local var 1
lw $t2, -8($fp) // local var 2
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

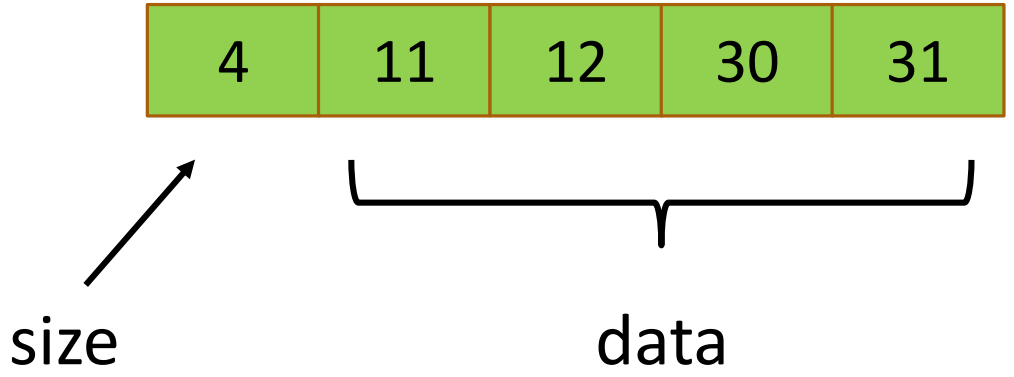
- Alternatively, create a function str_eq

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

```
lw $t1, -4($fp) // local var 1
lw $t2, -8($fp) // local var 2
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

- Array access

```
t0 = array_access t1, t2
```

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

SPIM

- TODO

Runtime Errors

- TODO

Classes

- TODO