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Lecture 7
Functions in MIPS
(Part I)

FIT 1008
Introduction to Computer Science

MONASH University
Information Technology

What we know…

- MIPS **architecture** and **instruction set** (the subset we will use)
- Storing and accessing variables
- Understand what happens at compilation.
- Compiling **basic arithmetic, selection, loops and array access** into assembler

- Everything **EXCEPT** for how to compile **function call/return**

Objectives

- To understand how **functions** are implemented in MIPS.
- In particular:
  - Use of the **jal** and **jr** instructions
  - Use of the **system stack** to satisfy function properties
- To understand the reasons behind the decisions taken by the **function calling convention**
- To understand what a **stack frame** is, and its purpose

?

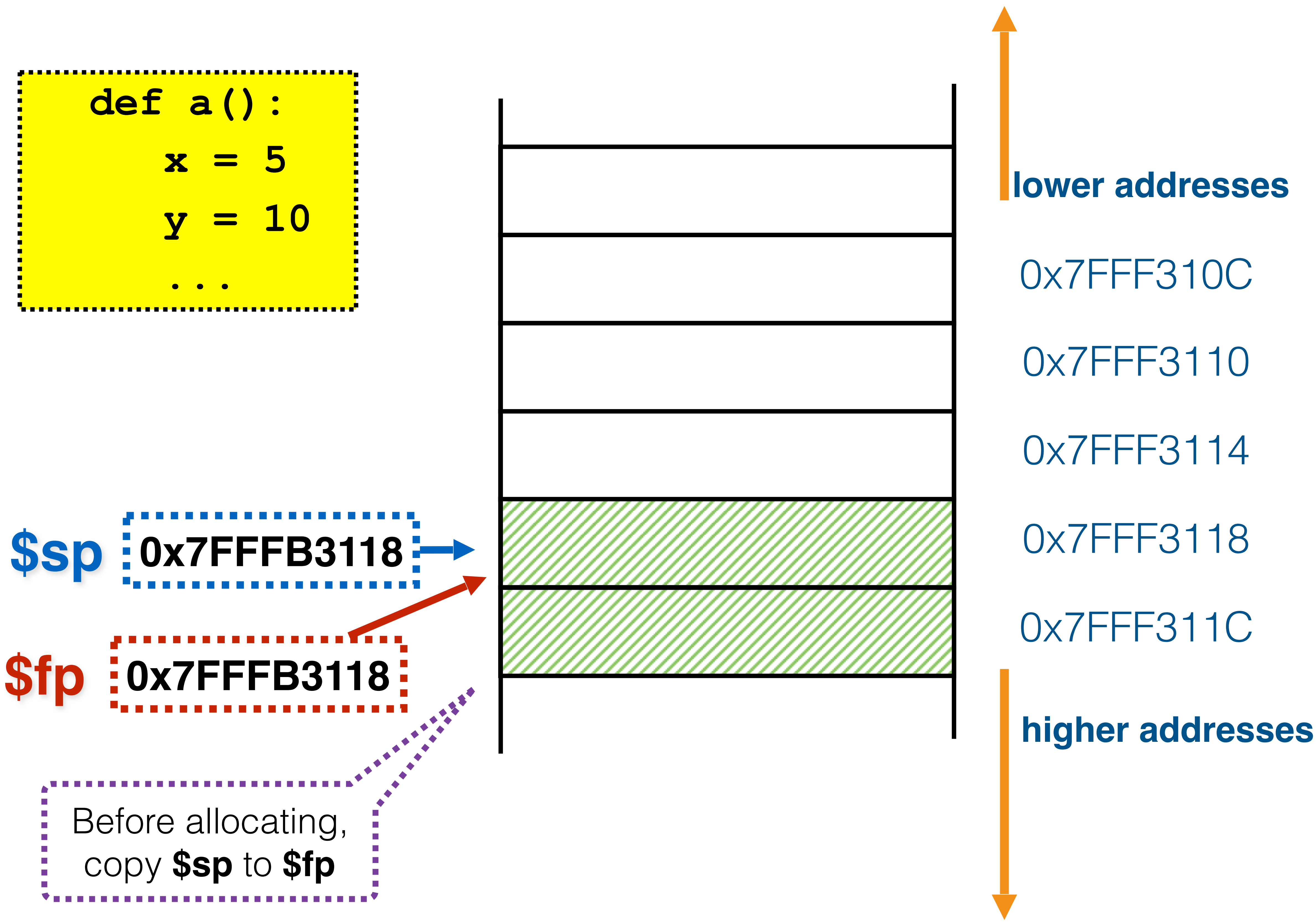
- Can access local variables relative to stack pointer (**$sp**).
- However, this may be problematic when passing arguments to **functions**:
  - Stack pointer moves to accommodate other function info
  - Relative locations of local variables change

Frame pointer

- Can access local variables relative to stack pointer (**$sp**).
- However, this may be <u>problematic when passing arguments to functions</u>:
  - Stack pointer moves to accommodate other function info
  - Relative locations of local variables change
- Better to access local variables relative to **saved copy of stack pointer**: Copy made before subtracting from **$sp** to allocate local variables
- Saved copy stored in register **$fp** (frame pointer): Local variables accessed relative to **$fp**.

Example

```
def a():
    x = 5
    y = 10
    ...
```



Example

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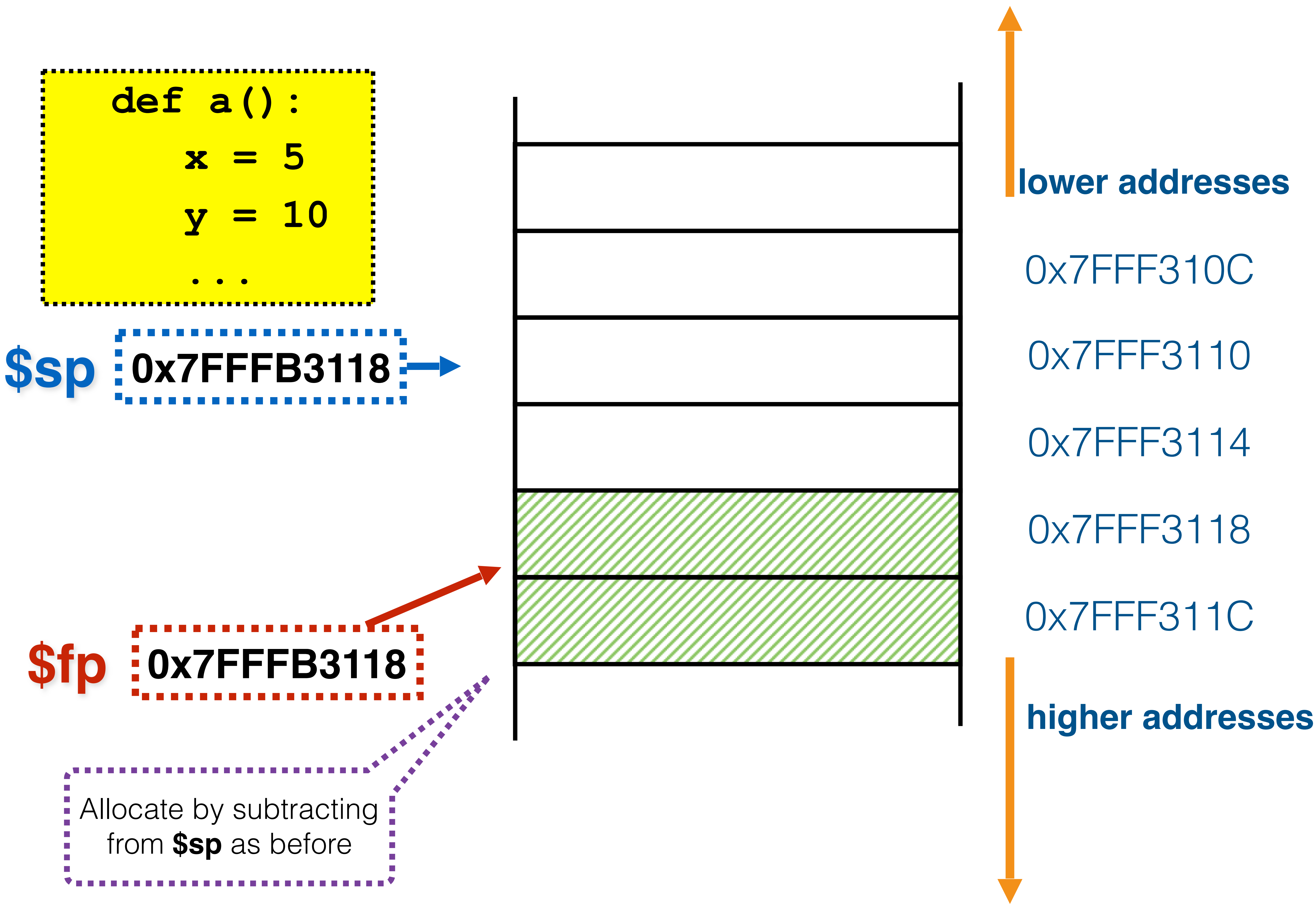
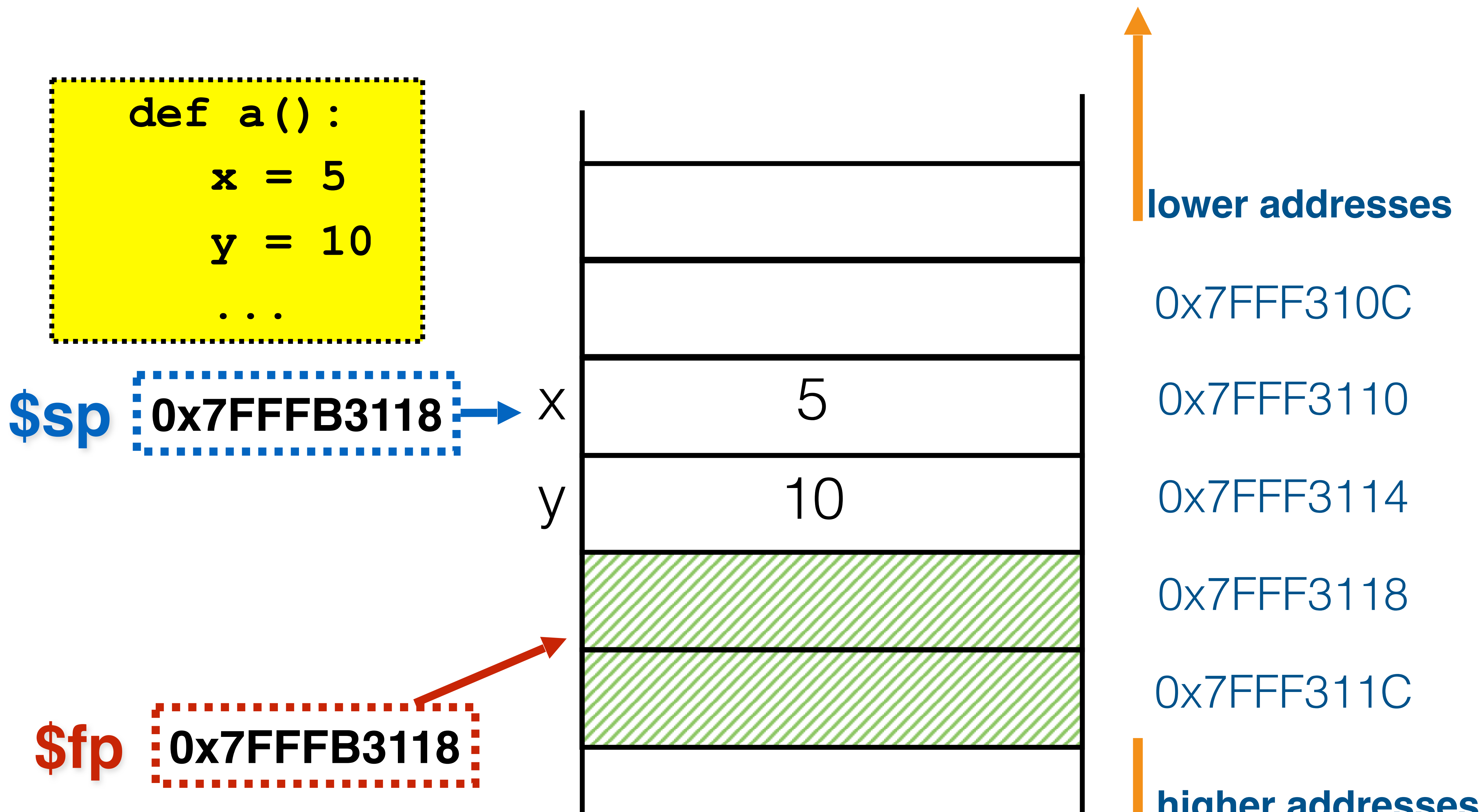


Example

```
def a():
    x = 5
    y = 10
    ...
```



access **y** at address **($fp – 4) = 0x7FFF3114**

access **x** at address **($fp – 8) = 0x7FFF3110**

- Local variables are referred to without names in MIPS.
- Therefore, remembering their address is vital: **diagrams help**

```
// A global variable
g = 123

def main():
   // Three local variables
   a = -5
   b = 0
   c = 230
   // Do some arithmetic
   b = g + a

   // Do some more arithmetic
   print(c - a)
```

```
.data
# g is global, allocate
# in data segment
g:          .word 123

.text
main:       # Copy $sp into $fp.
            addi $fp, $sp, 0

            # Allocate 12 bytes of
            # memory for local variables.
            addi $sp, $sp, -12

            # Initalize local
            # variables.

            addi $t0, $0, -5     # a
            sw $t0, -12($fp)

             sw $0, -8($fp)       # b

            addi $t0, $0, 230    # c
            sw $t0, -4($fp)

            # ... rest of program
            # follows next slide ...
```

Faithful translation: regs for **g** and **a** are not re-used, they are reloaded

```
// A global variable
g = 123

def main():

   // Three local variables
   a = -5
   b = 0
   c = 230

   // Do some arithmetic
   b = g + a

   // Do some more arithmetic
   print(c - a)
```

```
... here is the rest
# of the MIPS code ...

# b = g + a.
lw $t0, g                # g
lw $t1, -12($fp)         # a
add $t0, $t0, $t1        # g+a
sw $t0, -8($fp)          # store in b

# print(c-a)
addi $v0, $0, 1          # Print int
lw $t0, -4($fp)          # c
lw $t1, -12($fp)         # a
sub $a0, $t0, $t1        # c-a
syscall                  # Do print.

# Now exit.
addi $v0, $0, 10       # Exit.
syscall
```

```
.data
# g is global, allocate
# in data segment
g:       .word 123

.text
main:    # Copy $sp into $fp.
         addi $fp, $sp, 0

         # Allocate 12 bytes of
         # memory for local variable
         addi $sp, $sp, -12

         # Initalize local
         # variables.

         addi $t0, $0, -5     # a
         sw $t0, -12($fp)

          sw $0, -8($fp)       # b

         addi $t0, $0, 230    # c
         sw $t0, -4($fp)

         # ... rest of program
         # follows next slide ...
```

```
... here is the rest
# of the MIPS code ...

# b = g + a.
lw $t0, g                # g
lw $t1, -12($fp)         # a
add $t0, $t0, $t1        # g+a
sw $t0, -8($fp)          # store in b

# print(c-a)
addi $v0, $0, 1          # Print int
lw $t0, -4($fp)          # c
lw $t1, -12($fp)         # a
sub $a0, $t0, $t1        # c-a
syscall                  # Do print.

# Now exit.
addi $v0, $0, 10       # Exit.
syscall
```

```
// A global variable
g = 123

def main():

   // Three local variables
   a = -5
   b = 0
   c = 230

   // Do some arithmetic
   b = g + a

   // Do some more arithmetic
   print(c - a)
```

- System stack:
  - ➡ Pushing and popping
  - ➡ **$sp** and **$fp**
- Local variables:
  - ➡ Stored on stack
  - ➡ Accessed with negative offset from **$fp**
- Addressing: register + constant

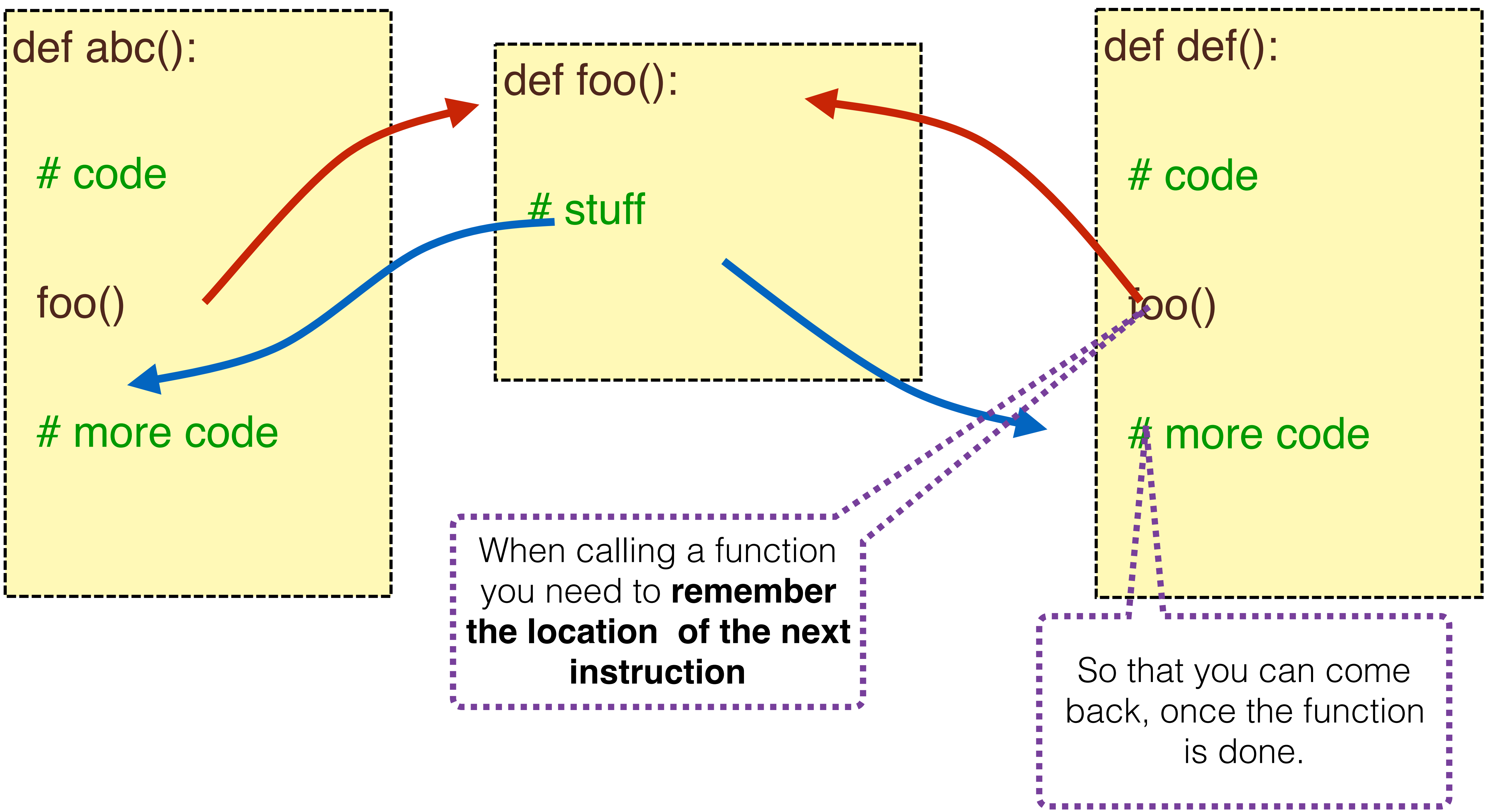
Reminder: why using functions?

- As **encapsulation** of a sequence of instructions:
  - ➡ Can be called repeatedly (**reuse**)
  - ➡ Can call other functions
  - ➡ Are self-contained
  - ➡ Can have their own private (local) variables/data

- As **abstractions**:
  - ➡ Can be generalised by taking parameters.
  - ➡ Can inform through return values.

- As **hiders** of information: make sure caller cannot access/ modify internal data

Function calling: return where?



Jump Instructions

- jump (go) to label, e.g.,
  ```
  j foo        # set PC = foo
               # so, go to foo
  ```
- jump to label and link (remember origin), e.g.,
  ```
  jal foo      # $ra = PC+4; PC = foo, so same
               # but setting a return address
  ```
- jump to address contained in register, e.g.,
  ```
  jr $t0       # set PC=$t0, so go to the
               # address contained in $t0
  ```
- jump to register and link (remember origin), e.g.,
  ```
  jalr $t0     # $ra = PC+4; PC = $t0, same
               # but setting a return address
  ```

sqr.py

```
def sqr(n):
    return n*n

print(sqr(int(input())))
```

Simple convention

```python
def sqr(n):
    return n*n

print(sqr(int(input())))
```

Recall:
jal stores
PC + 4 in $ra

```
            .text

            addi    $v0, $0, 5        # read integer
            syscall

            add     $a0, $0, $v0      # $a0 = $v0
            jal     sqr               # $v0 = sqr($a0)

            add     $a0, $0, $v0      # $a0 = $v0
            addi    $v0, $0, 1        # print $a0
            syscall

            addi    $v0, $0, 10       # exit
            syscall

sqr:        mult    $a0, $a0          # LO = $a0*$a0
            mflo    $v0               # $v0 = LO
            jr      $ra               # return $v0
```

Function calling in MIPS

To **write** a function

- ➡ Put **label** at the **start** of the function
- ➡ Write body of the function
- ➡ **End** function with jr $ra

To **call** a function

- ➡ Write jal label
- ➡ When the function returns, program will continue from the next instruction

Passing data

- Some functions take **parameters**. We need a way of passing parameters from caller to function.
- Some functions **return values**. We need a way of getting the return value safely back to caller.
- Reserve some **registers** for these tasks
  - We can use the **“syscall”** data passing method.
  - Pass function **parameters** in **$a0, $a1, $a2, $a3.**
  - **Return** values in **$v0, $v1**

sqr.py

```python
def sqr(n):
    return n*n

print(sqr(int(input())))
```

Only one argument

No other local variables

No function calls

Single value returned

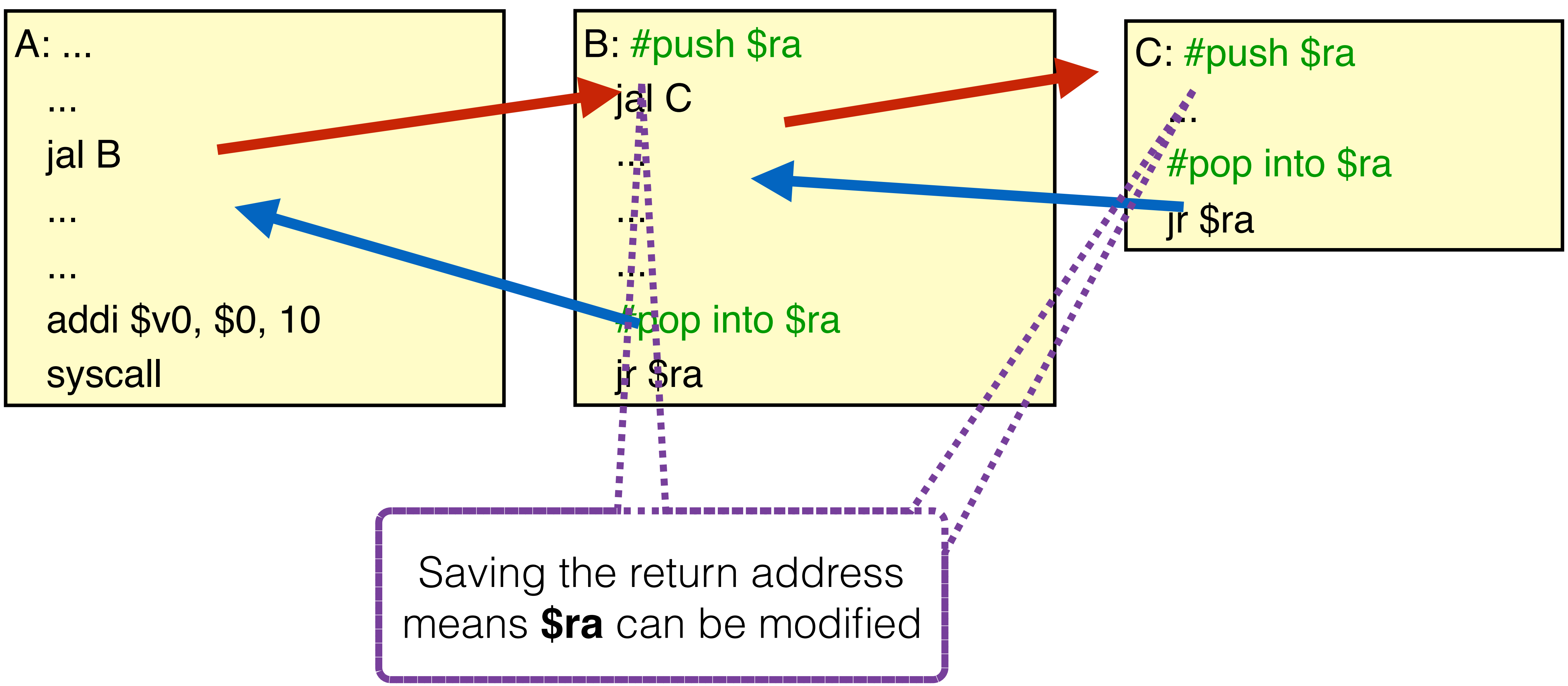
Limitations

This simple function-calling convention works, but has limits

- Function must not call other functions
- Function call is limited to four arguments (**$a0**-**$a3**)
- Function must only write to “safe” registers **$v0**-**$v1, $a0**-**$a3, $t0**-**$t9**
- Function must not use local variables, only arguments
- Function can only return two values **$v0** and **$v1**

Original **$ra** is lost!

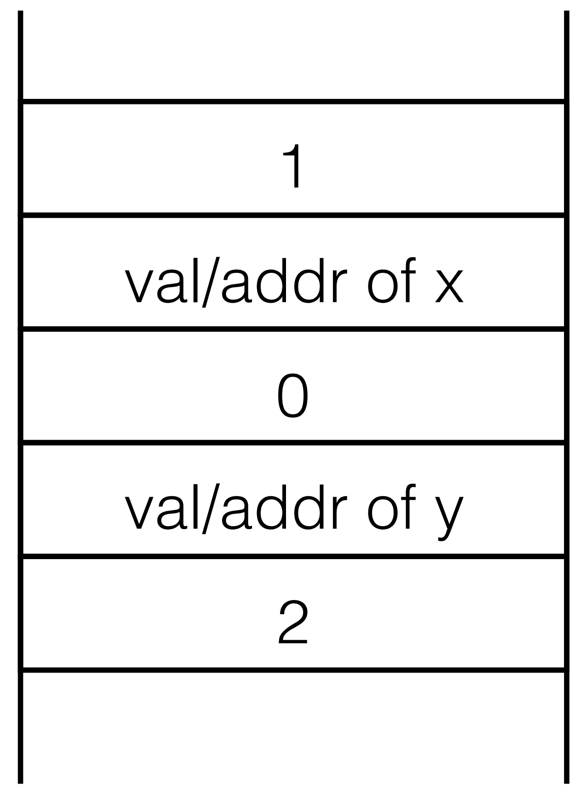
Solution: Save and restore $ra register on the stack upon function entry/exit.



Not enough registers to use as function arguments

Solution: Save arguments on the stack

```
# push 2
# push global y
# push 0
# push local x
# push 1
jal five
# pop
# pop
# pop
# pop
# pop
```




```
five: # takes 5
      # parameters
      ...
      # examine
      # stack
      ...
      jr $ra
```

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For simplicity we will use the stack to pass **all** arguments

Saving registers

```
...
lw $t0, a
...
...
jal func
...
...
# $t0 has been
# changed!
add $t0, $t0, $v0
...
```

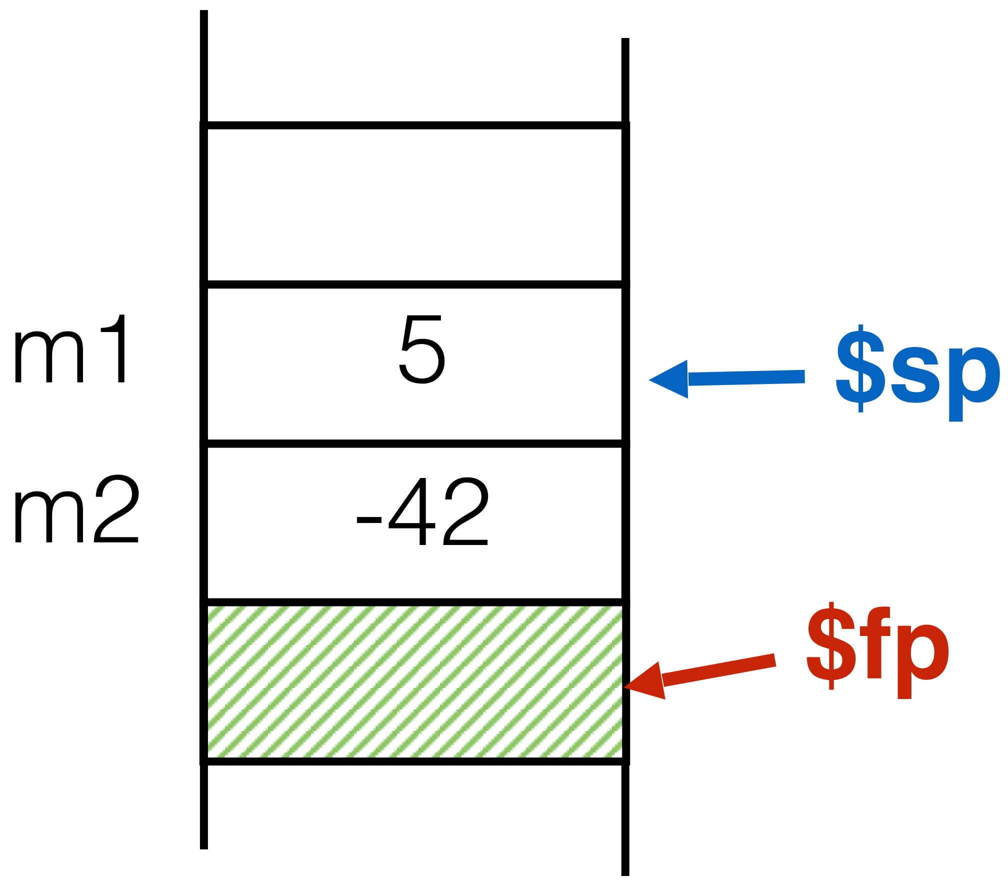
```
func: ...
      # trashes
      # $t0
      lw $t0, x
      ...
      jr $ra
```

Function may use registers which hold important values.

Solution: save/restore registers on stack.

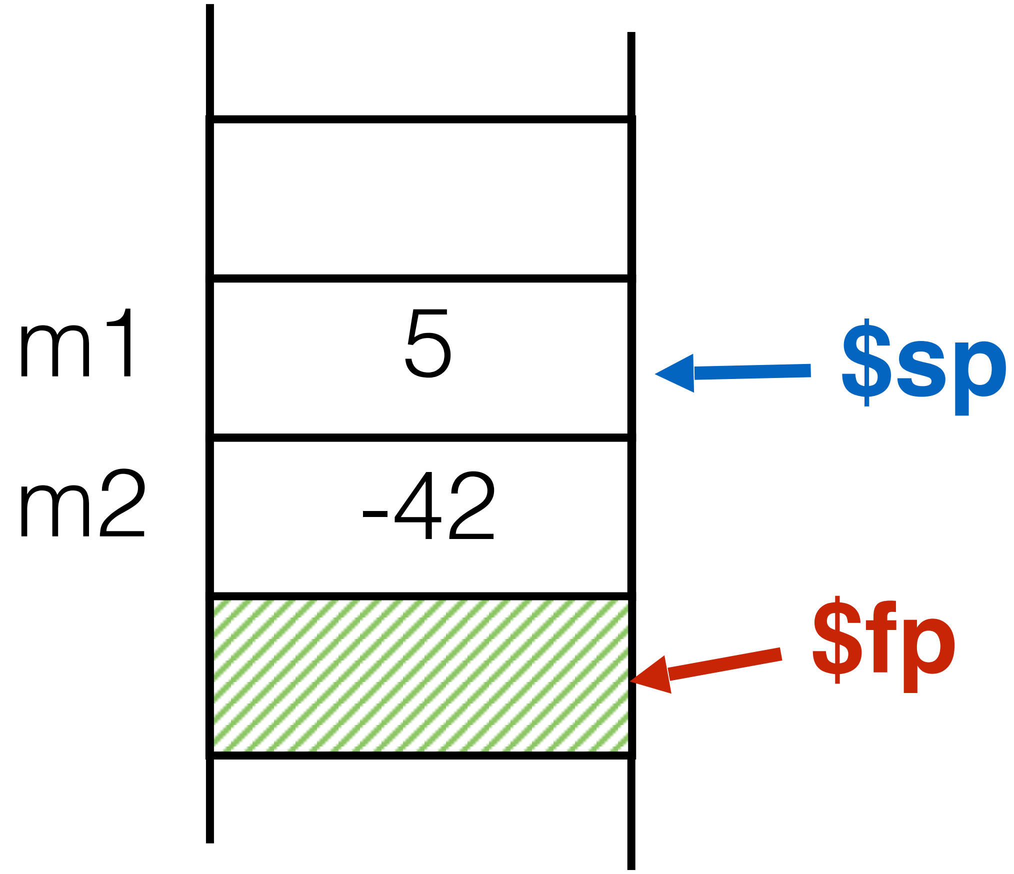
Local variables needed

```
def main():

  m1 = 5
  m2 = -42
   ...
  func()
```



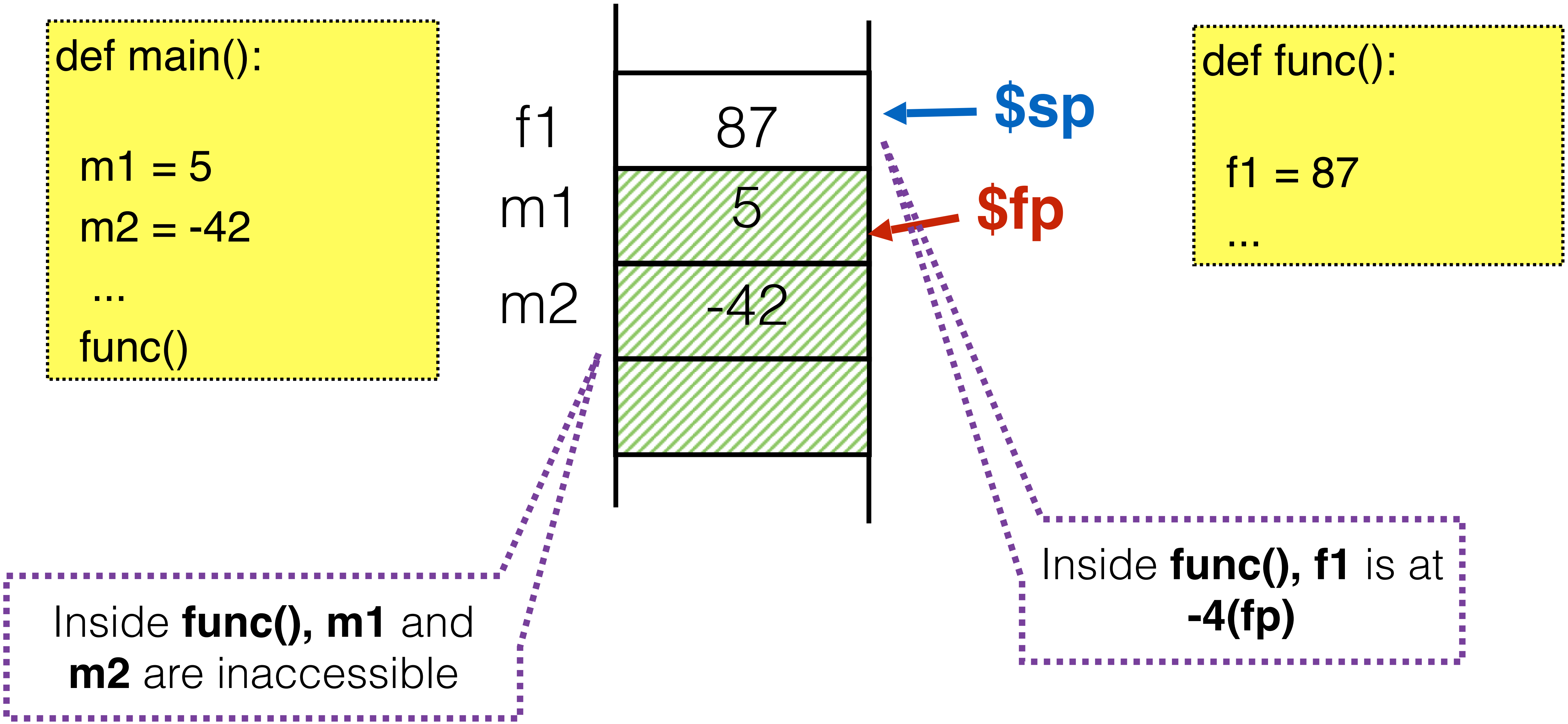
Allocate local variables

```
def main():

  m1 = 5
  m2 = -42
   ...
  func()
```



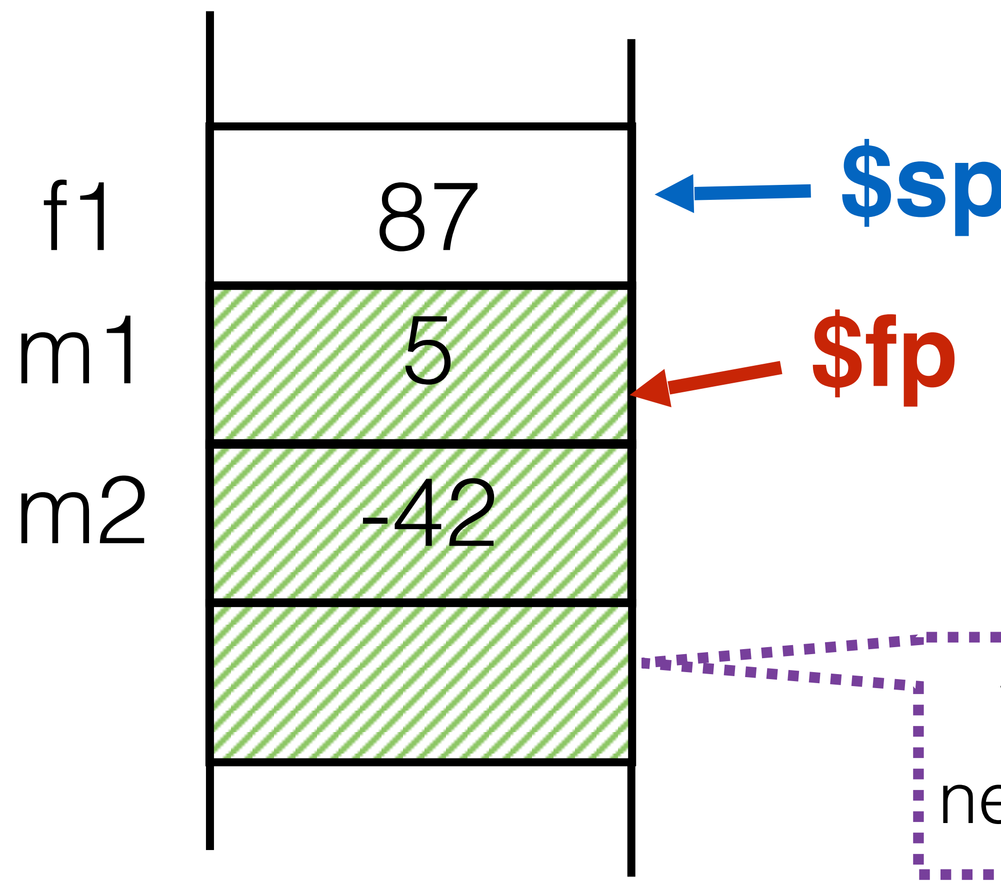

```
def func():

  f1 = 87
  ...
```

Allocate local variables



Restoring stack state

```
def main():

  m1 = 5
  m2 = -42
   ...
  func()
```




```
def func():

  f1 = 87
  ...
```

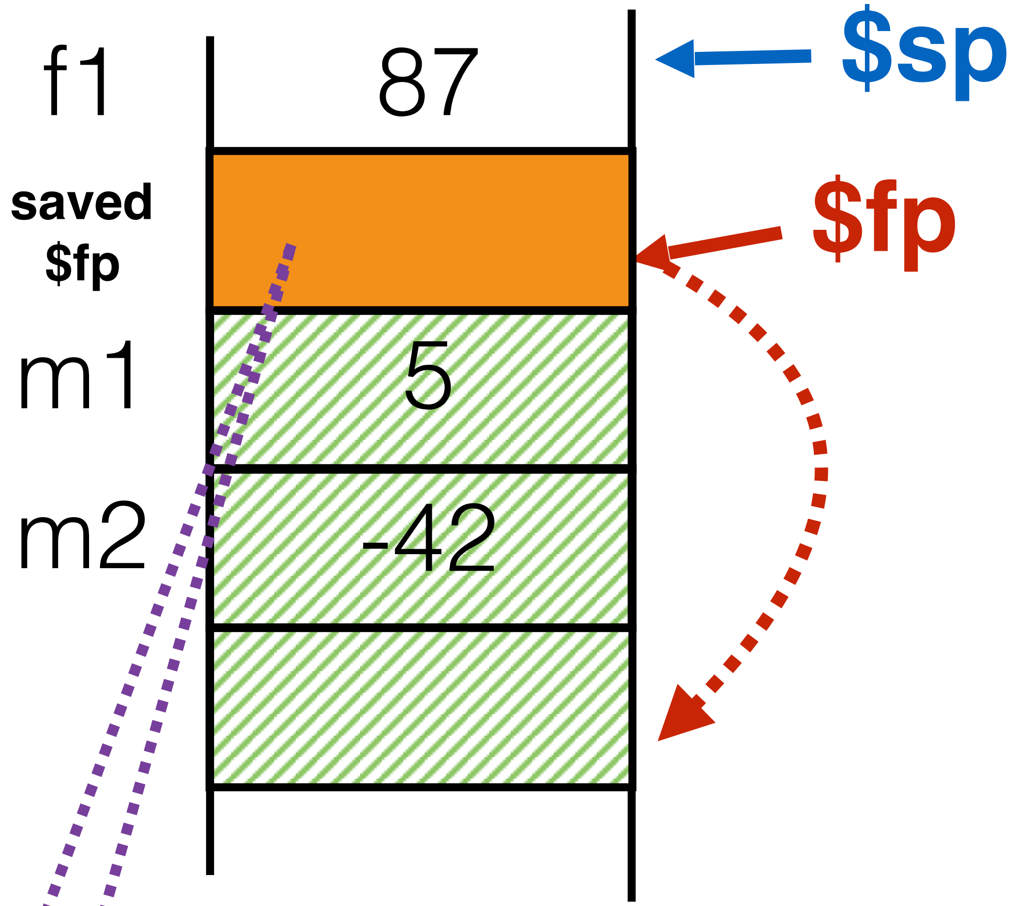
When **func()** ends **$fp** needs to move **back here**

Stack must be restored on function return

Stack must be restored on function return

Solution: Save restore $fp on stack

```
def main():

  m1 = 5
  m2 = -42
   ...
  func()
```




```
def func():
  # save $fp
  f1 = 87
  # restore $fp
  ...
```

By saving old **$fp** we can restore the stack state at the end of the function

Convention

Function calling convention

These **steps** must be performed **every time** a function starts:

1. Save temporary registers
2. Save arguments
3. Call function with **jal** instruction
4. Save $ra register
5. Save $fp register
6. Update $fp
7. Allocate local variables

What about function returning….