Frame pointer

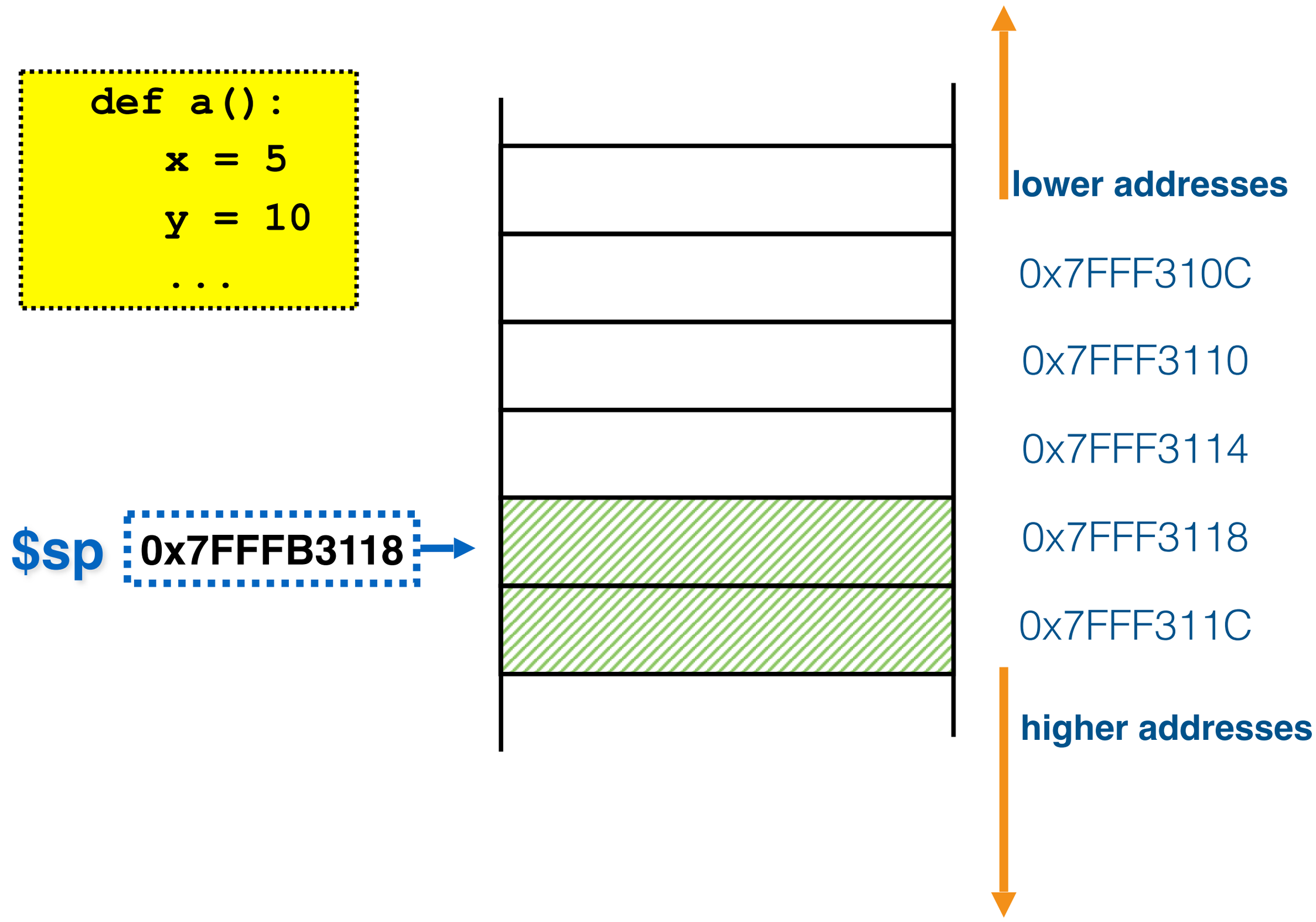
- Can access local variables relative to stack pointer (**$sp**).
- However, this may be problematic when passing arguments to functions:
  - Stack pointer moves to accommodate other function info
  - Relative locations of local variables change

Frame pointer

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

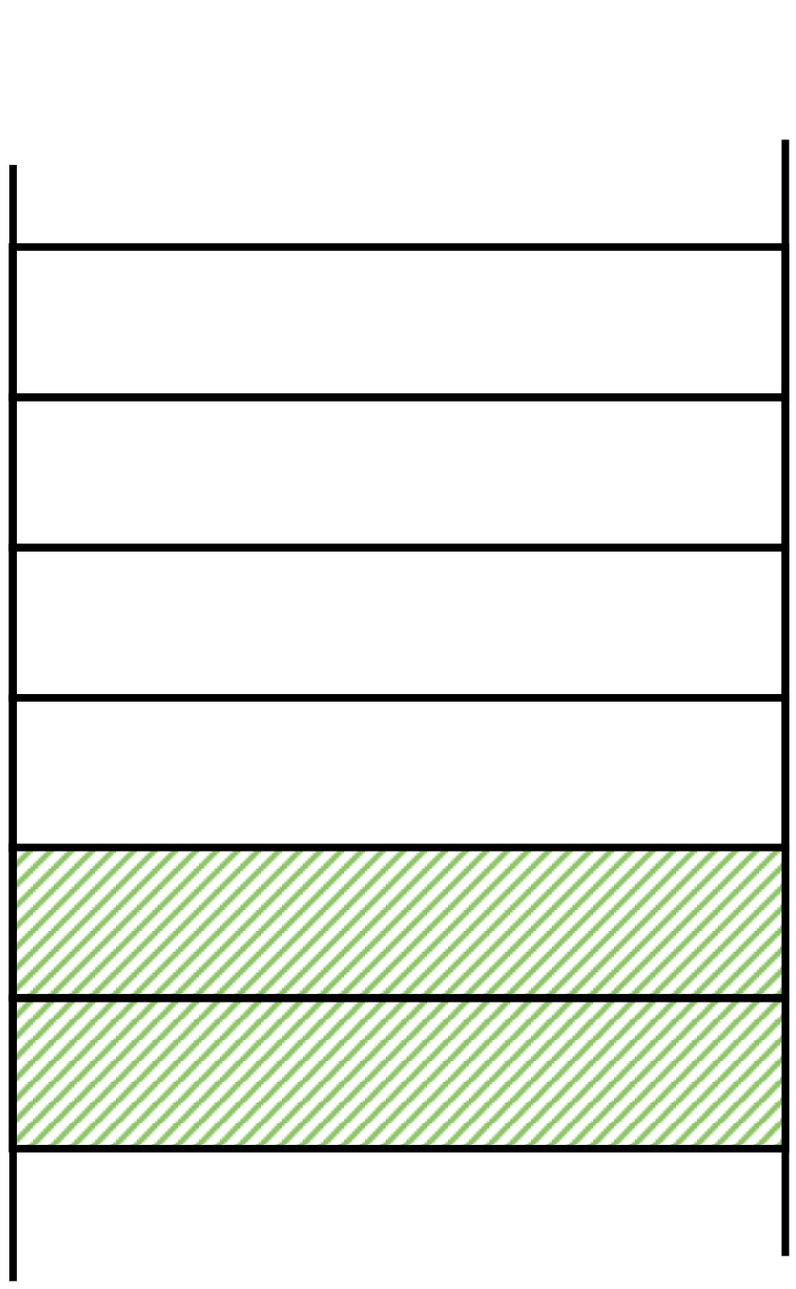
Example

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



Example

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



lower addresses

0x7FFF310C

0x7FFF3110

0x7FFF3114

0x7FFF3118

0x7FFF311C

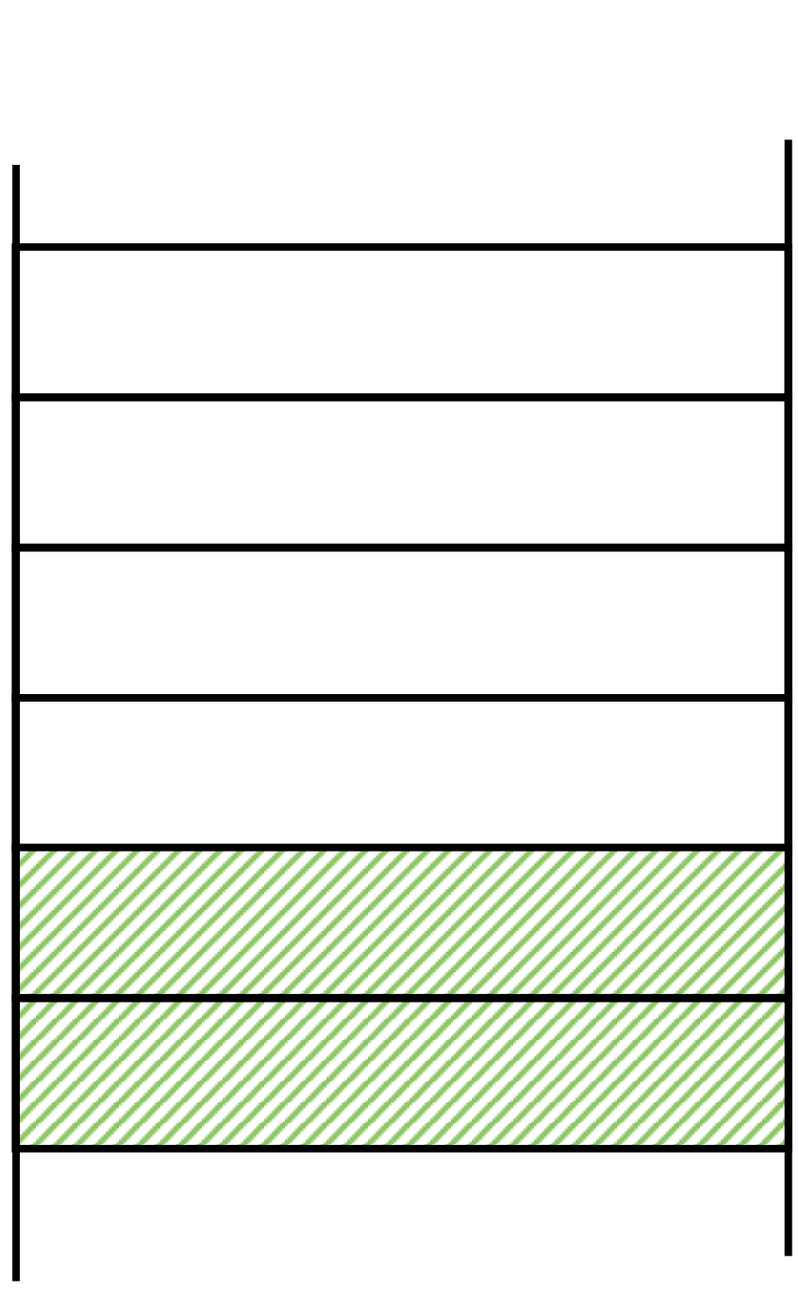
higher addresses

$sp **0x7FFFB3118**

Before allocating,
copy **$sp** to **$fp**

Example

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



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higher addresses

$sp 0x7FFFB3118

$fp 0x7FFFB3118

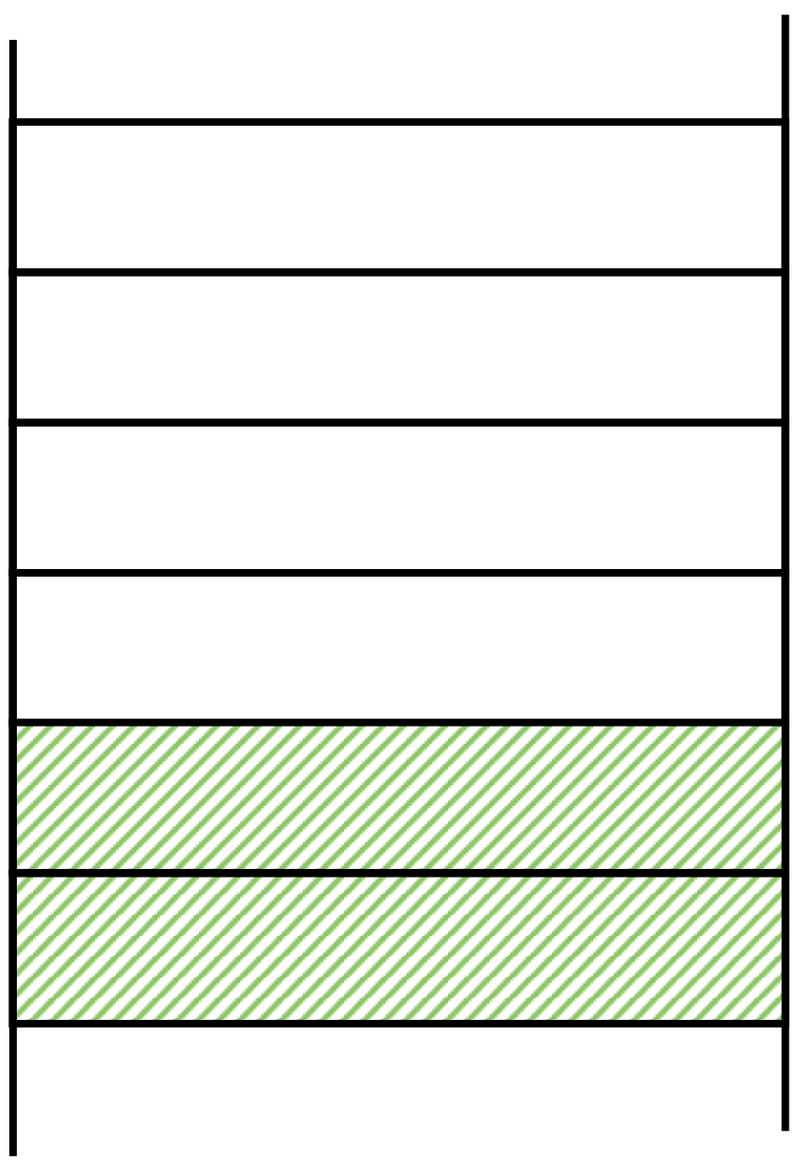
Before allocating, copy **$sp** to **$fp**

Example

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

$sp 0x7FFFB3118

$fp 0x7FFFB3118



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higher addresses

Example

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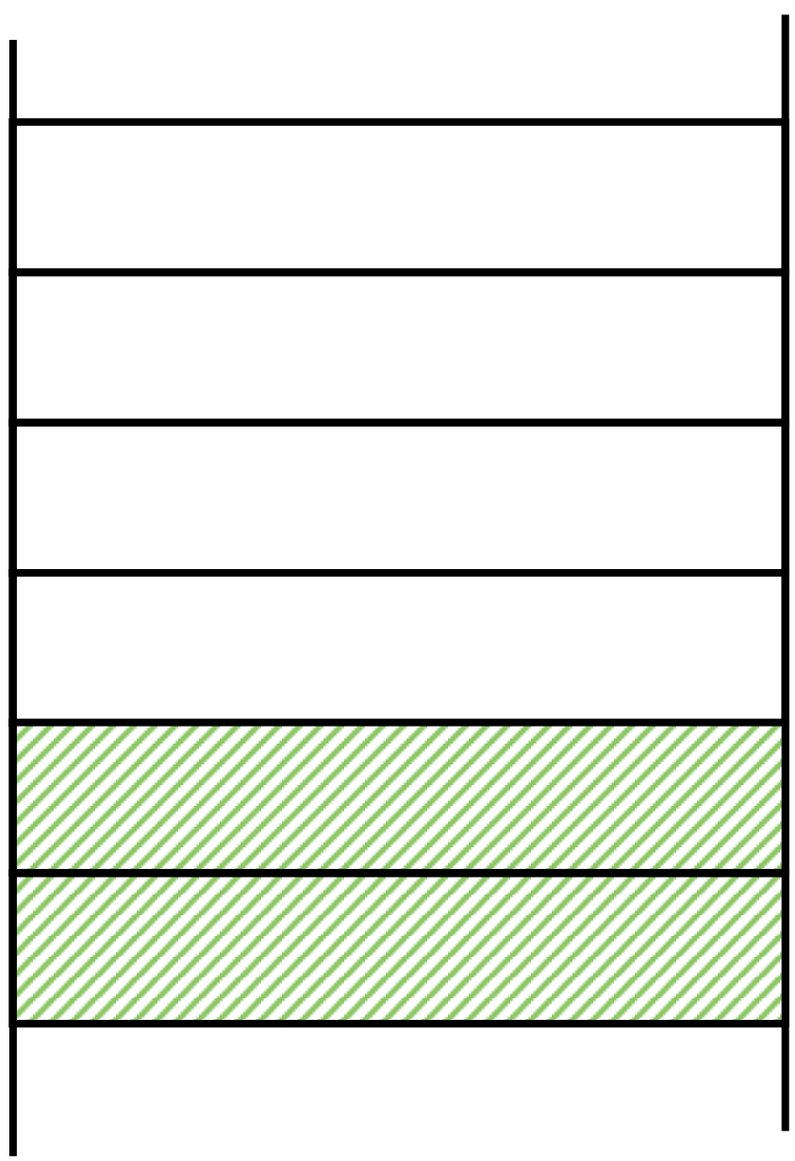
```



lower addresses

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0x7FFF3110

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higher addresses

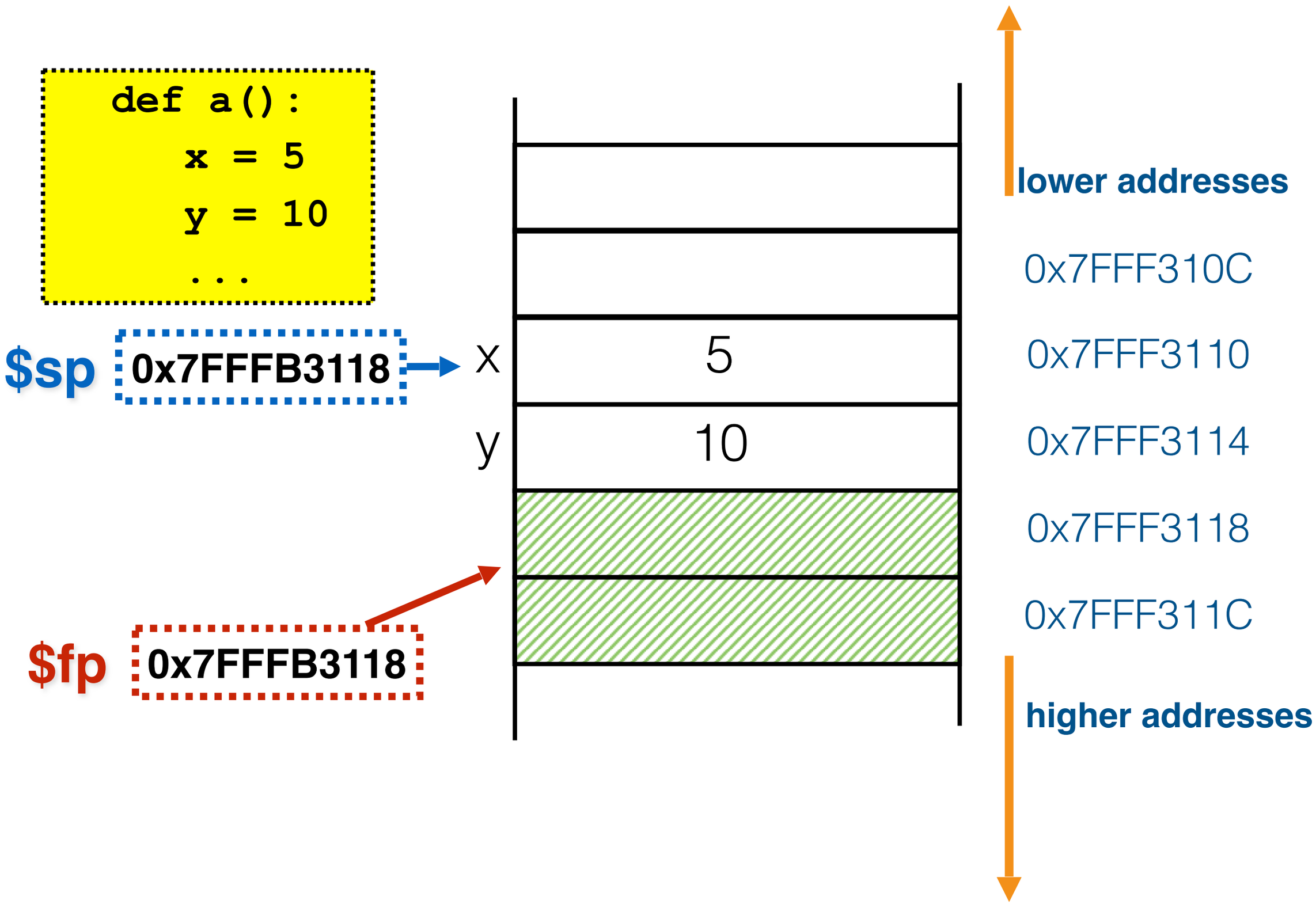
$sp **0x7FFFB3118**

$fp **0x7FFFB3118**

Allocate by subtracting from **$sp** as before

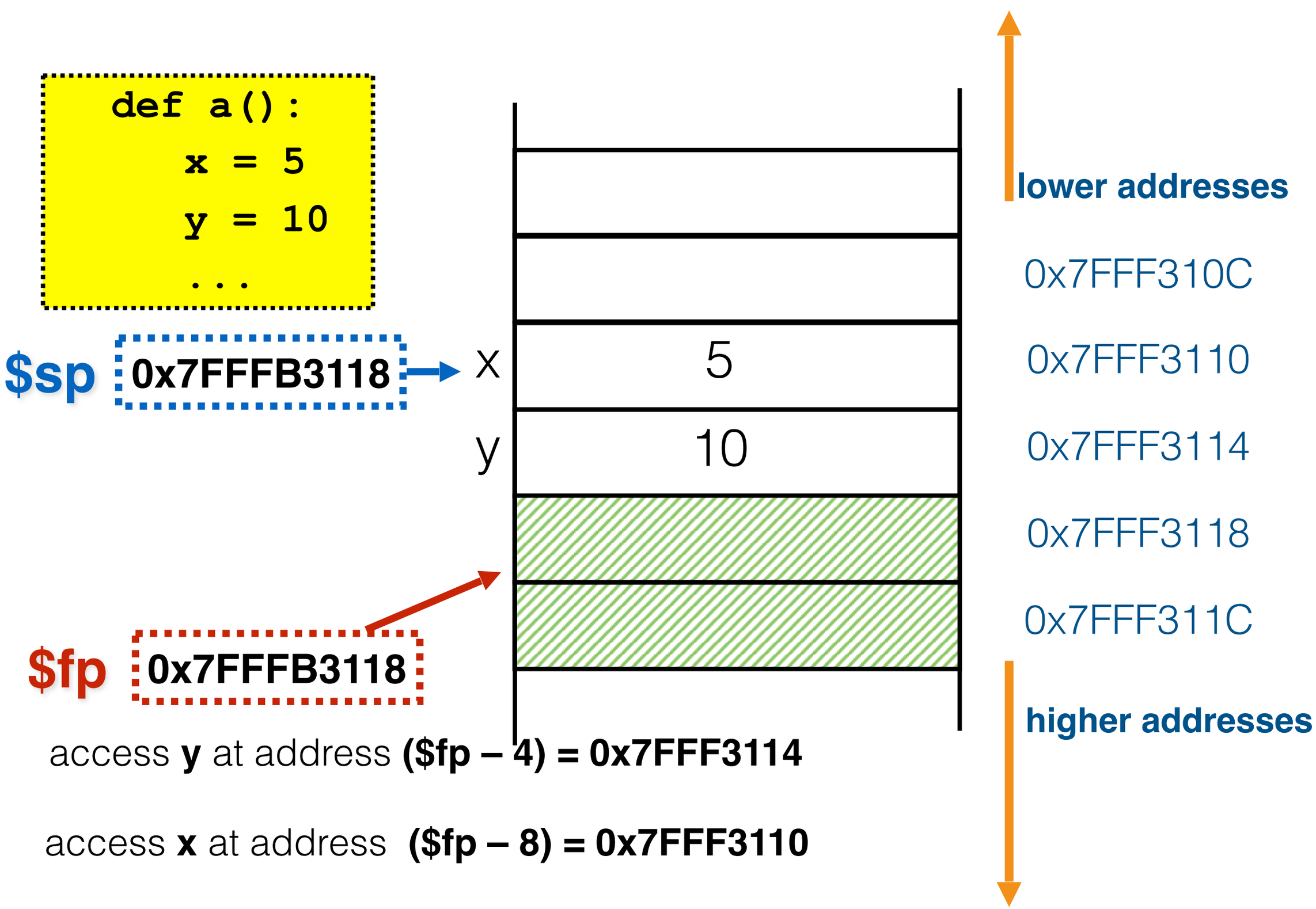
Example

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



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 ...
```

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def main():

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```

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

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syscall                 # Do print.

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


# If this function was not main
# it would need to deallocate
# local variables with:
# addi $sp, $sp, 12
```

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

.text
main:   # Copy $sp into $fp.
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  // Do some arithmetic
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  // 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?

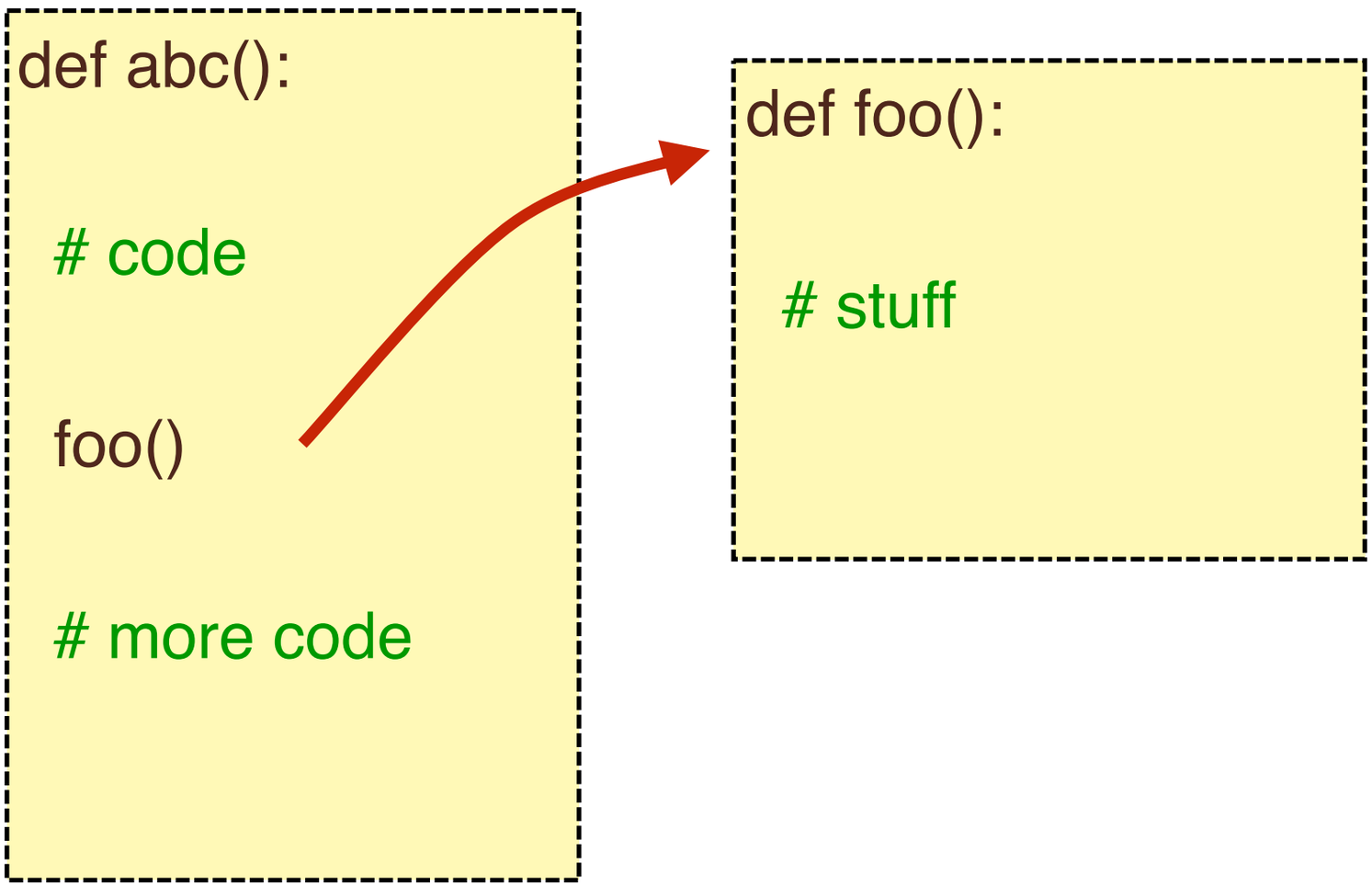
```
def foo():

  # stuff
```

Function calling: return where?

```
def abc():

  # code


  foo()

  # more code
```

```
def foo():

  # stuff
```

Function calling: return where?



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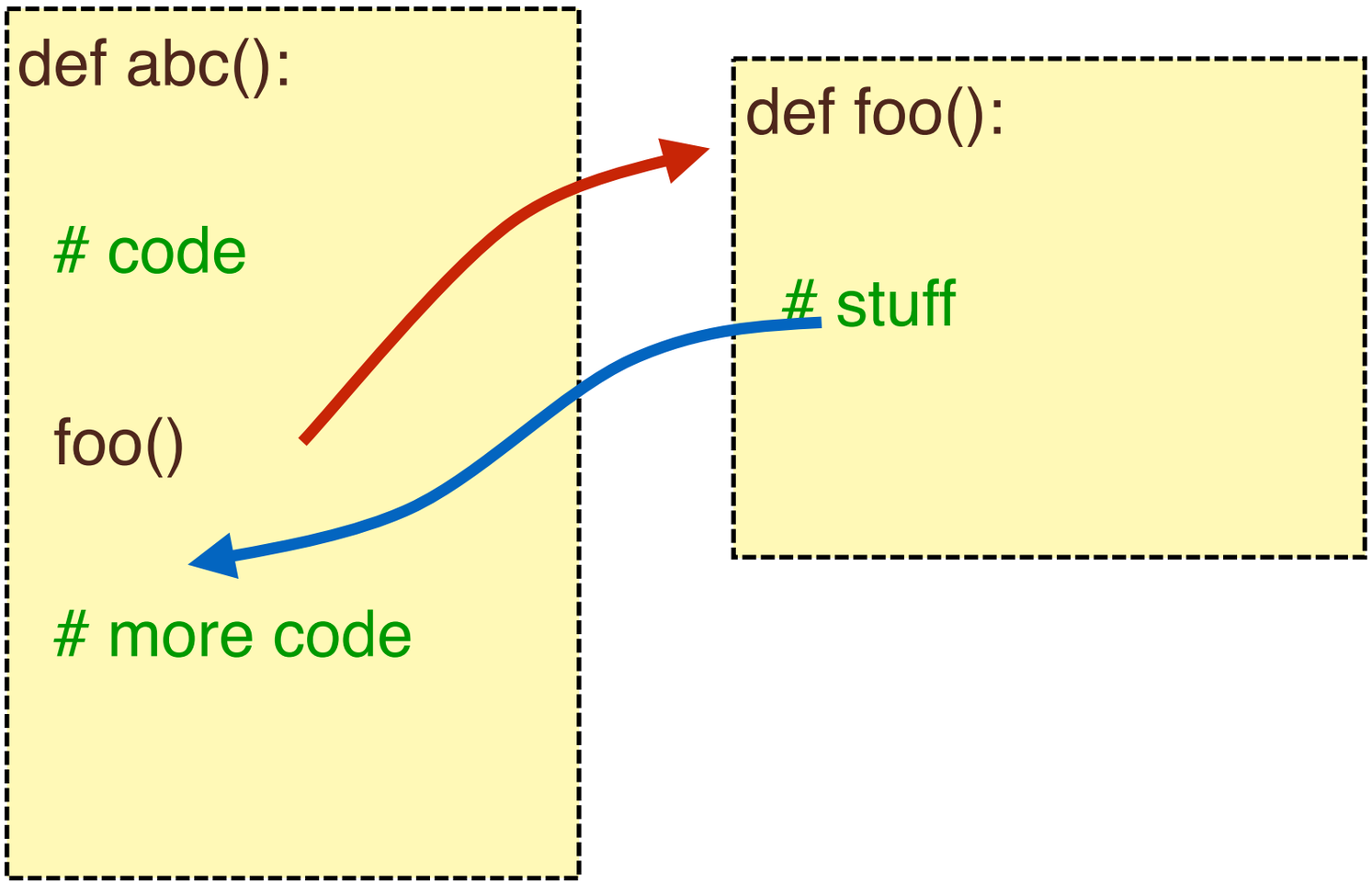

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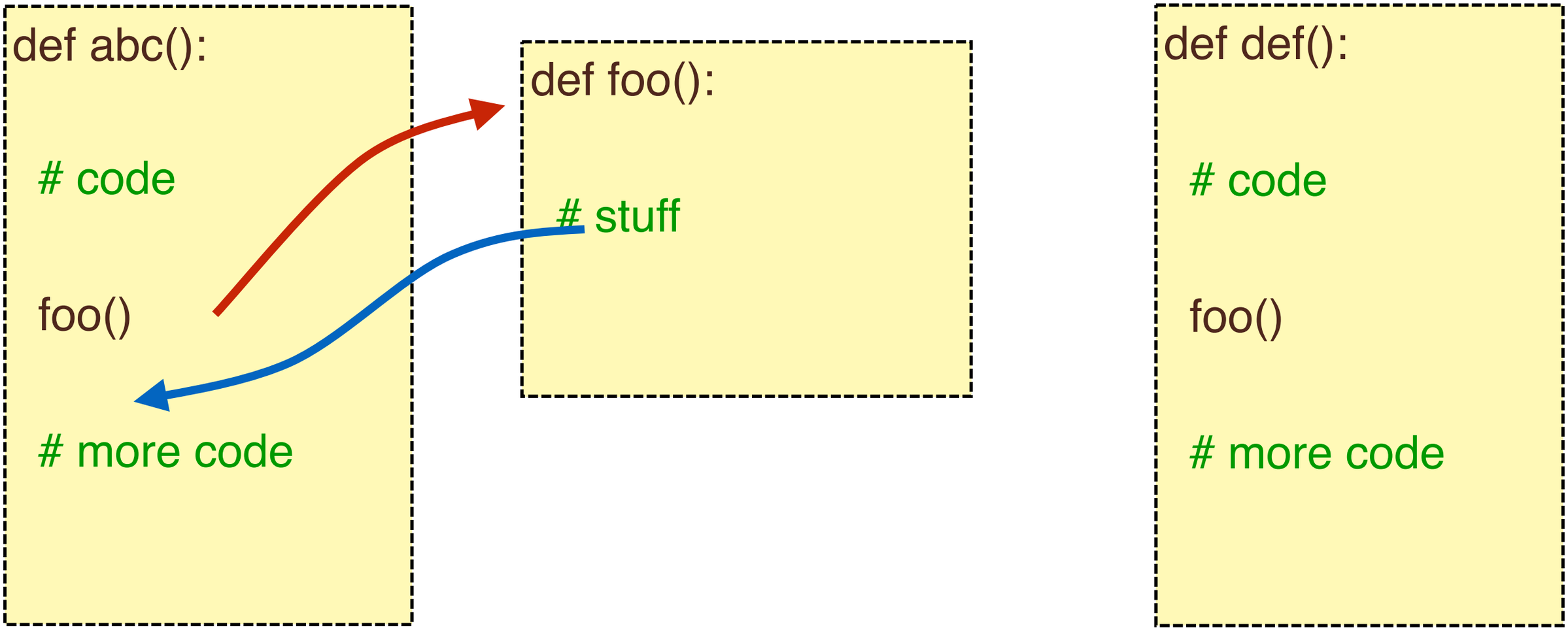

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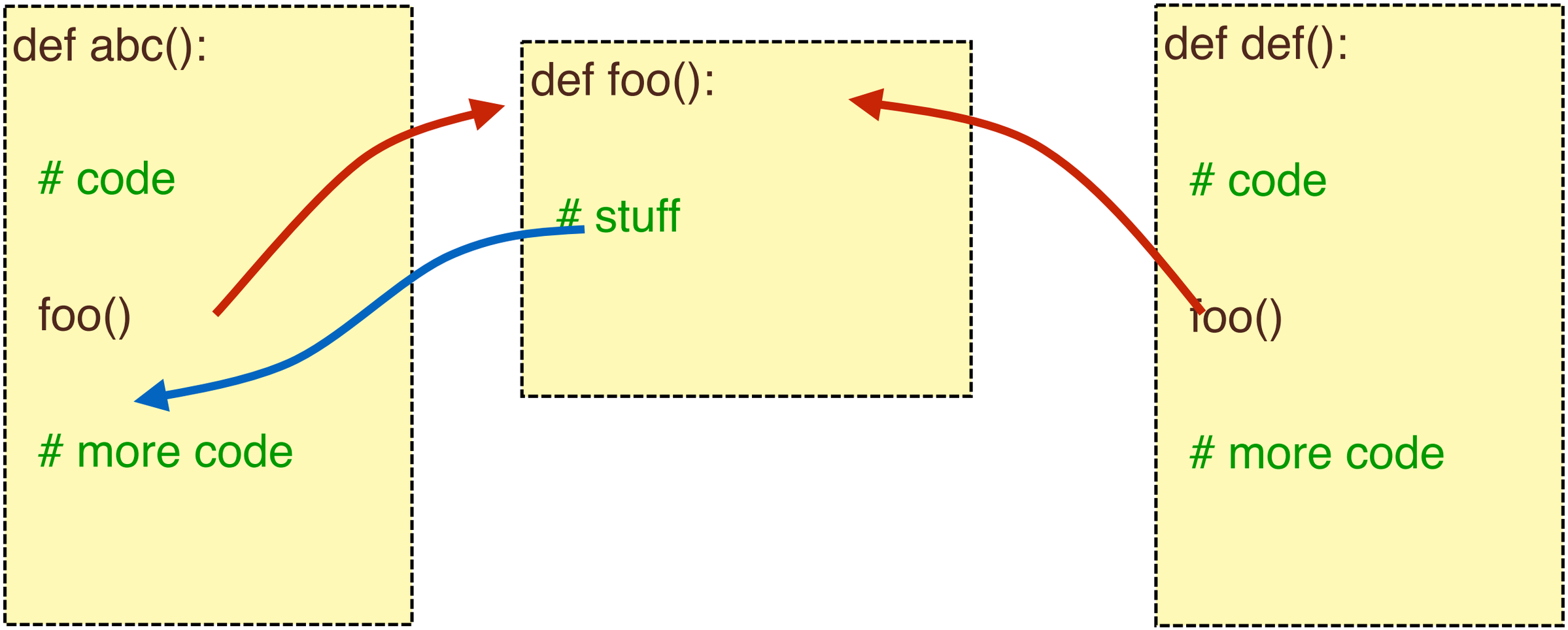

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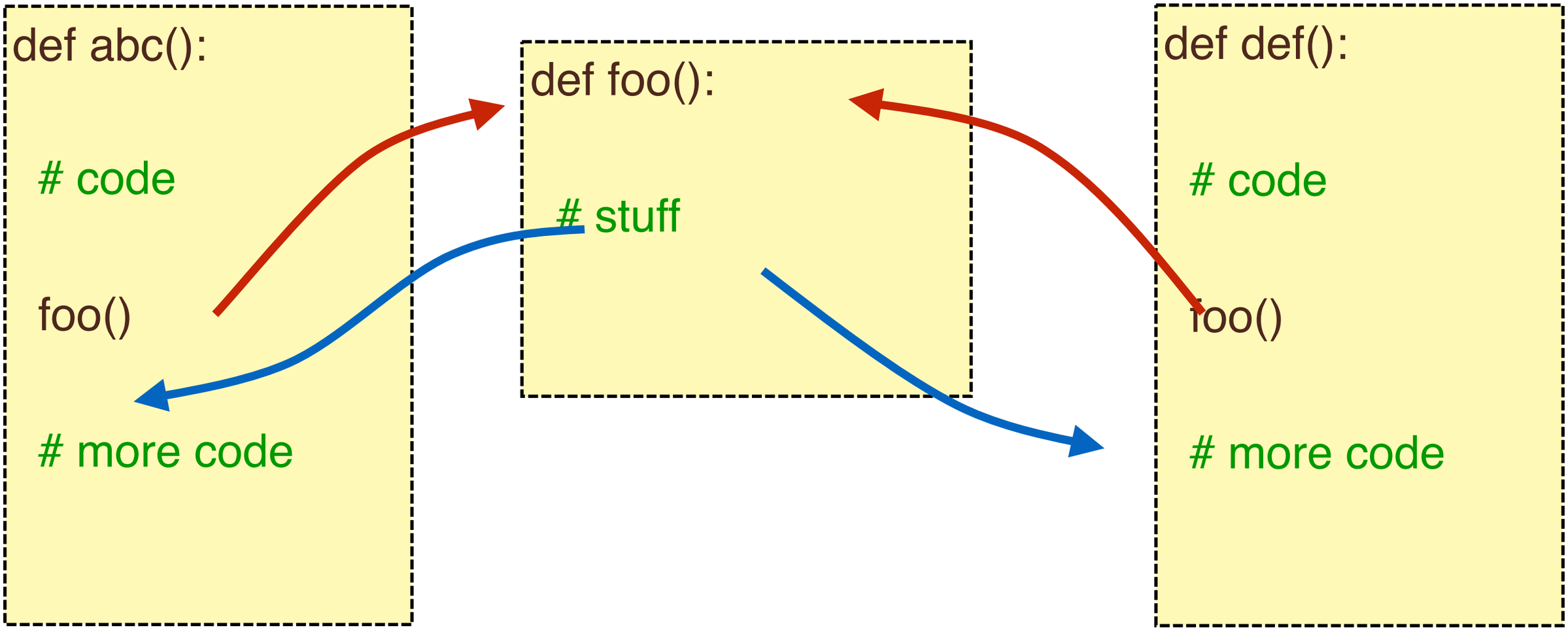

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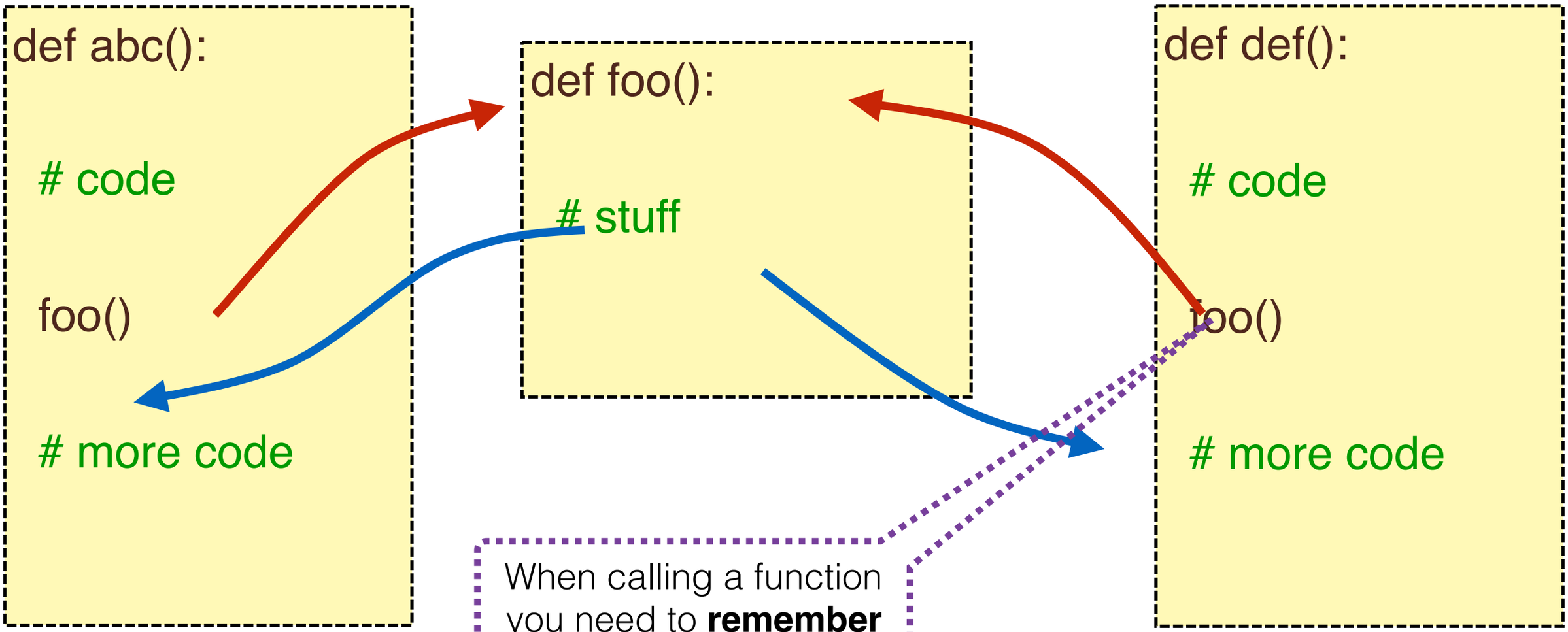

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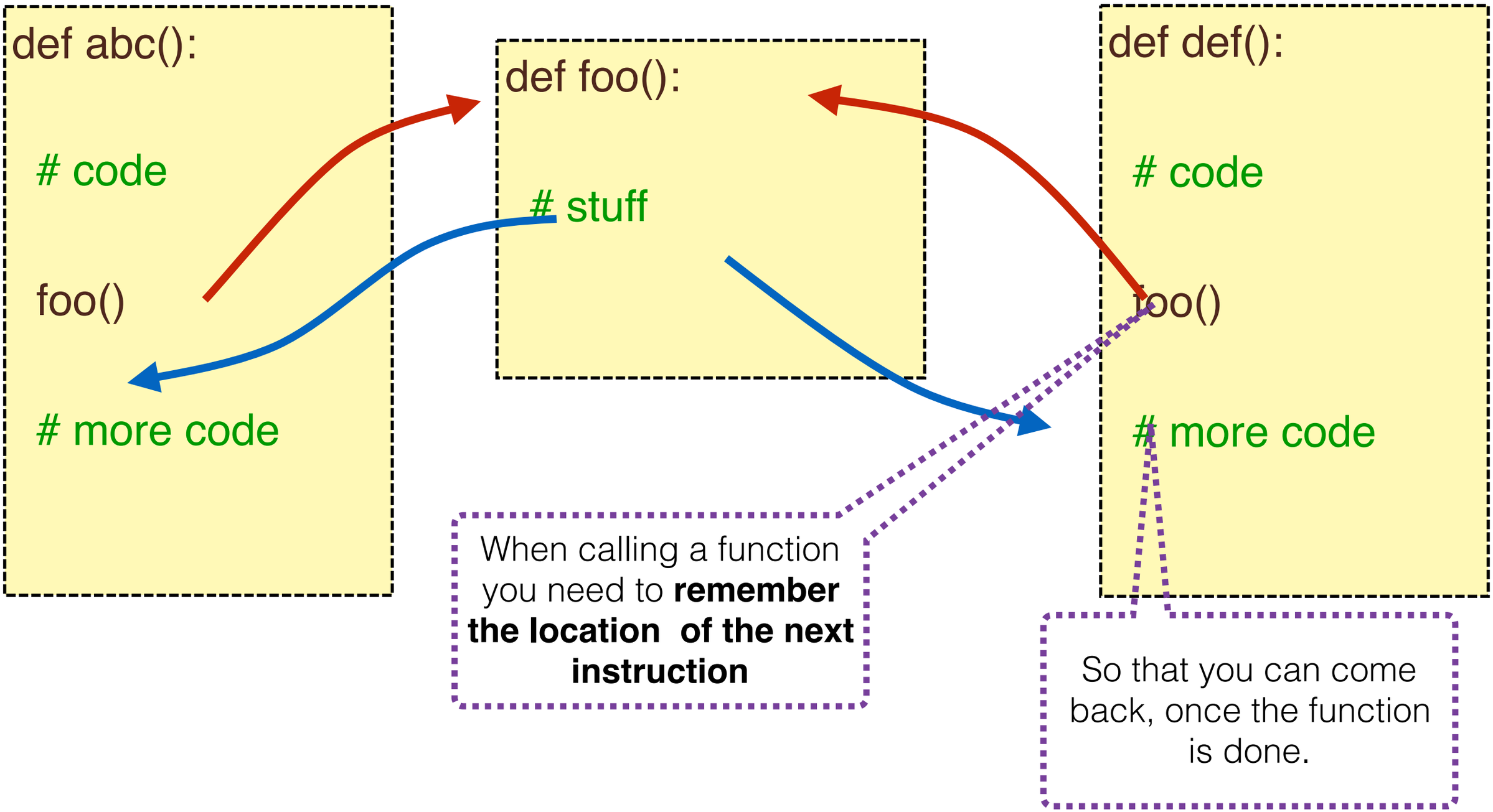

Jump Instructions

- 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())))
```

```
        .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
```

```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
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sqr:    mult    $a0, $a0        # LO = $a0*$a0
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Recall:
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.text

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        add     $a0, $0, $v0    # $a0 = $v0
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        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

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def sqr(n):
    return n*n

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

sqr.py

```
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**

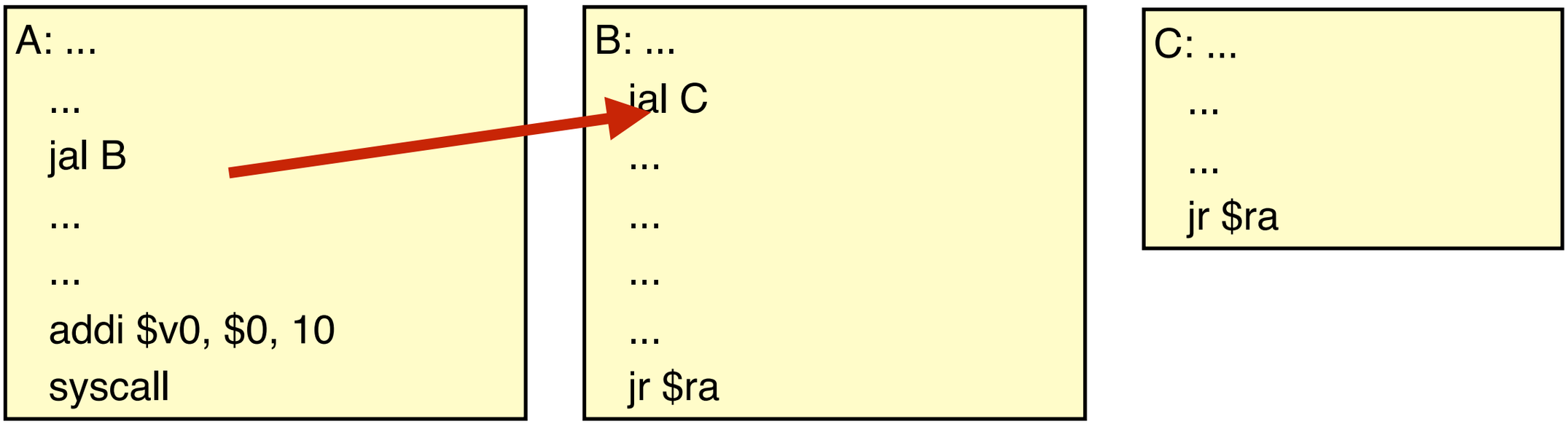
Function can call other functions

```
A: ...
   ...
   jal B
   ...
   ...
   addi $v0, $0, 10
   syscall
```

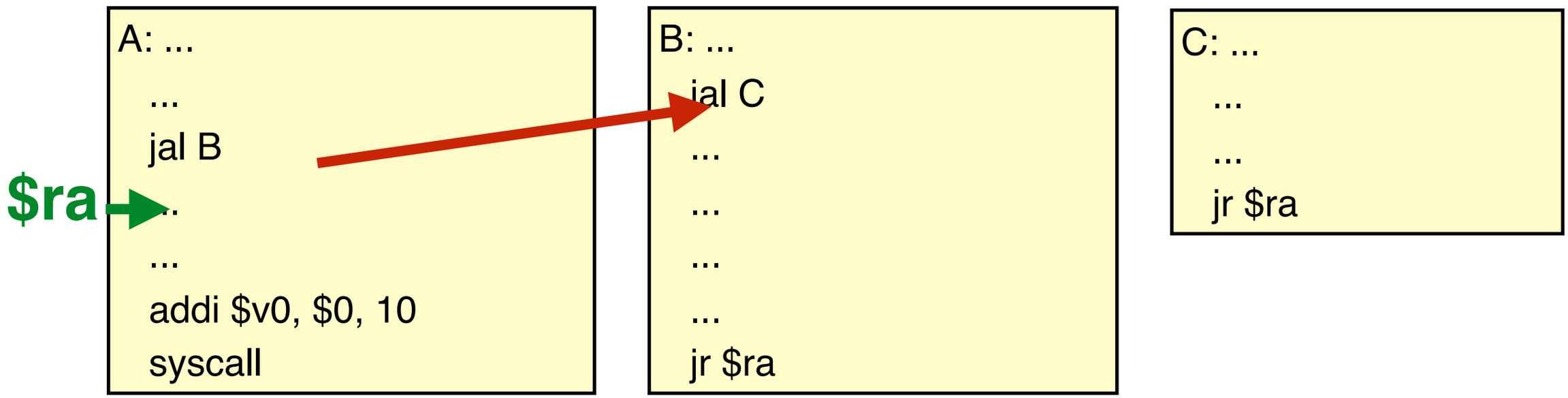
```
B: ...
   jal C
   ...
   ...
   ...
   ...
   jr $ra
```

```
C: ...
   ...
   ...
   jr $ra
```

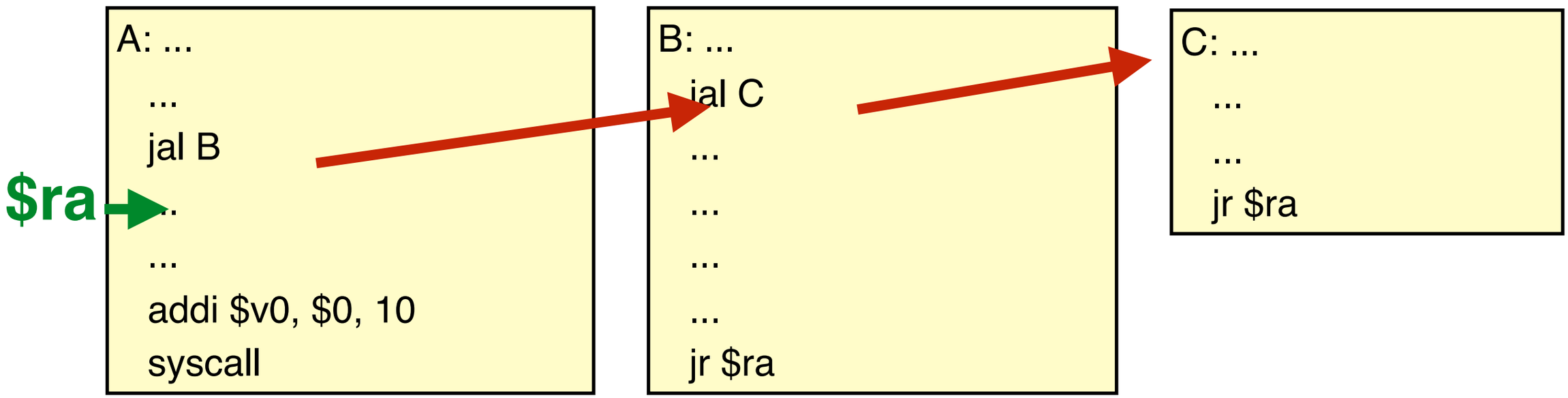
Function can call other functions



Function can call other functions



Function can call other functions



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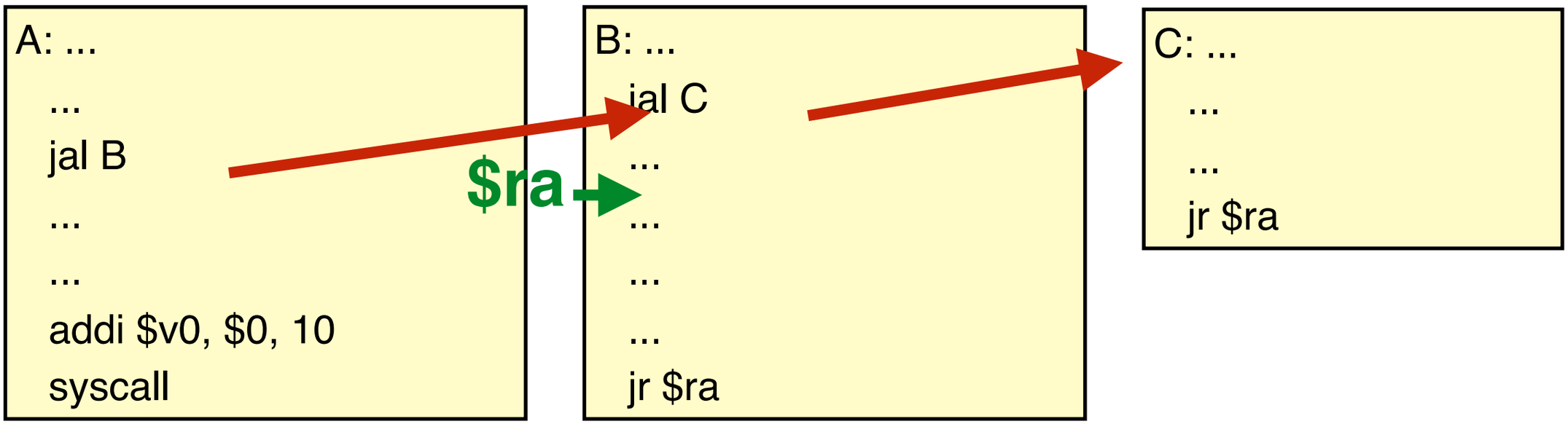

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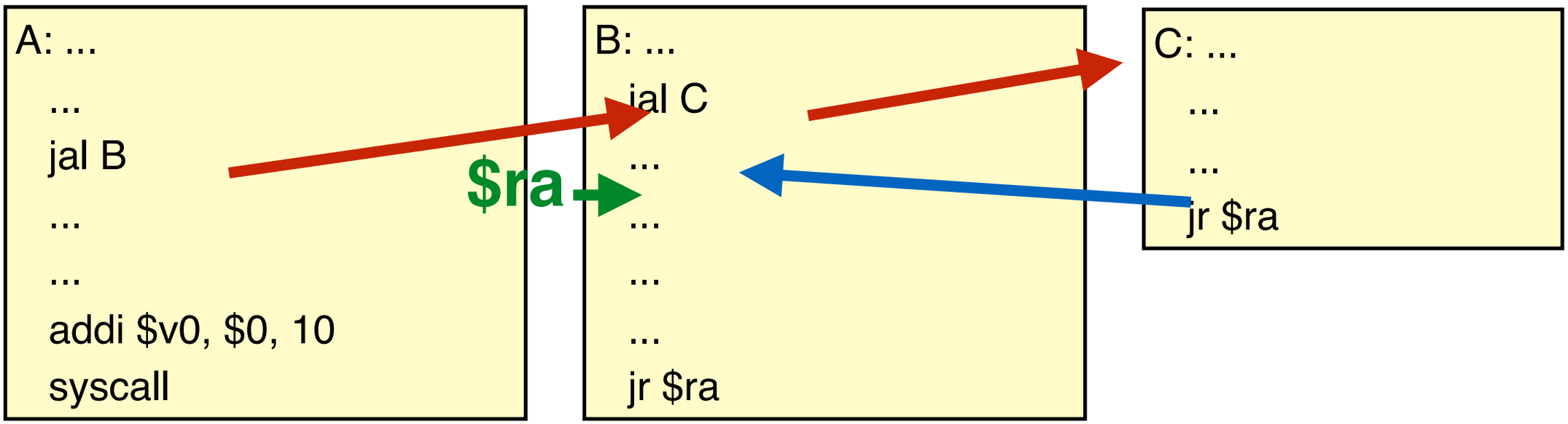

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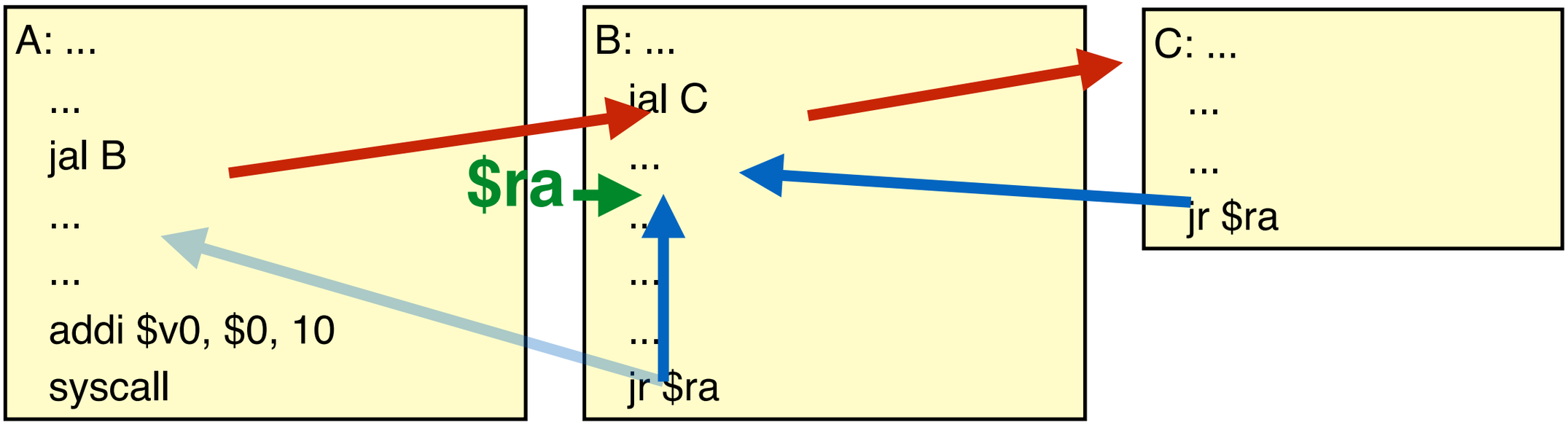

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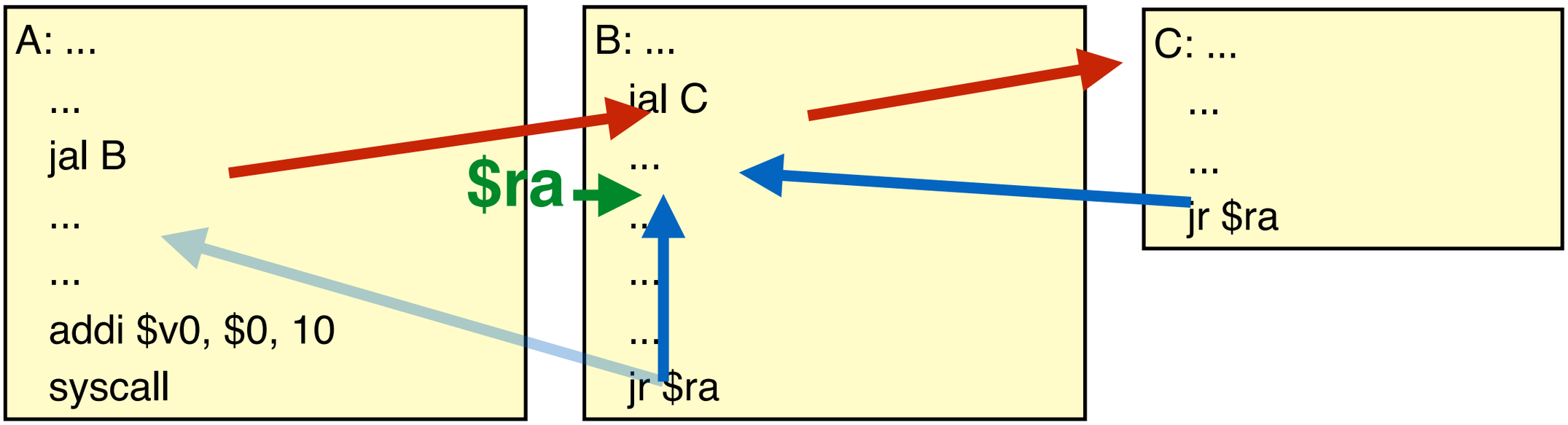

Original **$ra** is lost!

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```
A: ...
   ...
   jal B
   ...
   ...
   addi $v0, $0, 10
   syscall
```

```
B: #push $ra
   jal C
   ...
   ...
   ...
   #pop into $ra
   jr $ra
```

```
C: #push $ra
   ...
   #pop into $ra
   jr $ra
```

Original **$ra** is lost!

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

```
A: ...
   ...
   jal B
   ...
   ...
   addi $v0, $0, 10
   syscall
```

```
B: #push $ra
   jal C
   ...
   ...
   ...
   #pop into $ra
   jr $ra
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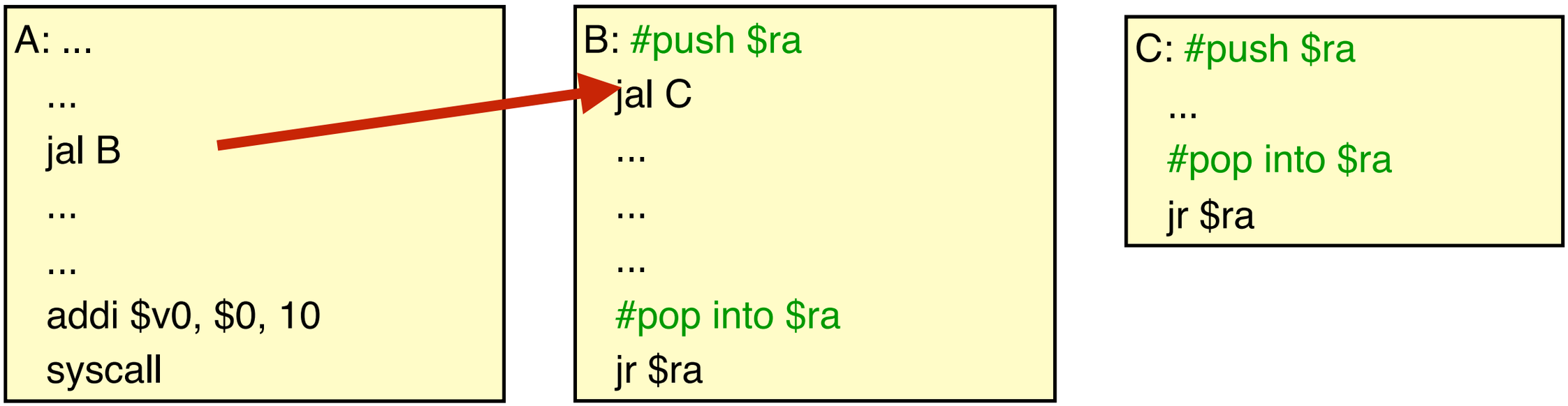

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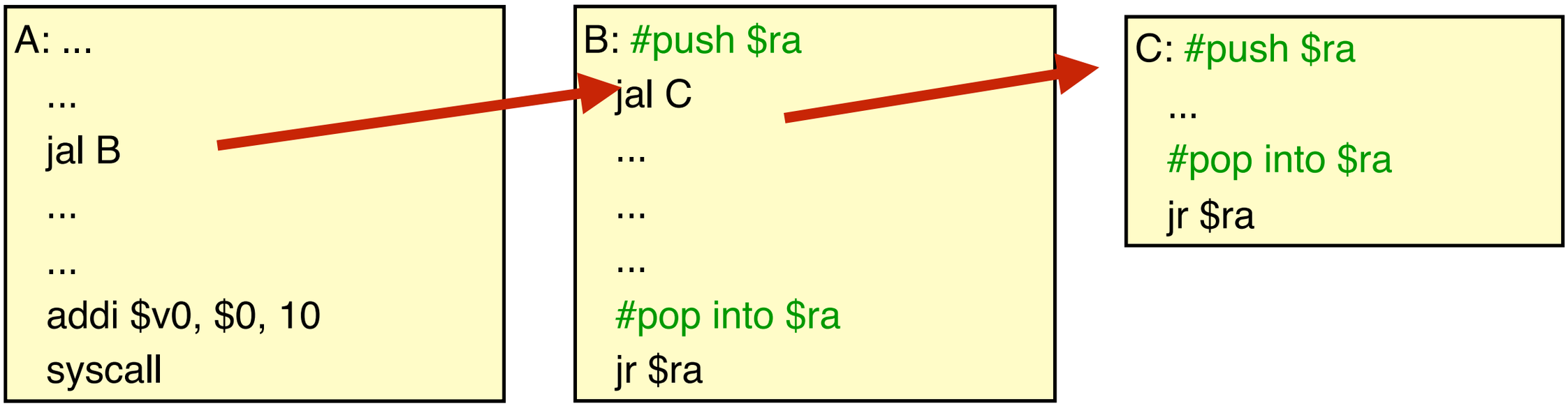

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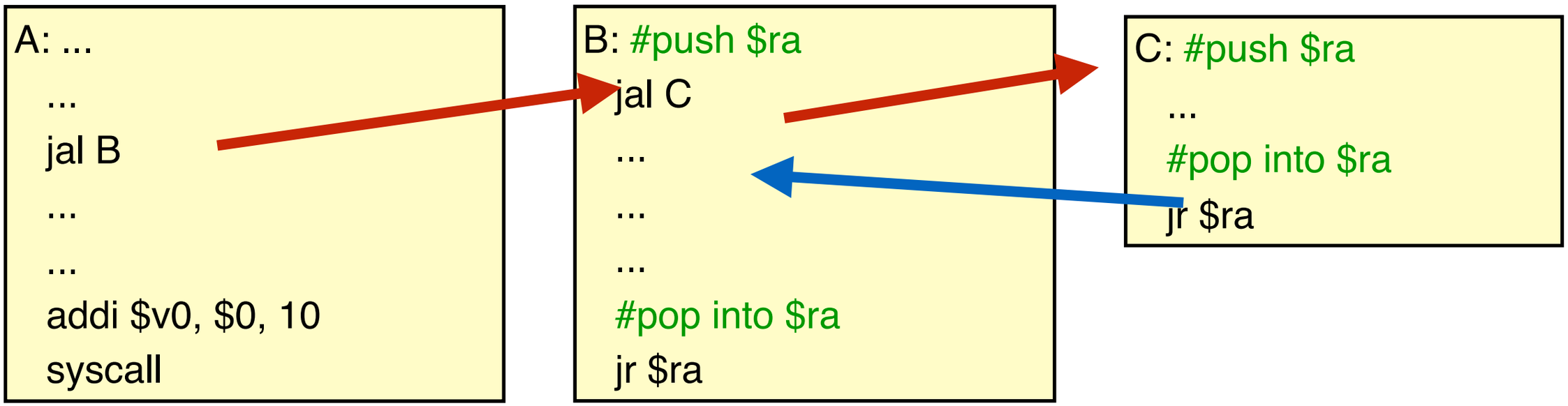

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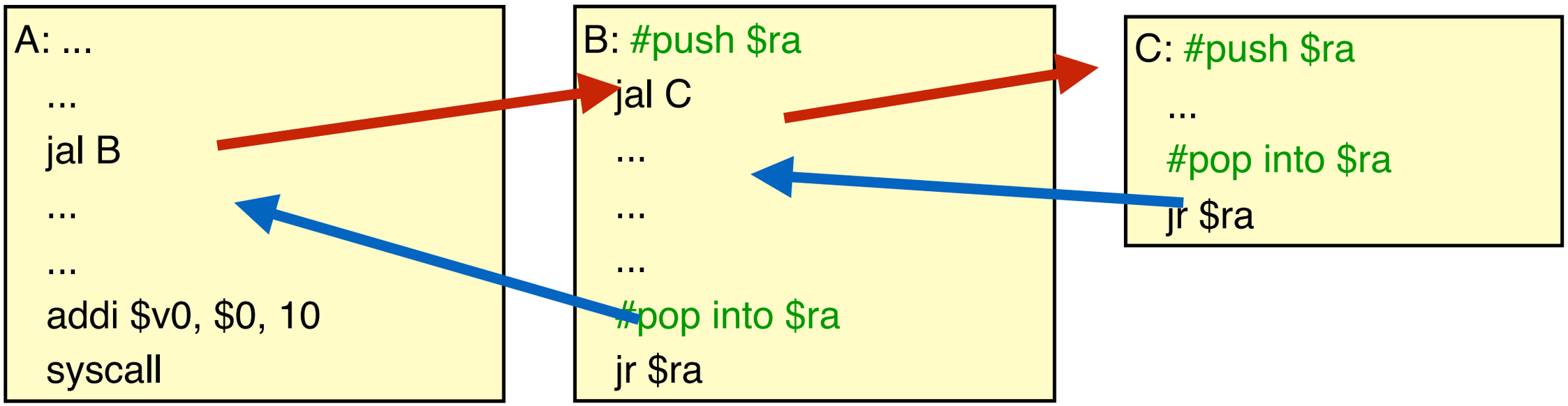

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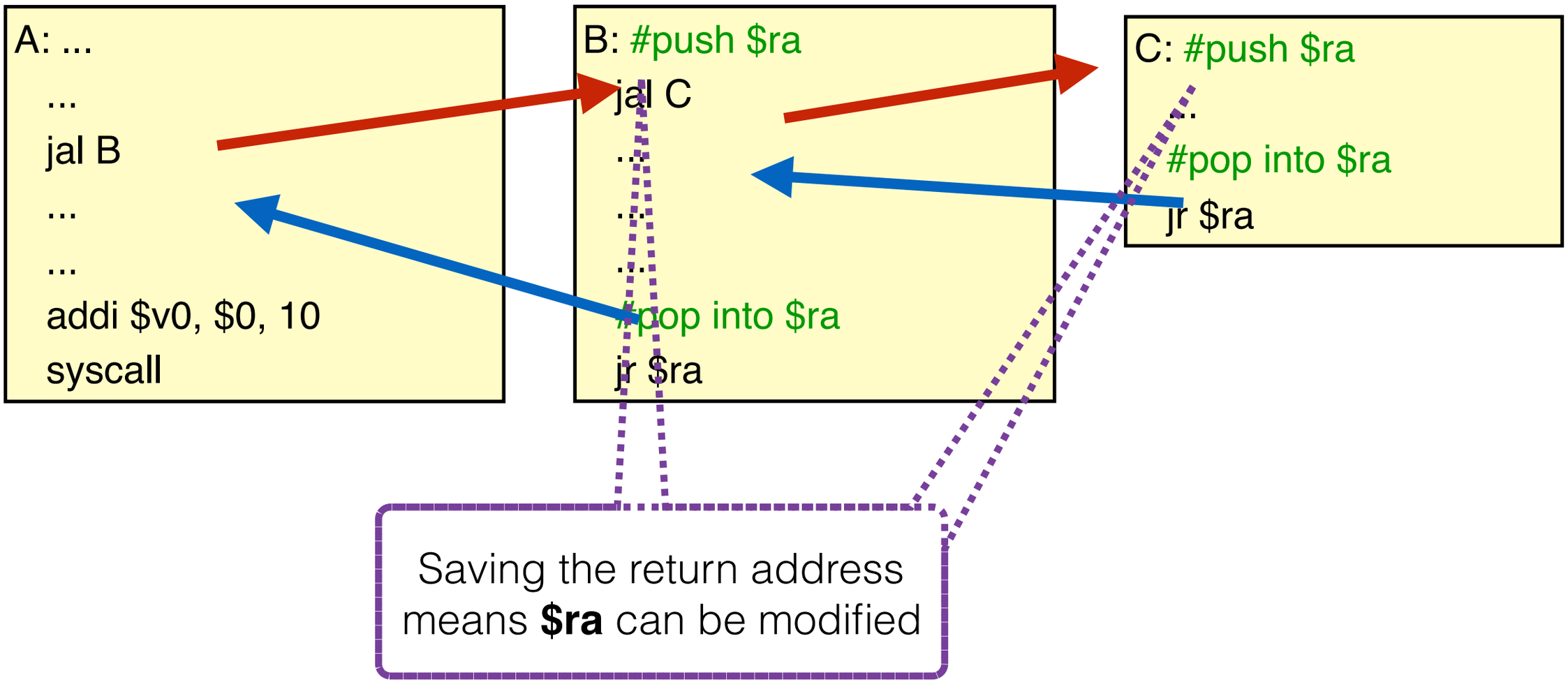

Too many arguments

```
addi $a0, $0, 1
lw $a1, x
addi $a2, $0, 0
lw $a3, -4($fp)
addi $??, $0, 2
jal five
...
```

```
five: # takes 5
      # parameters
      ...
      # examine
      # $a0, etc
      ...
      jr $ra
```

Too many arguments

```
addi $a0, $0, 1
lw $a1, x
addi $a2, $0, 0
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...
```

No such register **$a4**

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```

No such register **$a4**

Not enough registers to use as function arguments

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

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
```

Not enough registers to use as function arguments

Solution: Save arguments on the stack

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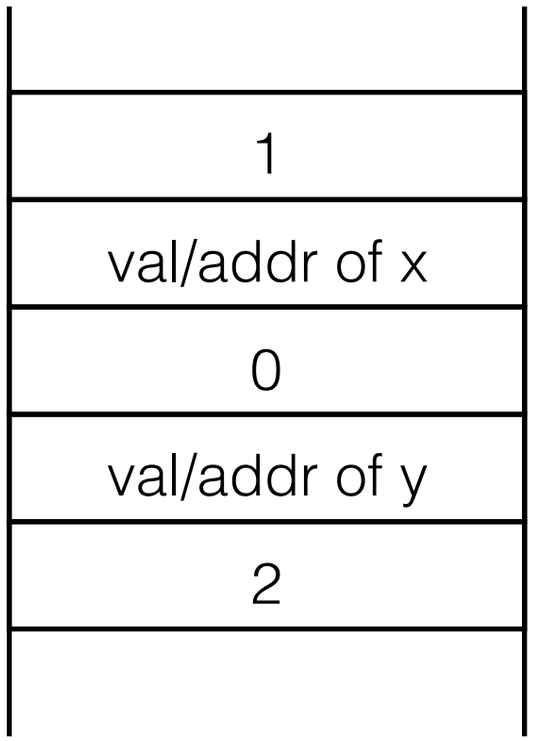
# push 1
jal five
# pop
# pop
# pop
# pop
# pop
```



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```
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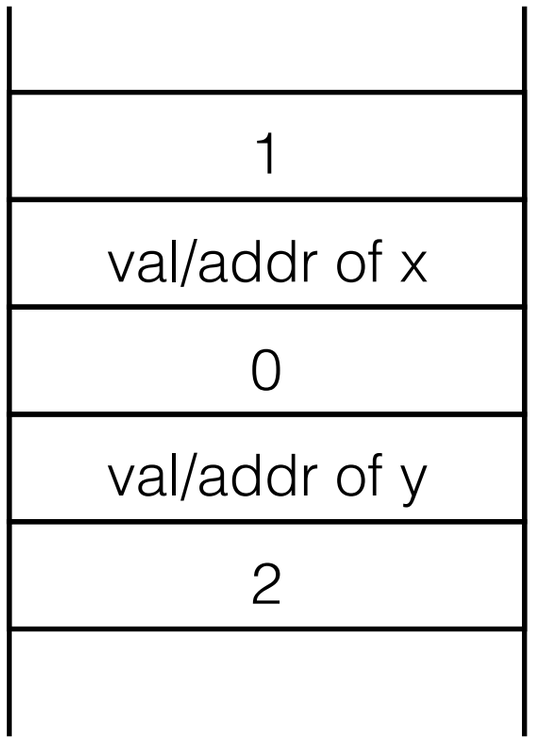


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      ...
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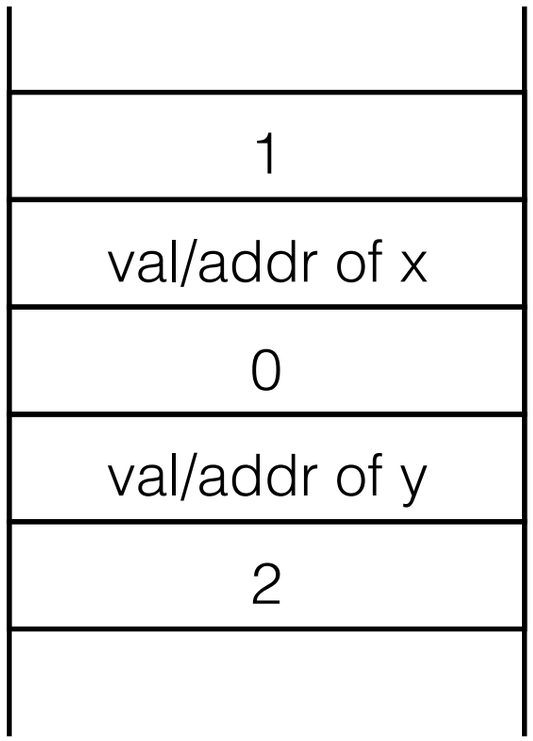


```
five: # takes 5
      # parameters
      ...
      # examine
      # stack
      ...
      jr $ra
```

FIT1008:

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.

Saving registers

```
...
lw $t0, a
...
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jal func
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# $t0 has been
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add $t0, $t0, $v0
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```
func: ...
      # trashes
      # $t0
      lw $t0, x
      ...
      jr $ra
```

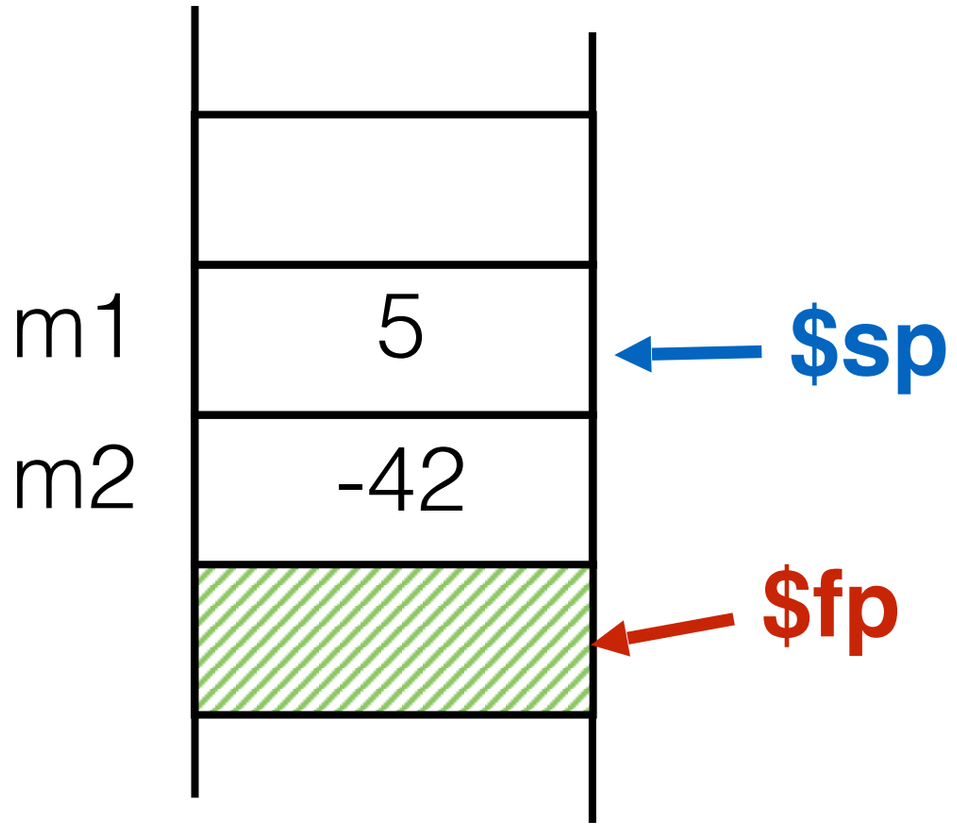
Function may use registers which hold important values.

Solution: save/restore registers on stack.

Local variables needed

```
def main():

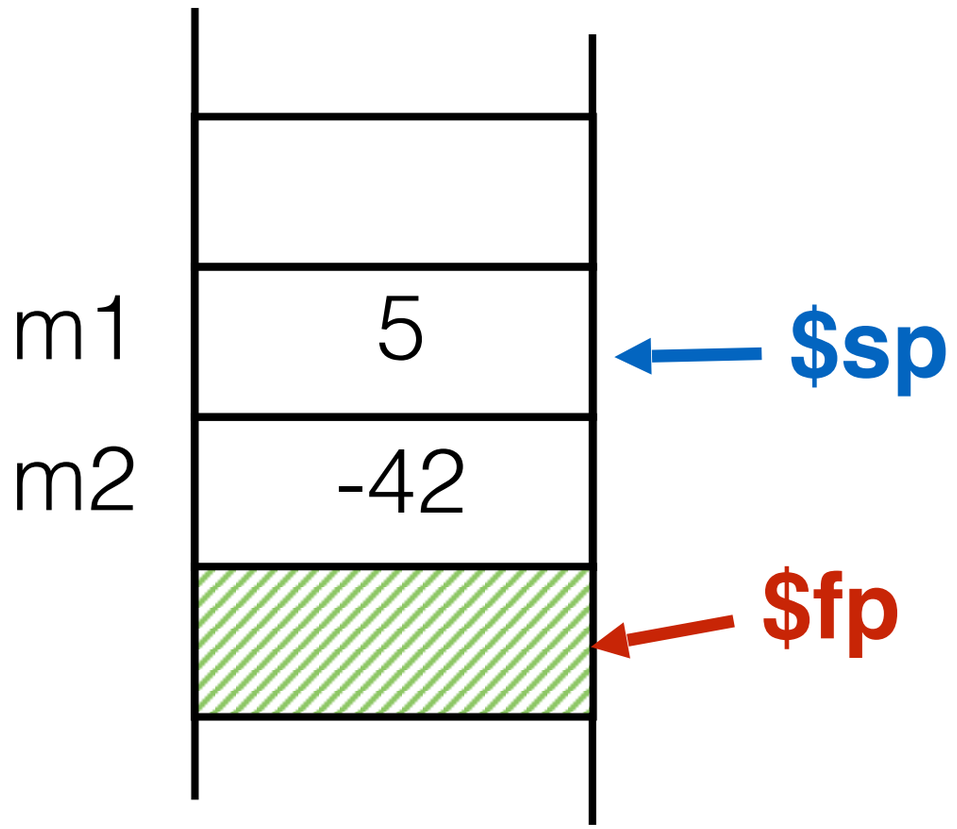
  m1 = 5
  m2 = -42
   ...
  func()
```



Allocate local variables

```
def main():

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




```
def func():

  f1 = 87
  ...
```

Allocate local variables

```
def main():

  m1 = 5
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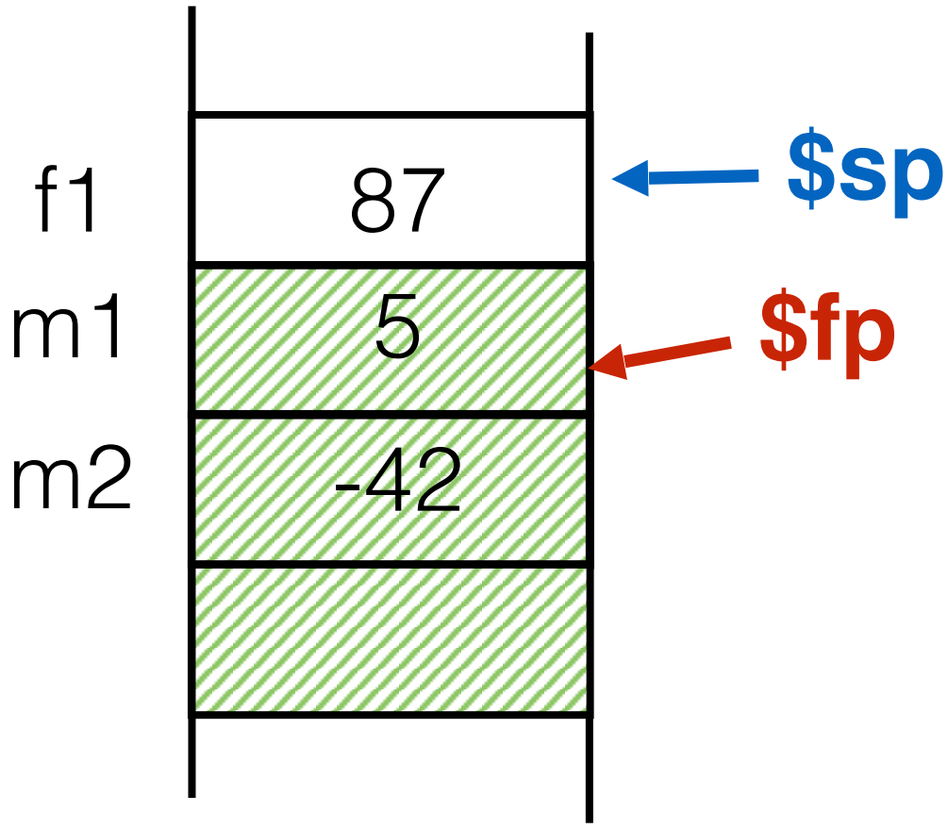


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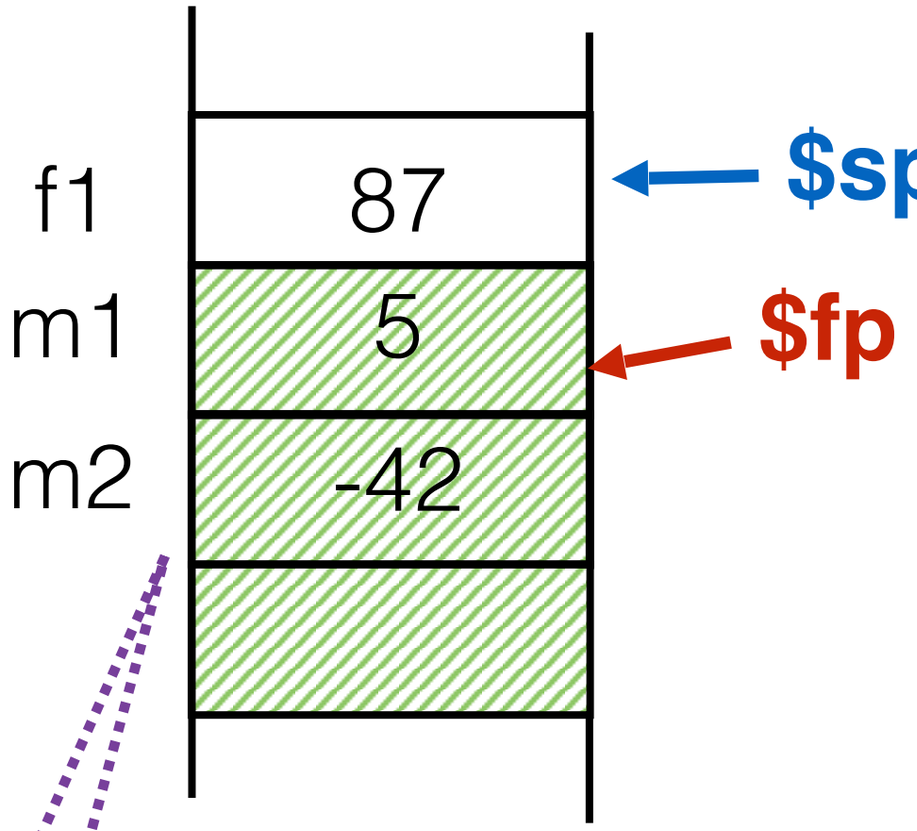


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Inside **func(), m1** and **m2** are inaccessible

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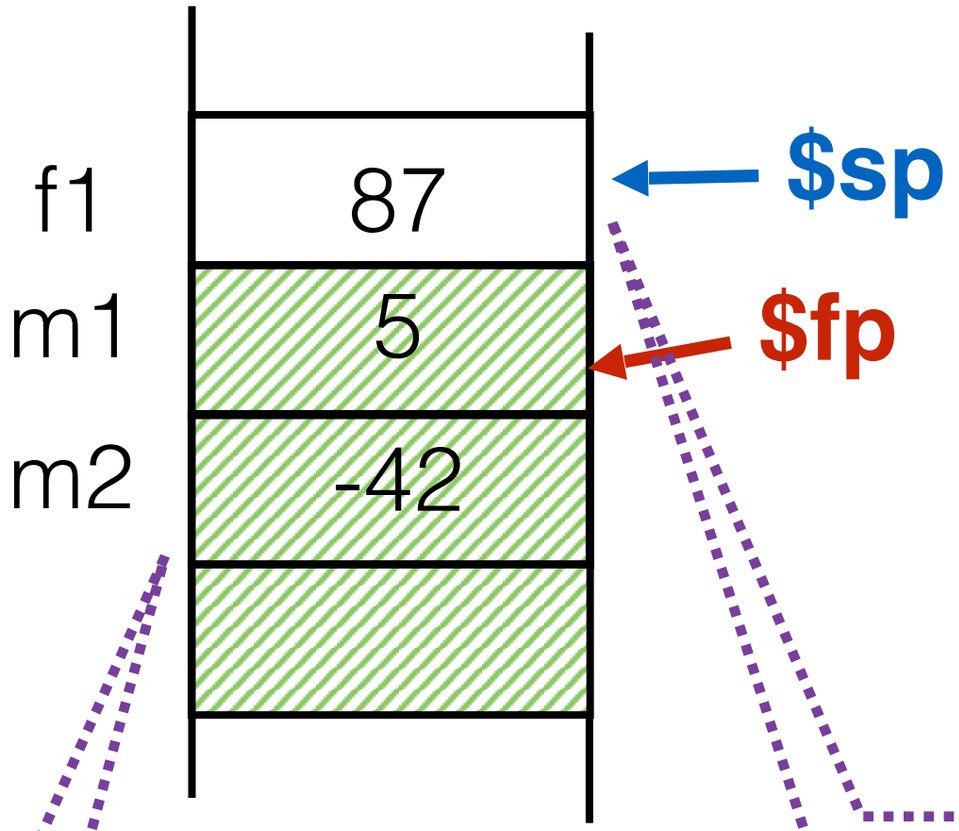


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  f1 = 87
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```

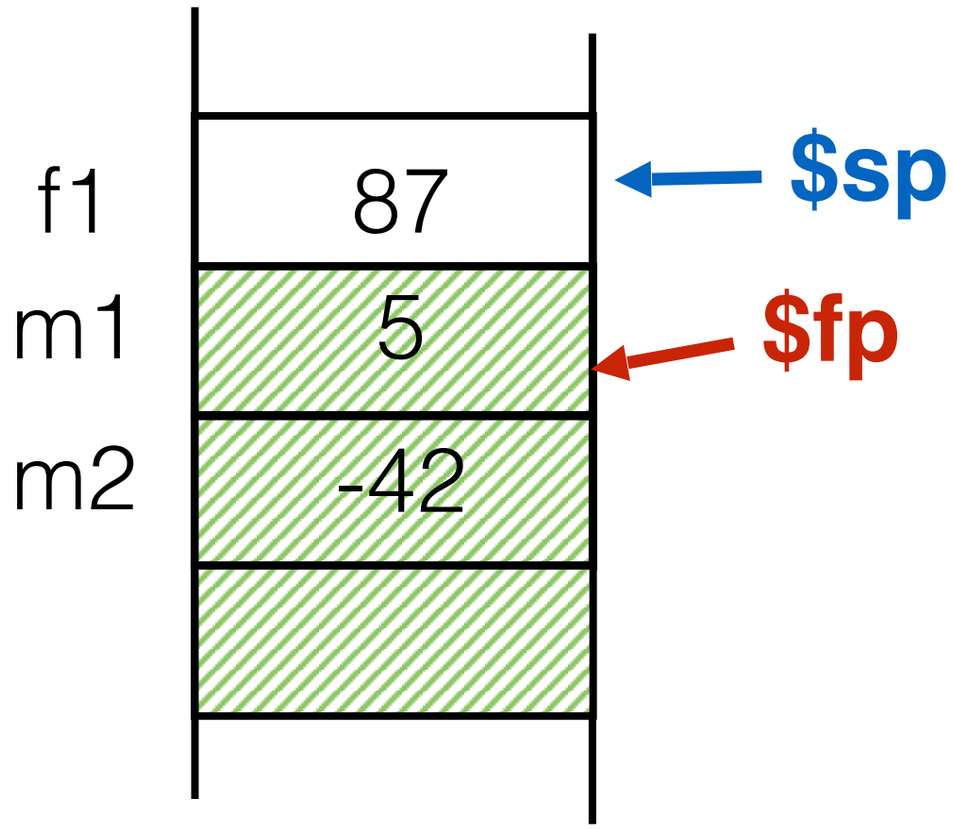
Inside **func(), m1** and **m2** are inaccessible

Inside **func(), f1** is at **-4(fp)**

Restoring stack state

```
def main():

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

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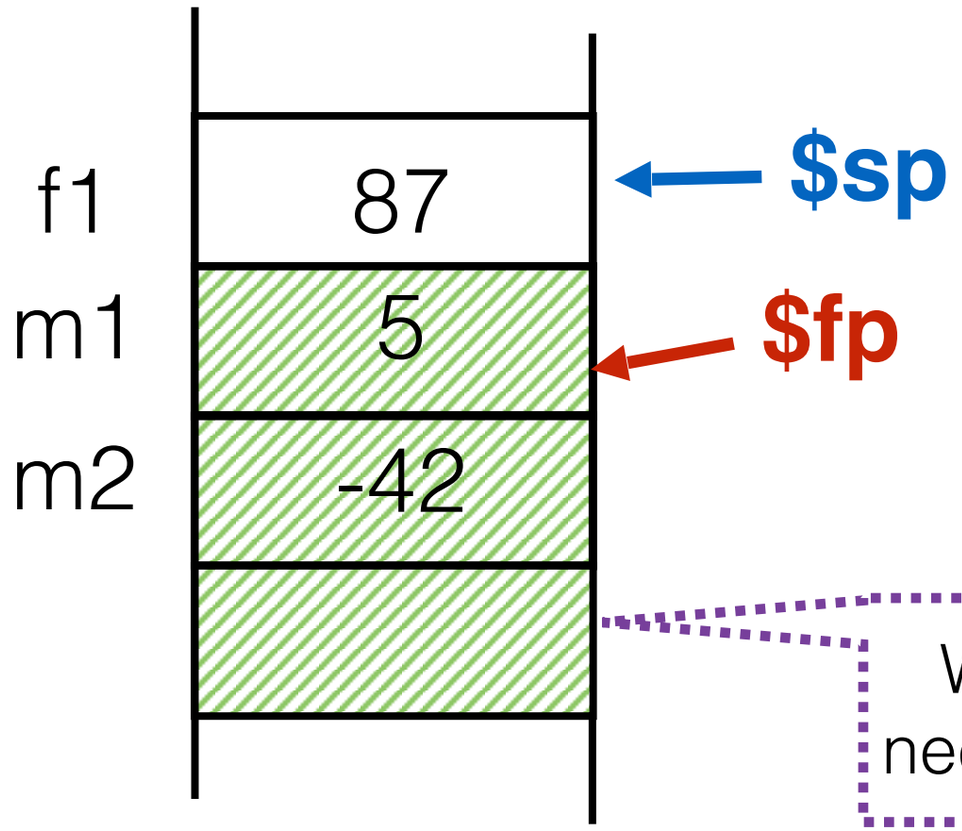


```
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When **func()** ends **$fp** needs to move **back here**

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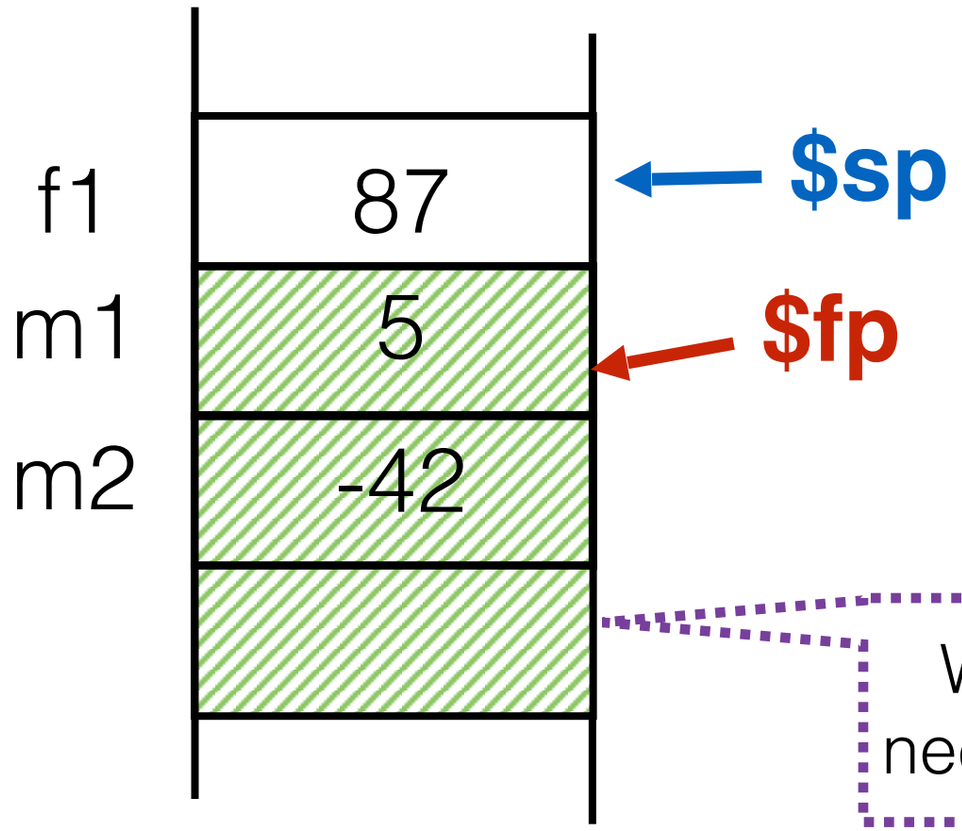


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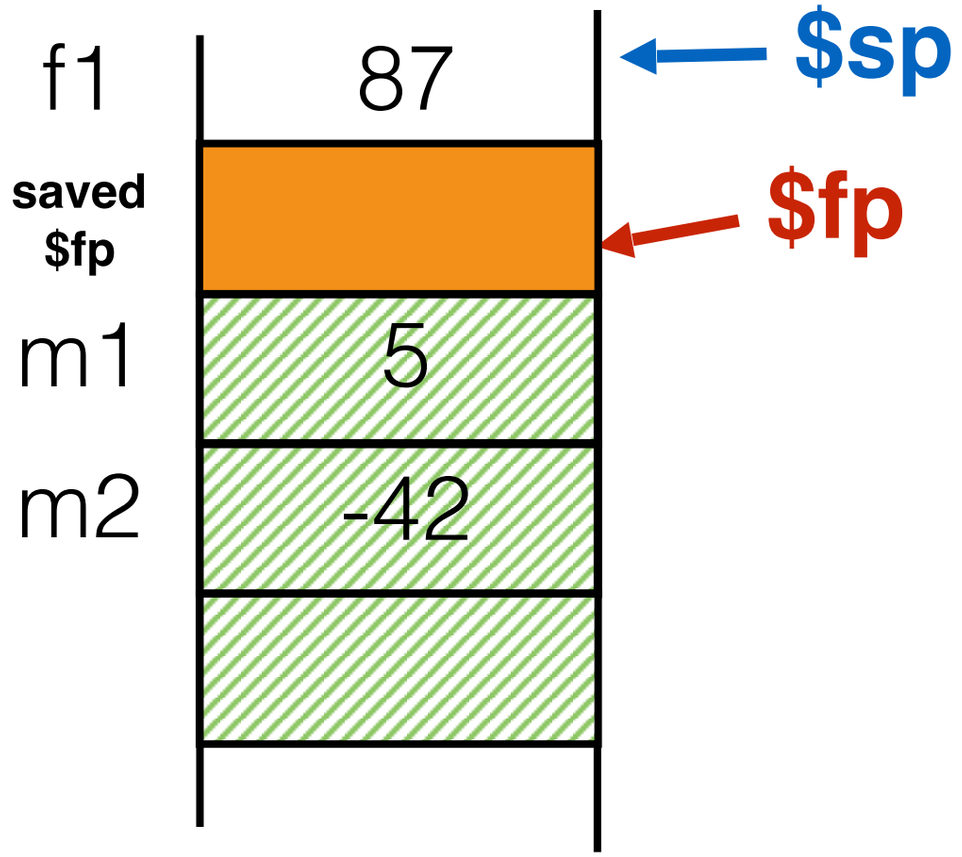


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Solution: Save restore $fp on stack

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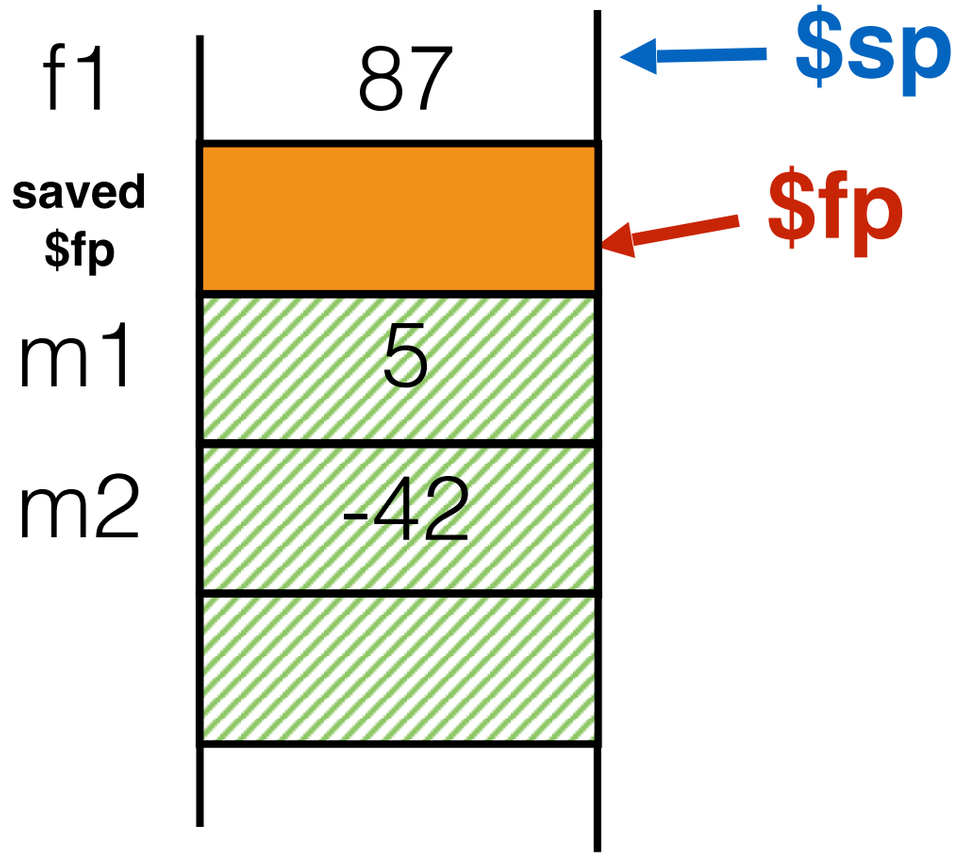


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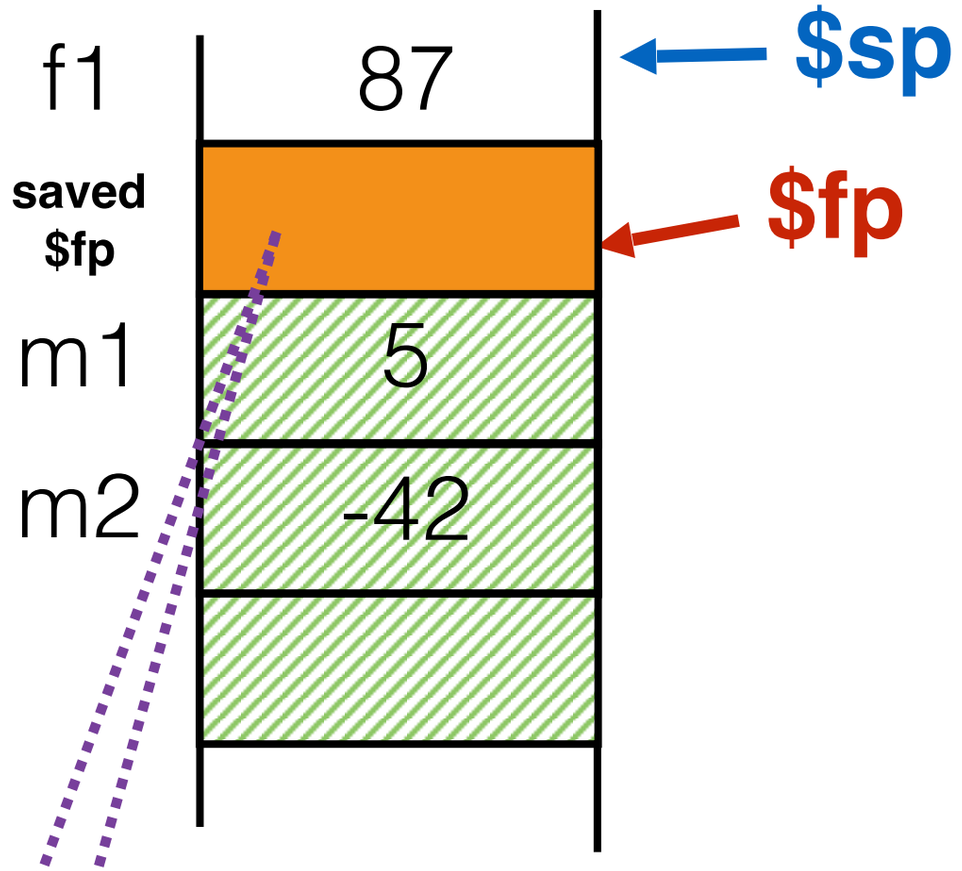


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def func():
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By saving old **$fp** we can restore the stack state at the end of the function

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Solution: Save restore $fp on stack

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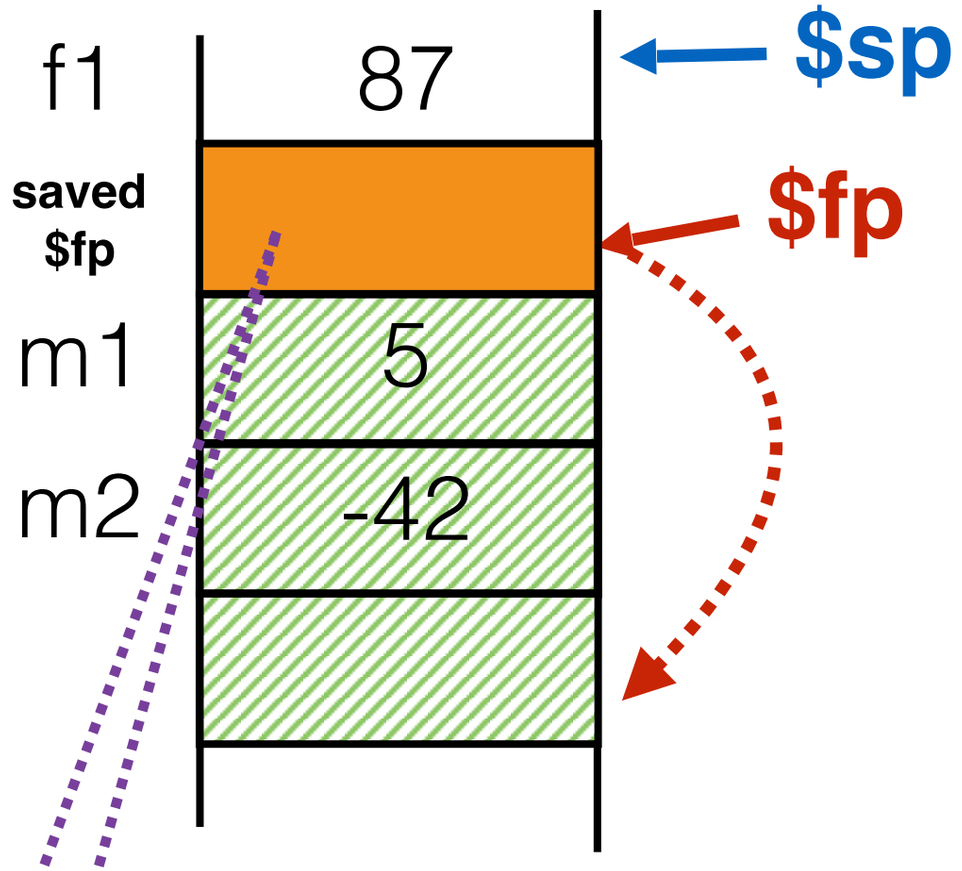


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Function calling convention

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

1. Save temporary registers
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4. Save $ra register
5. Save $fp register
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7. Allocate local variables