Lecture 02
Making Decisions: Conditional Execution

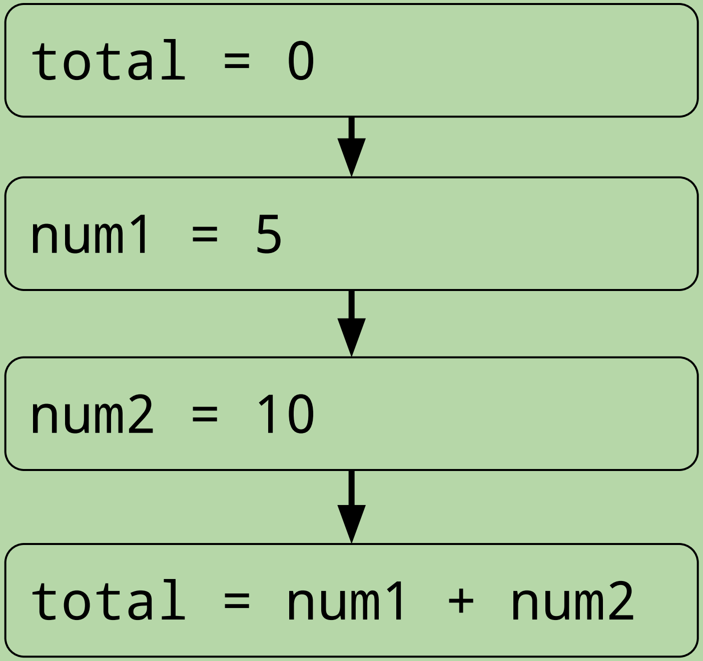
Flow of Control

- Flow of control = order in which statements are executed
- By default, a program's statements are executed sequentially, from top to bottom.

program

```
total = 0
num1  = 5
num2  = 10
total = num1 + num2
```

flowchart



```
total = 0
num1 = 5
num2 = 10
total = num1 + num2
```

Conditional Execution

- To solve many types of problems we need to change the standard flow of control

- Conditional execution allows you to *decide* whether to do something, based on some condition
  - example:

```
def abs_value(x):
    """ returns the absolute value of input x """
    if x < 0:
        x = -1 * x
    return x
```

  - examples of calling this function from the Shell:

```
>>> abs_value(-5)
5
>>> abs_value(10)
10
```

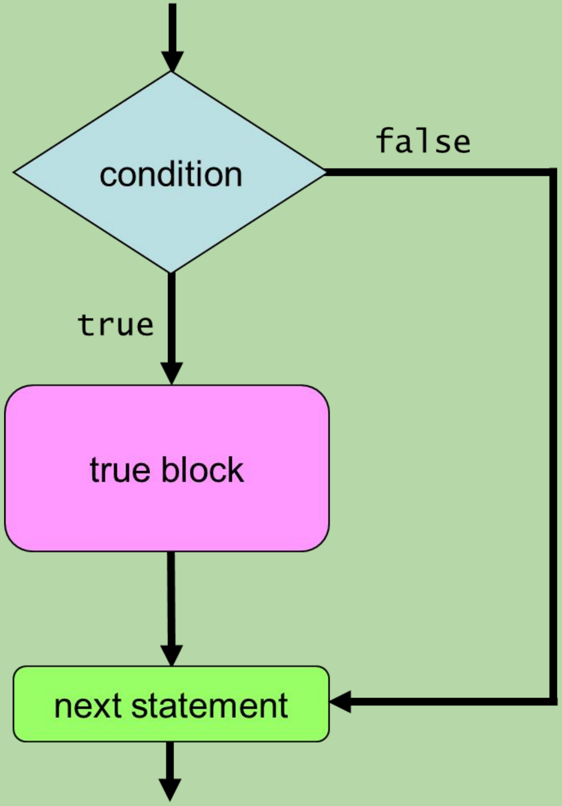
Simple Decisions: `if` Statements

- Syntax:

```
if condition:
    true block
```

where:

  - *condition* is an expression that is true or false
  - *true block* is one or more indented statements



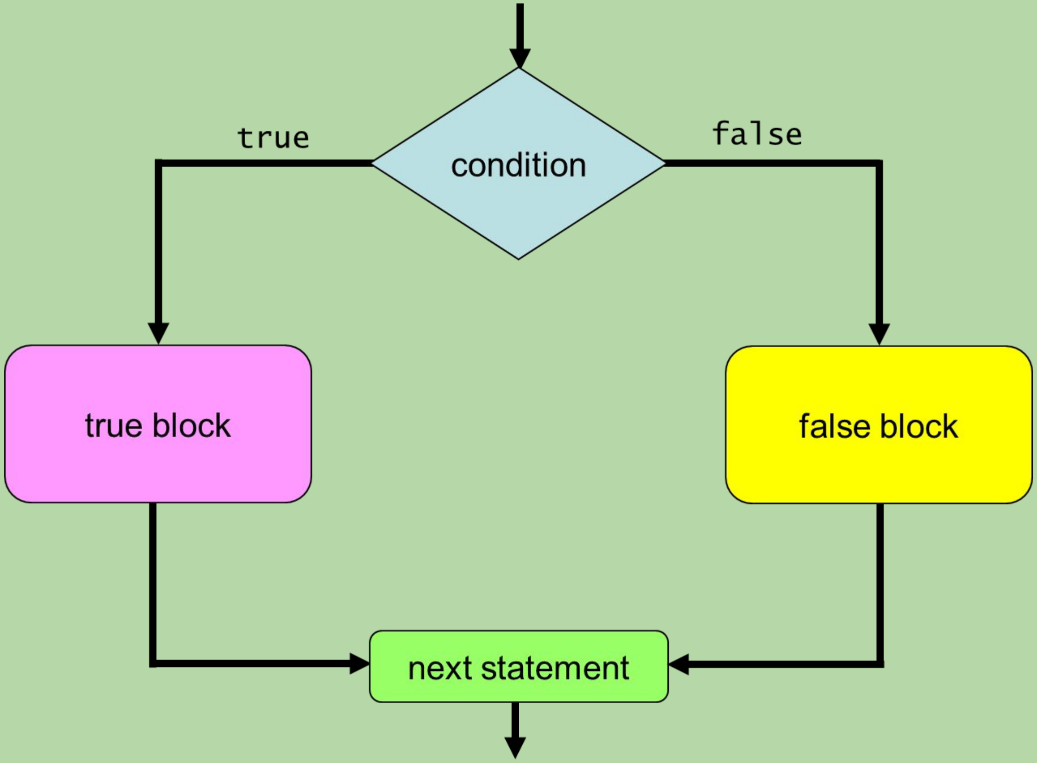
- Example:

```
def abs_value(x):
    """ returns the absolute value of input x """
    if x < 0:
        x = -1 * x      # true block
    return x
```

Two-Way Decisions: `if-else` Statements

- Syntax:

```
if  condition:
     true block
else:
     false block
```



- Example:

```
def pass_fail(avg):
    """ checks whether student passes/fails """
    if avg >= 60:
        grade = 'pass'     # true block
    else:
        grade = 'fail'     # false block
    return grade
```

A Word About Blocks

- A block can contain multiple statements.

```
def welcome(class):
    if class == 'frosh':
        print('Welcome to Brown U!')
        print('Have a great four years!')
    else:
        print('Welcome back!')
        print('Have a great semester!')
        print('Be nice to the frosh students.')
```

- A new block *begins* whenever we *increase* the amount of indenting.

- A block *ends* when we either:
  - reach a line with *less* indenting than the start of the block
  - reach the end of the program

Expressing Simple Conditions

- Python provides a set of *relational operators* for making comparisons:

operator	name	examples

`<`	less than	`val < 10`
		`price < 10.99`

`>`	greater than	`num > 60`
		`state > 'Ohio'`

`<=`	less than or equal to	`average <= 85.8`
`>=`	greater than or equal to	`name >= 'Jones'`

`==`
don't confuse ‘==’ with ‘=’
	equal to	`total == 10`
		`letter == 'P'`

`!=`	not equal to	`age != my_age`

Boolean Expressions

- A condition has one of two values: `True` or `False`.

```
 >>> 10 < 20
 True
>>> 10 < 20 < 15
 False
 >>> "Jones" == "Baker"
 False
```

- `True` and `False` are *not* strings.
  - they are literals from the bool data type

```
>>> type(True)
<class 'bool'>
>>> type(30 > 6)
<class 'bool'>
```

- An expression that evaluates to `True` or `False` is known as a *boolean expression.*

Forming More Complex Conditions

- Python provides *logical operators* for combining/modifying boolean expressions:

name	example and meaning
`and`	`age >= 18 and age <= 35` `True` *if both conditions are* `True`*;* `False` *otherwise*

`or`	`age < 3 or age > 65`
	`True` *if one or both of the conditions are* `True`*;*
	`False` *if both conditions are* `False`

`not`	`not (grade > 80)`
	`True` *if the condition is* `False`*;*
	`False` *if it is* `True`

Nesting

- We can "nest" one conditional statement in the true block or false block of another conditional statement.

```
def welcome(class):
    if class == 'frosh':
        print('Welcome to BU!')
        print('Have a great four years!')
    else:
        print('Welcome back!')
        if class == 'senior':
            print('Have a great last year!')
        else:
            print('Have a great semester!')
        print('Be nice to the frosh students.')
```

What is the output of this program?

```
x = 5
if x < 15:
    if x > 8:
        print('one')
    else:
        print('two')
else:
    if x > 2:
        print('three')
```

A. one

B. two

C. three

D. more than one of the above

E. nothing is output

What is the output of this program?

```
x = 5
if x < 15:    # true
    if x > 8:    # false
        ~~print('one')~~
    else:
        print('two')
else:
    ~~if x > 2:~~
        ~~print('three')~~
# program would go here next...
```

A. one

B. **two**

C. three

D. more than one of the above

E. nothing is output

What does this print? (note the changes!)

```
x = 5
if x < 15:
    if x > 8:
        print('one')
    else:
        print('two')
if x > 2:
    print('three')
```

A. one

B. two

C. three

D. more than one of the above

E. nothing is output

What does this print? (note the changes!)

```
x = 5
if x < 15:
    if x > 8:
        ~~print('one')~~
    else:
        print('two')
if x > 2:
    print('three')
```

A. one

B. two

C. three

D. **more than one of the above**

E. nothing is output

What does this print? (note the new changes!)

```
x = 5
if x < 15:
    if x > 8:
        print('one')
else:
    print('two')
if x > 2:
    print('three')
```

A. one

B. two

C. three

D. more than one of the above

E. nothing is output

What does this print? (note the new changes!)

```
x = 5
if x < 15:
    if x > 8:
        ~~print('one')~~
else:
    ~~print('two')~~
if x > 2:
    print('three')
```

A. one

B. two

C. **three**

D. more than one of the above

E. nothing is output

Multi-Way Decisions

- The following function doesn't work.

```
def letter_grade(avg):
    if avg >= 90:
       grade = 'A'
    if avg >= 80:
       grade = 'B'
    if avg >= 70:
       grade = 'C'
    if avg >= 60:
       grade = 'D'
    else:
       grade = 'F'
    return grade
```

- example:

```
>>> letter_grade(95)
'D'
```

Multi-Way Decisions (cont.)

- Here's a fixed version:

```
def letter_grade(avg):
    if avg >= 90:
       grade = 'A'
    elif avg >= 80:
       grade = 'B'
    elif avg >= 70:
       grade = 'C'
    elif avg >= 60:
       grade = 'D'
    else:
       grade = 'F'
    return grade
```

- example:

```
>>> letter_grade(95)
'A'
```

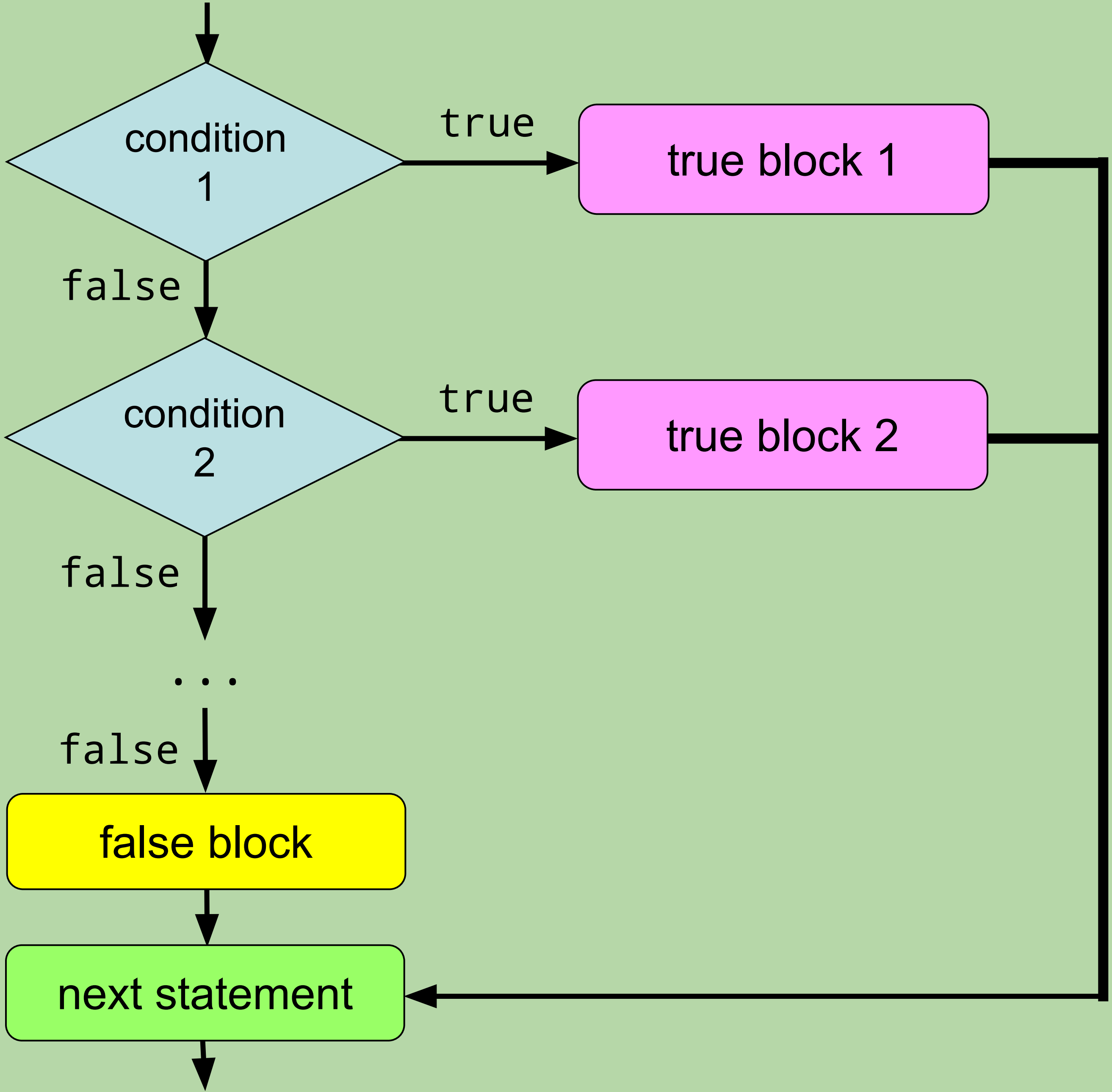
Multi-Way Decisions: `if-elif-else` Statements

- Syntax:

```
if  condition1:
     true block for condition1
elif  condition2:
     true block for condition2
elif  condition3:
     true block for condition3
...
else:
     false block
```

- The conditions are evaluated in order. The true block of the *first* true condition is executed.
- If none of the conditions are true, the false block is executed.

Flowchart for an `if-elif-else` Statement



How many lines does this print?

```
x = 5
if x == 8:
    print('how')
elif x > 1:
    print('now')
elif x < 20:
    print(’brown')
print('cow')
```

A. 0

B. 1

C. 2

D. 3

E. 4

How many lines does this print?

```
x = 5
if x == 8:
    print('how')
elif x > 1:
    print('now')
elif x < 20:
    print(’brown')
print('cow')
```

A. 0

B. 1

C. **2**

D. 3

E. 4

How many lines does this print?

```
x = 5
if x == 8:
    print('how')
if x > 1:
    print('now')
if x < 20:
    print(’brown')
print('cow')
```

A. 0

B. 1

C. 2

D. 3

E. 4

How many lines does this print?

```
x = 5
if x == 8:
    print('how')
if x > 1:
    print('now')
if x < 20:
    print('wow')
print('cow')
```

A. 0

B. 1

C. 2

D. 3

E. 4

What is the output of this code?

```
def mystery(a, b):
    if a == 0 or a == 1:
        return b
    return a * b


print(mystery(0, 5))
```

A. 5

B. 1

C. 0

D. none of these, because an error is produced

E. none of these, but an error is not produced

What is the output of this code?

a	b
0	5

```
def mystery(a, b):
    if a == 0 or a == 1:
        return b
    return a * b


print(mystery(0, 5))
```

A. 5

B. 1

C. 0

D. none of these, because an error is produced

E. none of these, but an error is not produced

What is the output of this code?

a	b
0	5

```
def mystery(a, b):
    if a == 0 or a == 1:
        return b     # return 5
    return a * b


print(mystery(0, 5))     # print(5)
```

A. **5**

B. 1

C. 0

D. none of these, because an error is produced

E. none of these, but an error is not produced

A `return` statement ends a function call, regardless of whether the function has more lines after the `return`.

Common Mistake When Using `and` / `or`

```
def mystery(a, b):
    if a == 0 or 1:       # this is problematic
        return b
    return a * b

print(mystery(0, 5))
```

- When using `and` / `or`, both sides of the operator should be a boolean expression that could stand on its own.

```
 boolean      boolean               boolean     integer
  a == 0   or   a == 1                a == 0   or   1
       (do this)                             (don't do this)
```

- Unfortunately, Python *doesn't* complain about code like the problematic code above.
  - but it won't typically work the way you want it to!

Avoid Overly Complicated Code

- The following also involves decisions based on a person's age:

```
age = ...   # let the user enter his/her age
if age < 13:
    print('You are a child.')
elif age >= 13 and age < 20:
    print('You are a teenager.')
elif age >= 20 and age < 30:
    print('You are in your twenties.')
elif age >= 30 and age < 40:
    print('You are in your thirties.')
else:
    print('You are a survivor.')
```

- How could it be simplified?

Avoid Overly Complicated Code

- The following also involves decisions based on a person's age:

```
age = ...   # let the user enter his/her age
if age < 13:
    print('You are a child.')
elif~~ age >= 13 and~~ age < 20:
    print('You are a teenager.')
elif~~ age >= 20 and~~ age < 30:
    print('You are in your twenties.')
elif~~ age >= 30 and~~ age < 40:
    print('You are in your thirties.')
else:
    print('You are a survivor.')
```

- How could it be simplified?

Variable Scope
Functions Calling Functions

Variable Scope

- The *scope* of a variable is the portion of your program in which the variable can be used.

- We need to distinguish between:
  - *local* variables: limited to a particular function
  - *global* variables: can be accessed anywhere

Local Variables

```
def mystery(x, y):
    b = x - y           # b is a local var of mystery
    return 2*b          # we can access b here

c = 7
mystery(5, 2)
print(b + c)            # we can't access b here!
```

- When we assign a value to a variable inside a function, we create a *local variable*.
  - it "belongs" to that function
  - it can't be accessed outside of that function
- The parameters of a function are also limited to that function.
  - example: the parameters `x` and `y` above

Global Variables

```
def mystery(x, y):
    b = x - y
    return 2*b + c # works, but not recommended

c = 7              # c is a global variable
mystery(5, 2)
print(b + c)       # we can access c here
```

- When we assign a value to a variable *outside* of a function, we create a *global variable*.
  - it belongs to the *global scope*

- A global variable can be used anywhere in your program.
  - in code that is outside of any function
  - in code inside a function (but this is not recommended)

Neither globals nor locals exist until they are assigned a value!

Different Variables With the Same Name!

```
def mystery(x, y):
    b = x - y     # this b is local
    return 2*b    # we access the local b here

b = 1             # this b is global
c = 7
mystery(5, 2)
print(b + c)      # we access the global b here
```

- The program above has two different variables called `b`.
  - one local variable
  - one global variable

- When this happens, the *local* variable has priority inside the function to which it belongs.

What is the output of this code?

```
def mystery2(a, b):
    x = a + b
    return x + 1

x = 8
mystery2(3, 2)
print(x)
```

A. 5

B. 6

C. 8

D. 9

E. none of these, because an error is produced

What is the output of this code?

```
def mystery2(a, b): # there are two different x's!
    x = a + b       # this x is local to mystery2
    return x + 1

x = 8               # this x is global
mystery2(3, 2)
print(x)
```

A. 5

B. 6

C. **8**

D. 9

E. none of these, because an error is produced

What is the output of this code?

```
def mystery2(a, b): # there are two different x's!
    x = a + b       # this x is local to mystery2
    return x + 1

x = 8               # this x is global
mystery2(3, 2)
print(x)
```

A. 5

B. 6

C. 8

D. 9

E. none of these, because an error is produced

Follow-up question:

Why don't we see the following?

```
6
8
```

What is the output of this code?

```
def mystery2(a, b): # there are two different x's!
    x = a + b         # this x is local to mystery2
    return x + 1

x = 8                 # this x is global
mystery2(3, 2)
print(x)
```

A. 5

B. 6

C. **8**

D. 9

E. none of these, because an error is produced

Follow-up question:

Why don't we see the following?

```
6
8
```

`mystery2(3, 2)` returns 6,
but we don't print the return value.
We essentially "throw it away"!

What is the output of this code? (version 2)

```
def mystery2(a, b):
    x = a + b
    return x + 1

~~x = 8~~
mystery2(3, 2)
print(x)
```

A. 5

B. 6

C. 8

D. 9

E. none of these, because an error is produced

What is the output of this code? (version 2)

```
def mystery2(a, b):
    x = a + b
    return x + 1

~~x = 8~~
mystery2(3, 2)
print(x)       # the only x belongs to mystery2,
               # so we can't access it here.
```

A. 5

B. 6

C. 8

D. 9

E. **none of these, because an error is produced**

A Note About Globals

- It's not a good idea to access a global variable inside a function.
    - for example, you shouldn't do this:

```
def average3(a, b):
    total = a + b + c    # accessing a global c
    return total/3

c = 7
print(average3(5, 7))
```

A Note About Globals

- It's not a good idea to access a global variable inside a function.
    - for example, you shouldn't do this:

```
def average3(a, b):
    total = a + b + c   # accessing a global c
    return total/3

c = 7
print(average3(5, 7))
```

- Instead, you should pass it in as a parameter/input:

```
def average3(a, b, c):
    total = a + b + c   # accessing input c
    return total/3

c = 7
print(average3(5, 7, c))
```

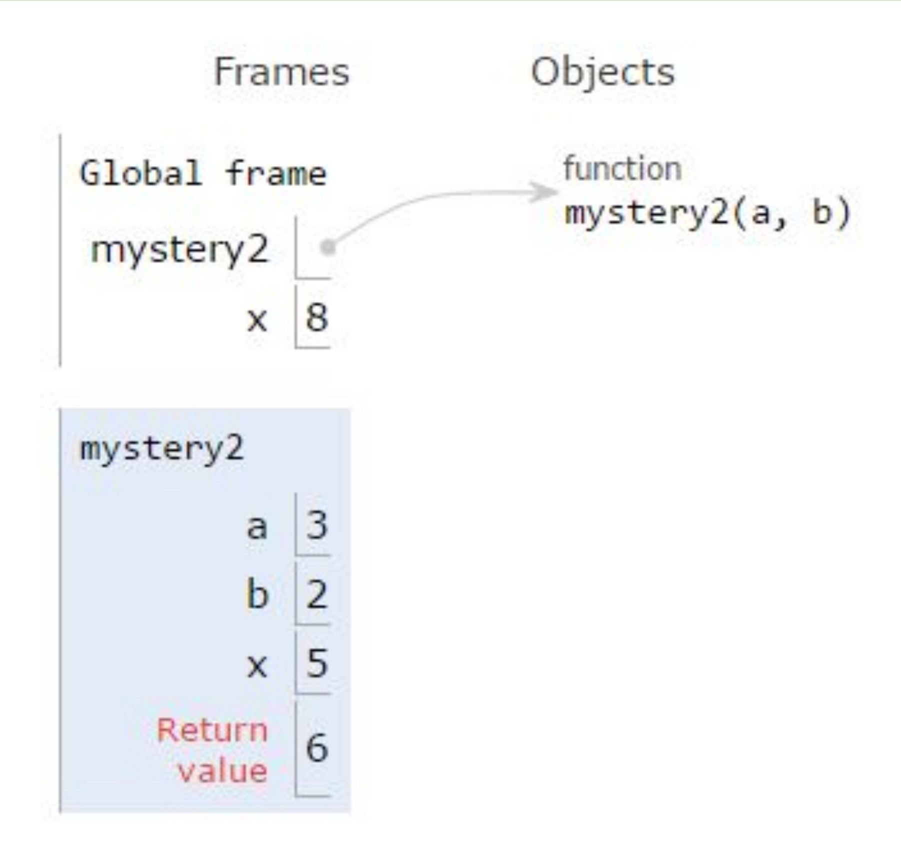
Frames and the Stack

- Variables are stored in blocks of memory known as *frames.*

- Each function call gets a frame for its local variables.
  - goes away when the function returns

- Global variables are stored in the global frame.

- The *stack* is the region of the computer's memory in which the frames are stored.
  - thus, they are also known as *stack frames*



Visualizing How Functions Work

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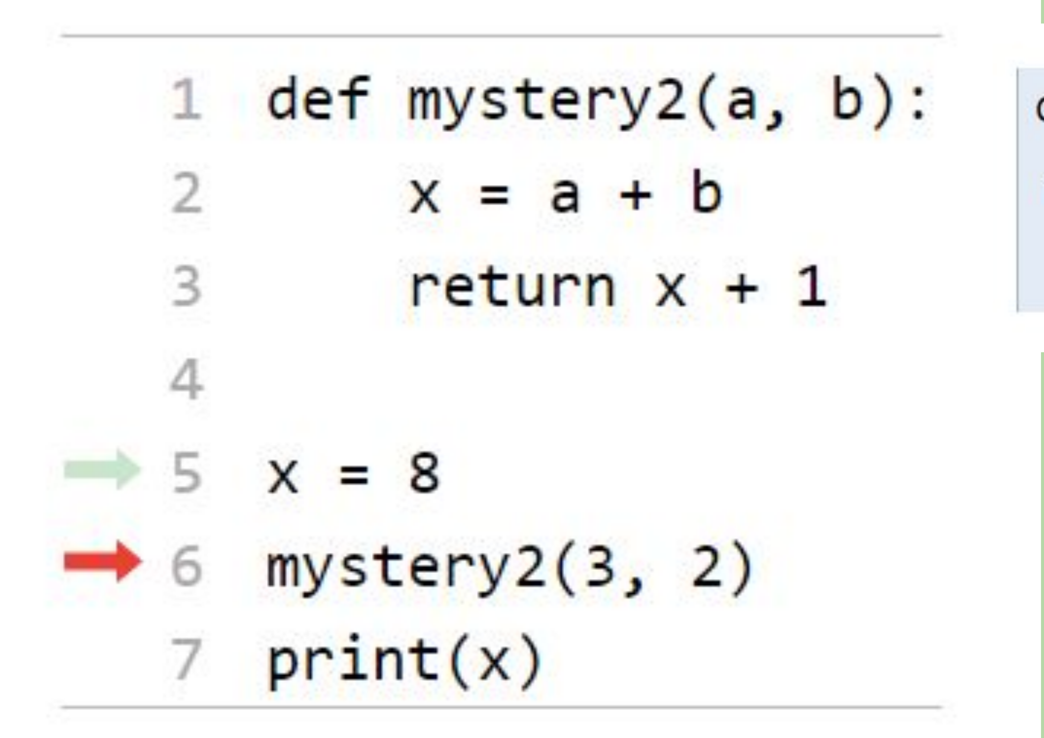
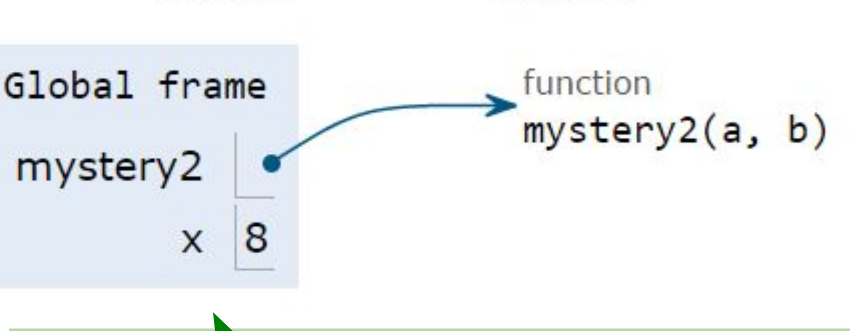
- Before the call to `mystery2`:

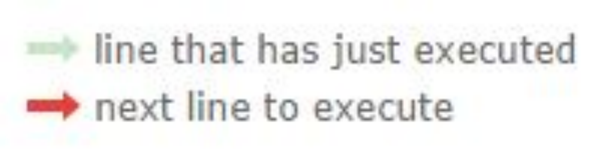


```
def mystery2(a, b):
    x = a + b
    return x + 1

x = 8
mystery2(3, 2)
print(x)
```



The global frame includes the function names and the global variables.



→ line that has just executed

→ next line to execute

Visualizing How Functions Work

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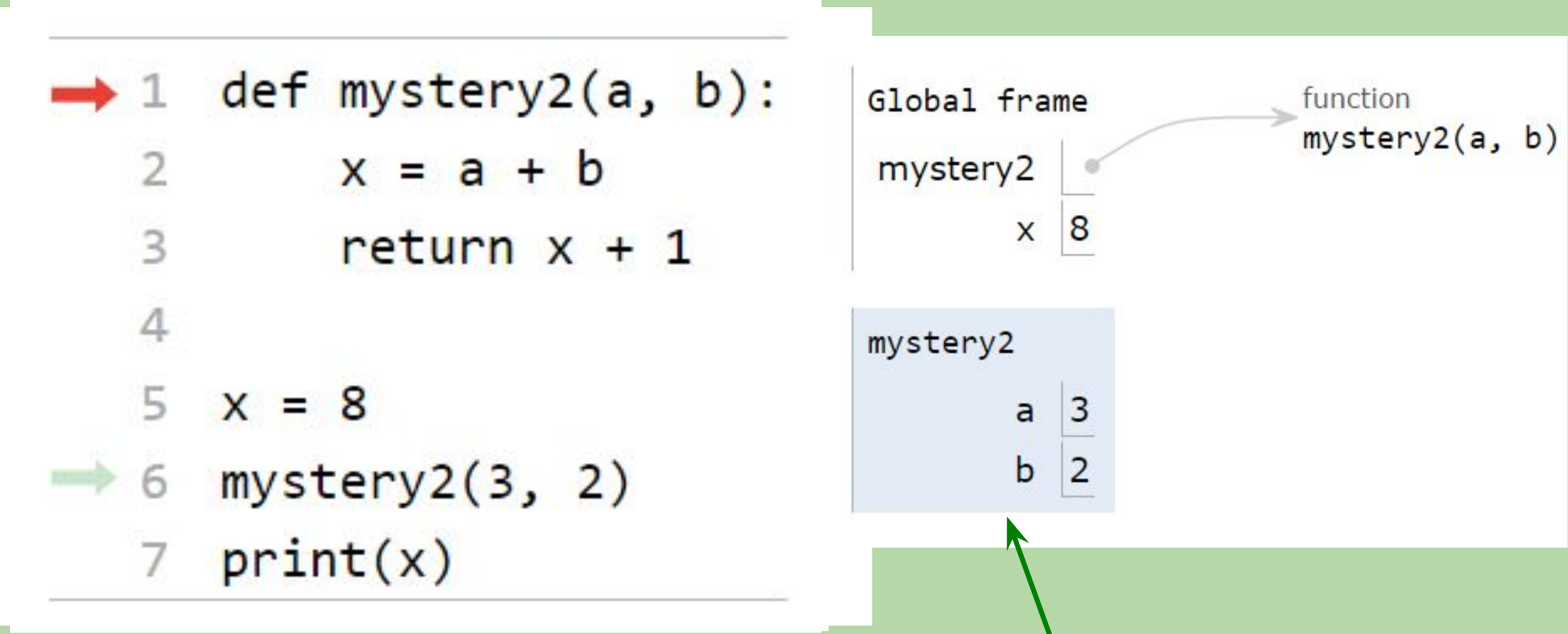
- At the start of the call to `mystery2`:



```
def mystery2(a, b):
    x = a + b
    return x + 1

x = 8
mystery2(3, 2)
print(x)
```

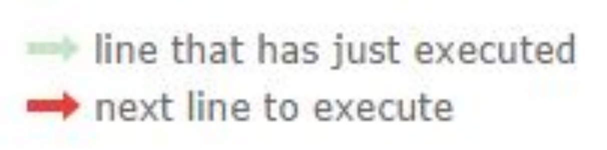
Global frame

mystery2	●
x	8

function
`mystery2(a, b)`

mystery2

a	3
b	2



→ line that has just executed

→ next line to execute

`mystery2(3, 2)` gets its own frame containing the variables that belong to it. `mystery2`'s x isn't shown yet because we haven't assigned anything to it.

Visualizing How Functions Work

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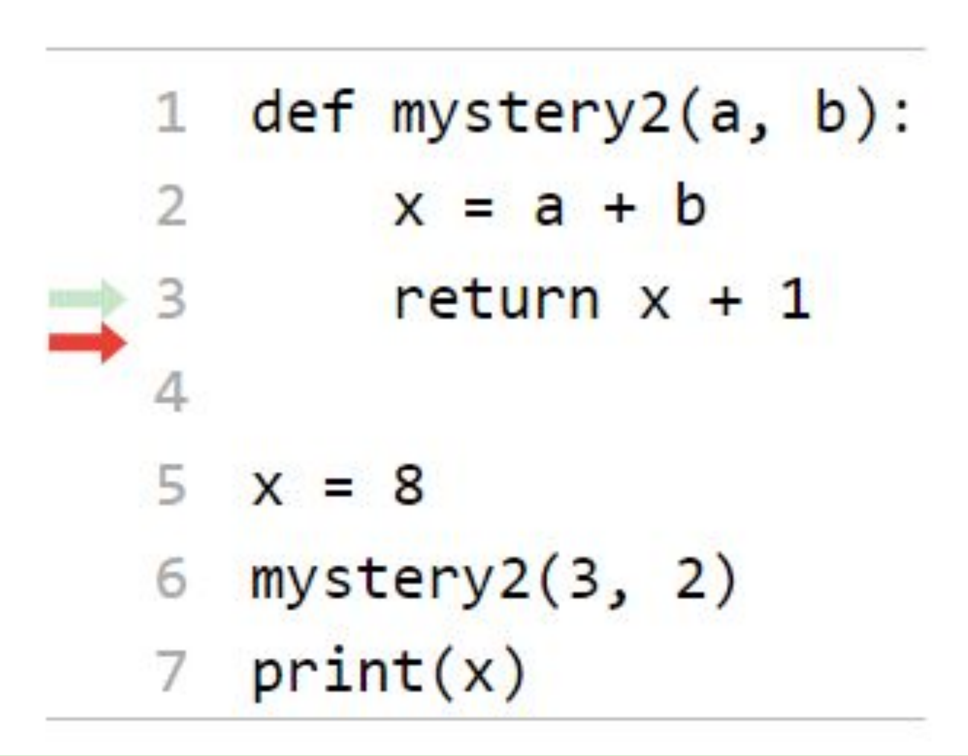
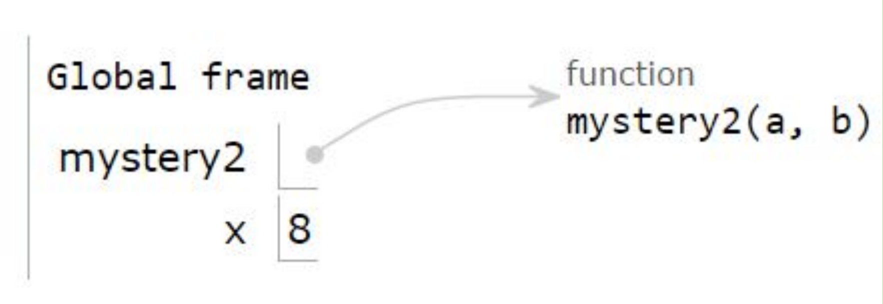
- When the call to `mystery2` is about to return:



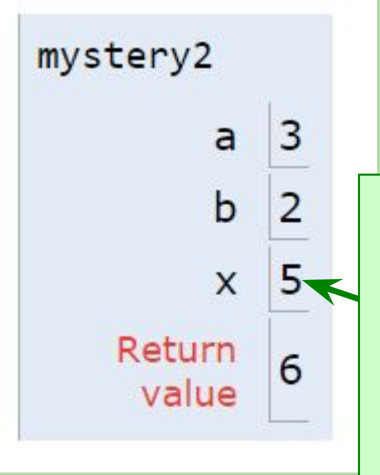
```
def mystery2(a, b):
    x = a + b
    return x + 1

x = 8
mystery2(3, 2)
print(x)
```



Global frame

mystery2 → function mystery2(a, b)

x 8



mystery2

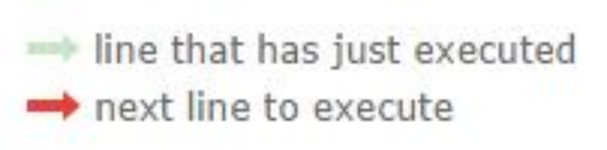
a 3

b 2

x 5

Return value 6

Python looks for a variable in the current frame first, so the local x will be used instead of the global x when returning x + 1.



→ line that has just executed

→ next line to execute

Visualizing How Functions Work

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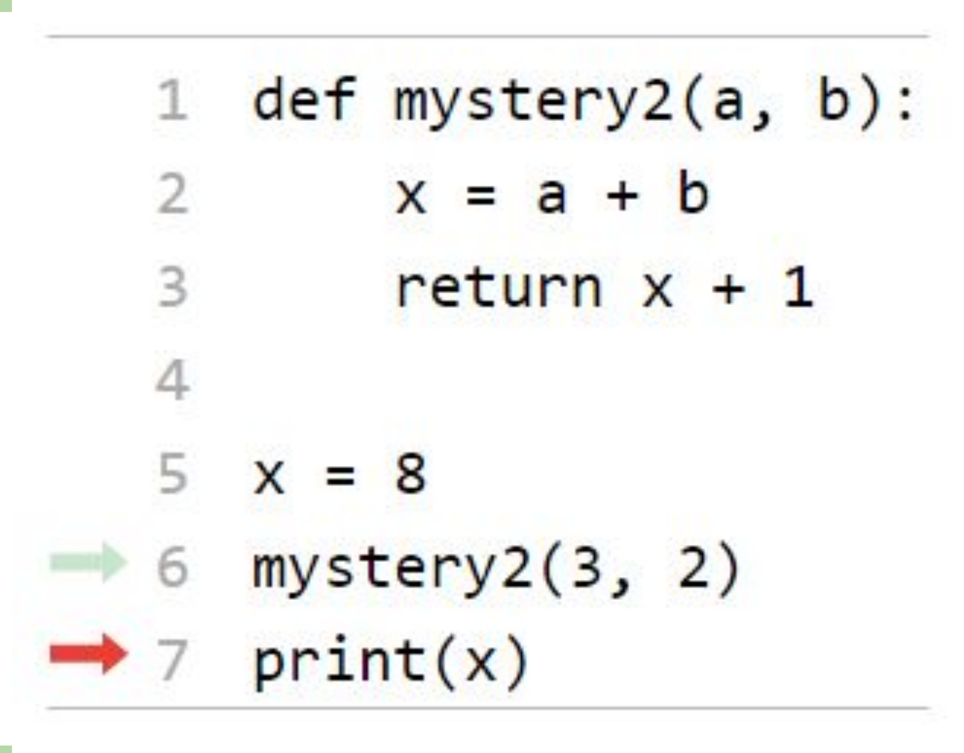
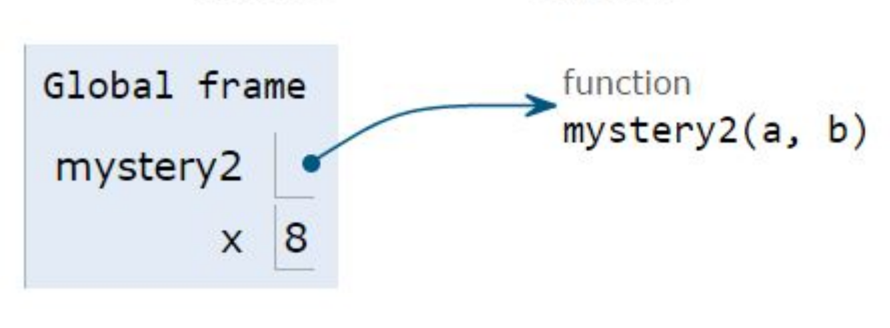
- After the call to `mystery2` has returned:



```
def mystery2(a, b):
    x = a + b
    return x + 1

x = 8
mystery2(3, 2)
print(x)
```



When a function call returns, its frame is removed from memory. Its local variables can no longer be accessed.

- The only x that remains is the global `x`, so its value is printed.

What is the output of this code?

```
def quadruple(y):
    y = 4 * y
    return y

y = 8
quadruple(y)

print(y)
```

A. 4

B. 8

C. 12

D. 32

E. none of these, because an error is produced

What is the output of this code?

```
def quadruple(y):    # the parameter y is local
    y = 4 * y
    return y

y = 8               # this y is global
quadruple(y)

print(y)
```

A. 4

B. 8

C. 12

D. 32

E. none of these, because an error is produced

What is the output of this code?

```
def quadruple(y):    # 3. local y = 8
    y = 4 * y
    return y

y = 8               # 1. global y = 8
quadruple(y)        # 2. pass in global y's value

print(y)
```

A. 4

B. 8

C. 12

D. 32

E. none of these, because an error is produced

What is the output of this code?

```
def quadruple(y):   # 3. local y = 8
    y = 4 * y       # 4. local y = 4 * 8 = 32
    return y        # 5. return local y's value
           32
y = 8            # 1. global y = 8
quadruple(y)     # 2. pass in global y's value
                 # 6. return value thrown away!
print(y)
```

A. 4

B. 8

C. 12

D. 32

E. none of these, because an error is produced

What is the output of this code?

```
def quadruple(y):   # 3. local y = 8
    y = 4 * y       # 4. local y = 4 * 8 = 32
    return y        # 5. return local y's value
           32
y = 8            # 1. global y = 8
quadruple(y)     # 2. pass in global y's value
                 # 6. return value thrown away!
print(y)         # 7. print global y's value,
                 #    which is unchanged!
```

A. 4

B. **8**

C. 12

D. 32

E. none of these, because an error is produced

You ***can't*** change the value of a variable by passing it into a function!

How could we change this to see the return value of quadruple?

```
def quadruple(y):
    y = 4 * y
    return y

y = 8
quadruple(y)
print(y)
```

Seeing the return value (option 1)

```
def quadruple(y):
    y = 4 * y
    return y

y = 8
y = quadruple(y)   # assign return val to global y
print(y)
```

Seeing the return value (option 2)

```
def quadruple(y):
    y = 4 * y
    return y

y = 8
print(quadruple(y))   # print return val
                      # no need for print(y)
```

What is the output of this program?

```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))
```

A. 4

B. 42

C. 44

D. 46

E. none of these

Functions Calling Other Functions!

```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))
```

stack frame

```
demo
  x = -4
  return -4 + f(-4)
```

demo		f		g	
x	ret	x	ret	x	ret
-4					

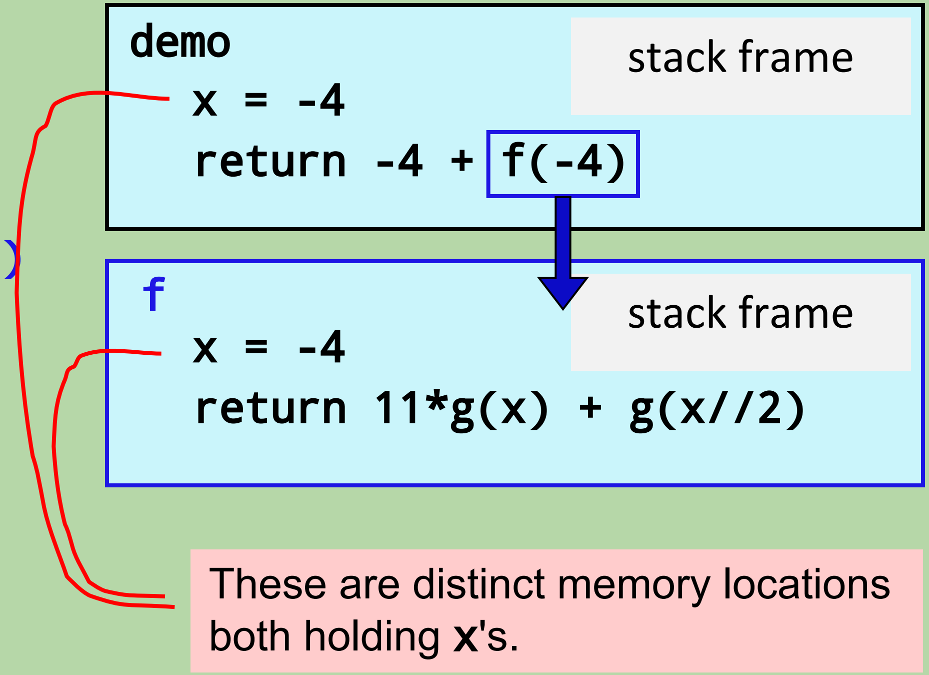
Functions Calling Other Functions!

```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))
```



demo

stack frame

```
x = -4
return -4 + f(-4)
```

f

stack frame

```
x = -4
return 11*g(x) + g(x//2)
```

These are distinct memory locations both holding **x**'s.

```
  demo         f          g
x | ret     x | ret    x | ret
-4 |        -4 |          |
```

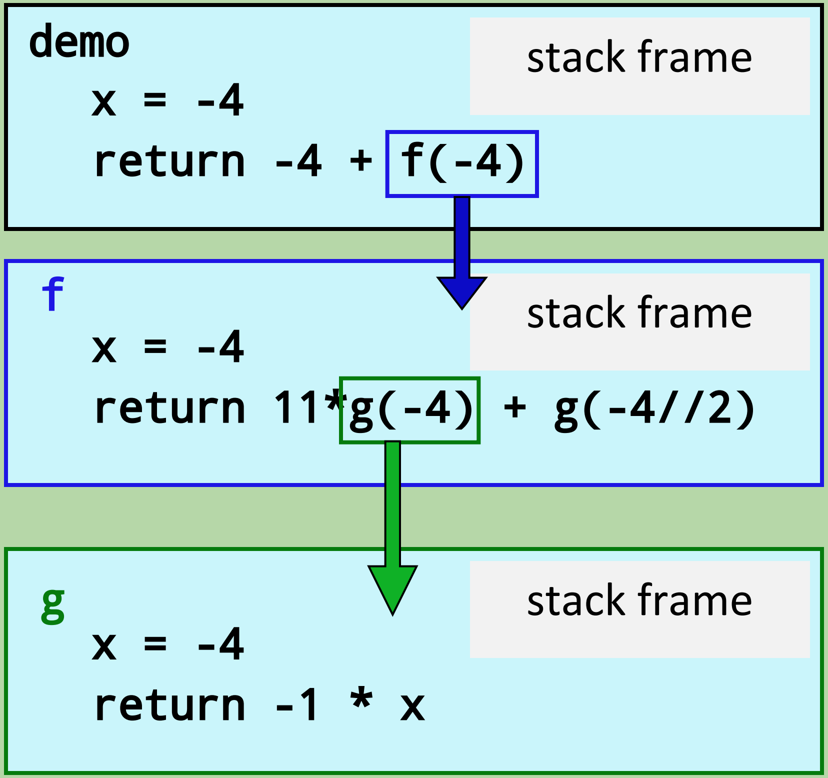
Functions Calling Other Functions!

```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))
```



```
demo
   x = -4
   return -4 + f(-4)
```

stack frame

```
f
   x = -4
   return 11*g(-4) + g(-4//2)
```

stack frame

```
g
   x = -4
   return -1 * x
```

stack frame

demo		f		g	
x	ret	x	ret	x	ret
-4		-4		-4	

Functions Calling Other Functions!

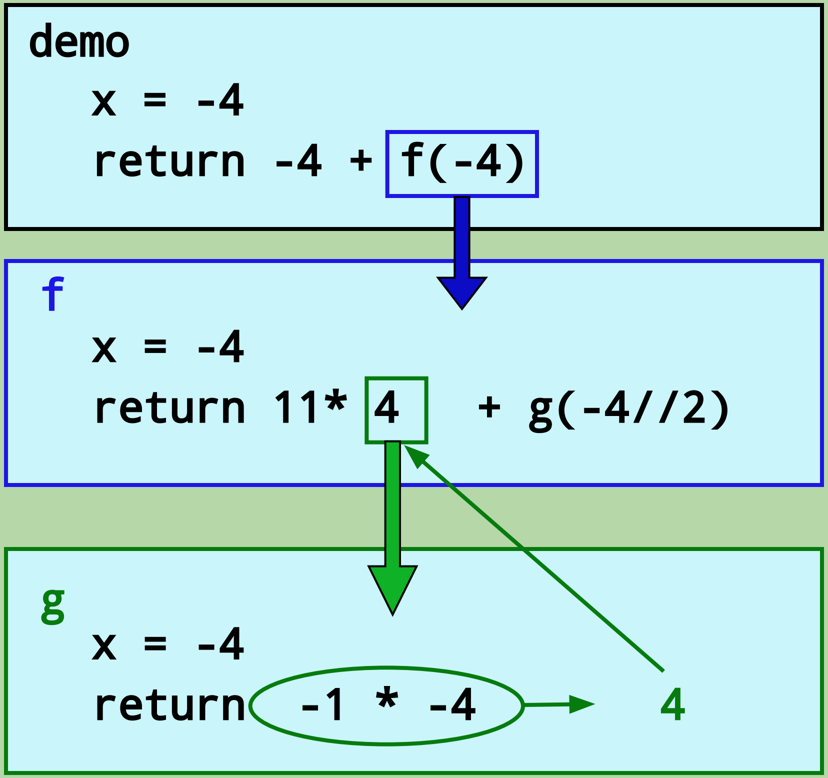
```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))
```

```
  demo          f          g
x | ret     x | ret    x | ret
-4 |        -4 |       -4 |  4
```



Functions Calling Other Functions!

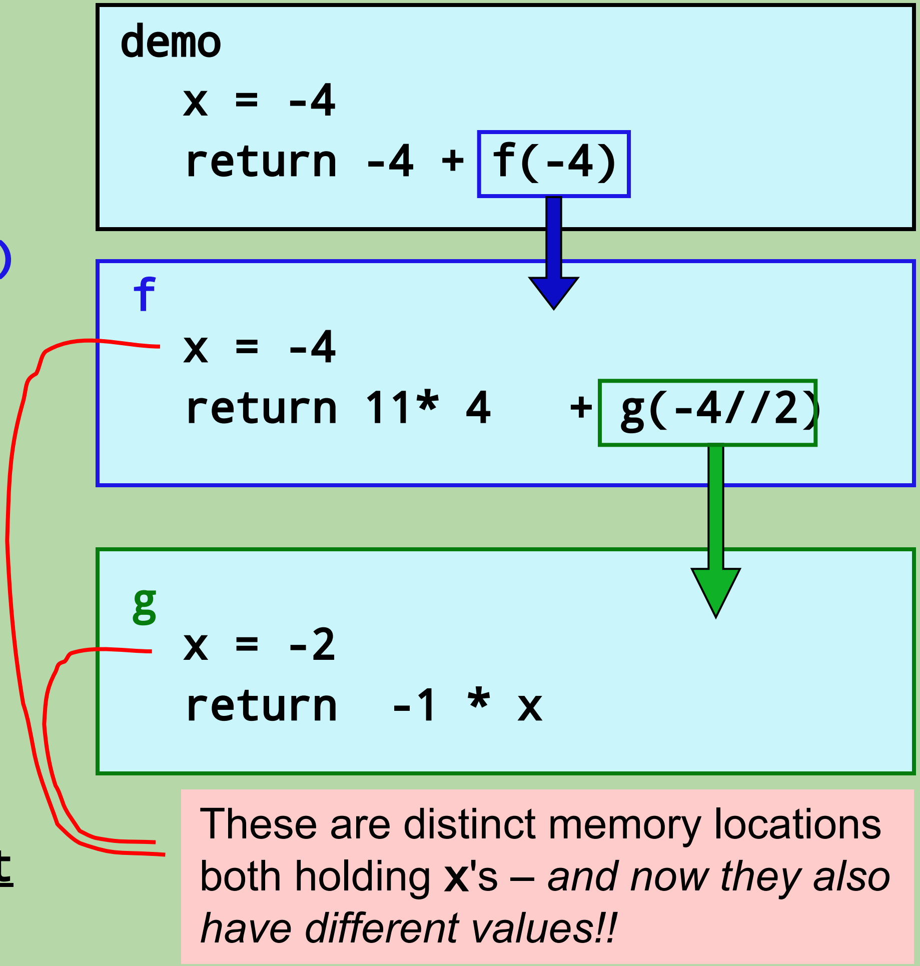
```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))
```

demo		f		g	
x	ret	x	ret	x	ret
-4		-4		-4	4
				-2	



```
demo
   x = -4
   return -4 + f(-4)

f
   x = -4
   return 11* 4    + g(-4//2)

g
   x = -2
   return  -1 * x
```

These are distinct memory locations both holding **x**'s – *and now they also have different values!!*

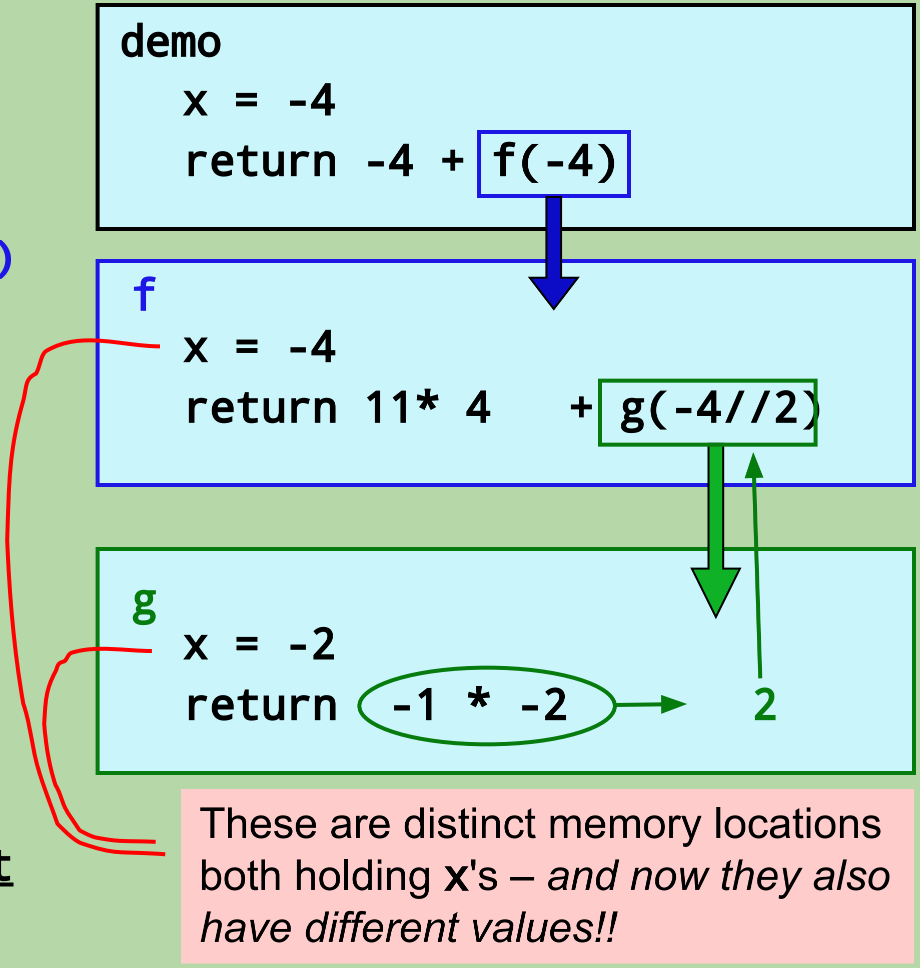
Functions Calling Other Functions!

```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))
```



```
demo
   x = -4
   return -4 + f(-4)
```

```
f
   x = -4
   return 11* 4    + g(-4//2)
```

```
g
   x = -2
   return -1 * -2  2
```

These are distinct memory locations both holding **x**'s – *and now they also have different values!!*

demo		f		g	
x	ret	x	ret	x	ret
-4		-4		-4	4
				-2	2

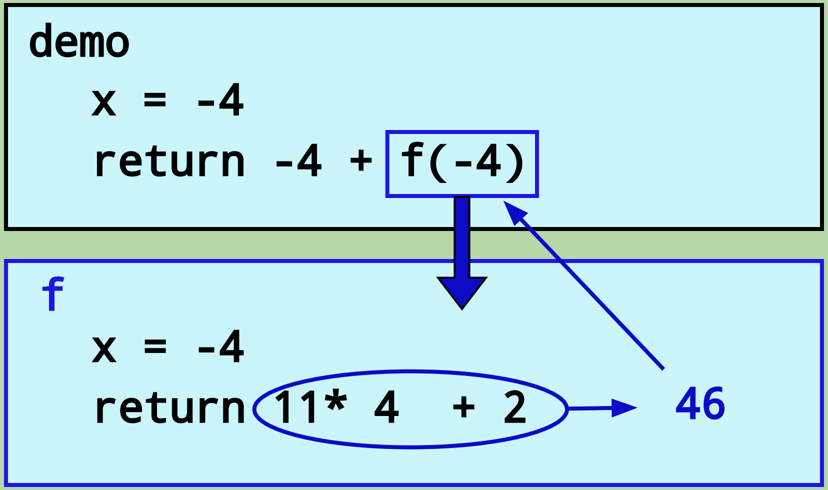
Functions Calling Other Functions!

```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))
```



```
demo
   x = -4
   return -4 + f(-4)

f
   x = -4
   return 11* 4  + 2      46
```

```
  demo          f            g

x | ret     x | ret     x | ret
-4 |       -4 |  46    -4 |  4
                       -2 |  2
```

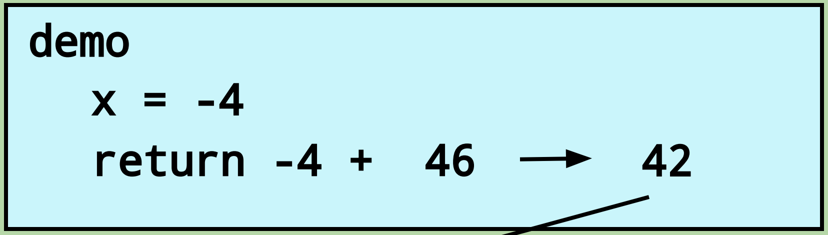
Functions Calling Other Functions!

```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))
```



```
demo
   x = -4
   return -4 +  46 → 42
```

demo		f		g	
x	ret	x	ret	x	ret
-4	42	-4	46	-4	4
				-2	2

Functions Calling Other Functions!

```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))   # print(42)
```

```
42
```

What is the output of this program?

```
def demo(x):
    return x + f(x)

def f(x):
    return 11*g(x) + g(x//2)

def g(x):
    return -1 * x

print(demo(-4))
```

A. 4

B. **42**

C. 44

D. 46

E. none of these

Tracing Function Calls

```
def foo(x, y):
    y = y + 1
    x = x + y
    print(x, y)
    return x

x = 2
y = 0

y = foo(y, x)
print(x, y)

foo(x, x)
print(x, y)

print(foo(x, y))
print(x, y)
```

foo

x | y | ret

global

x | y

output

Tracing Function Calls

```
def foo(x, y):
    y = y + 1
    x = x + y
    print(x, y)
    return x

x = 2
y = 0

y = foo(y, x)
print(x, y)

foo(x, x)
print(x, y)

print(foo(x, y))
print(x, y)
```

foo

x	y	ret
0	2	3

global

x	y
2	0
2	3

output

```
3 3
```

Tracing Function Calls

```
def foo(x, y):
    y = y + 1
    x = x + y
    print(x, y)
    return x

x = 2
y = 0

y = foo(y, x)
print(x, y)

foo(x, x)
print(x, y)

print(foo(x, y))
print(x, y)
```

foo

x	y	ret
0	2	3
2	2	5
2	3	6

global

x	y
2	0
2	3

output

```
3 3
2 3
5 3
2 3
6 4
6
2 3
```