Lecture 12: Generators

Check-in and Reminders

- Pick up **graded Homework 4** from box up front
- Reminder: **Midterm exam on March 12 (Thursday)**
    - Room: TPL 203, 5.45-7.45 pm and 8-10 pm
    - Closed book exam
    - Practice thinking about code on paper
- **Midterm review session: Monday, March 9**
    - TPL 203, 7-8.30 pm
    - Come with all your questions
- Next week's lab (on plotting data) will also be partnered
- It will be short and due the day off

Do You Have Any Questions?

Review: Functions

- Functions taken in some input and return some output
- Parameters of a functions are “holes” in the body of the function, that are filled in with the argument value for each invocation
- A particular. name for a parameter is irrelevant, as long, as we use it consistently within the body

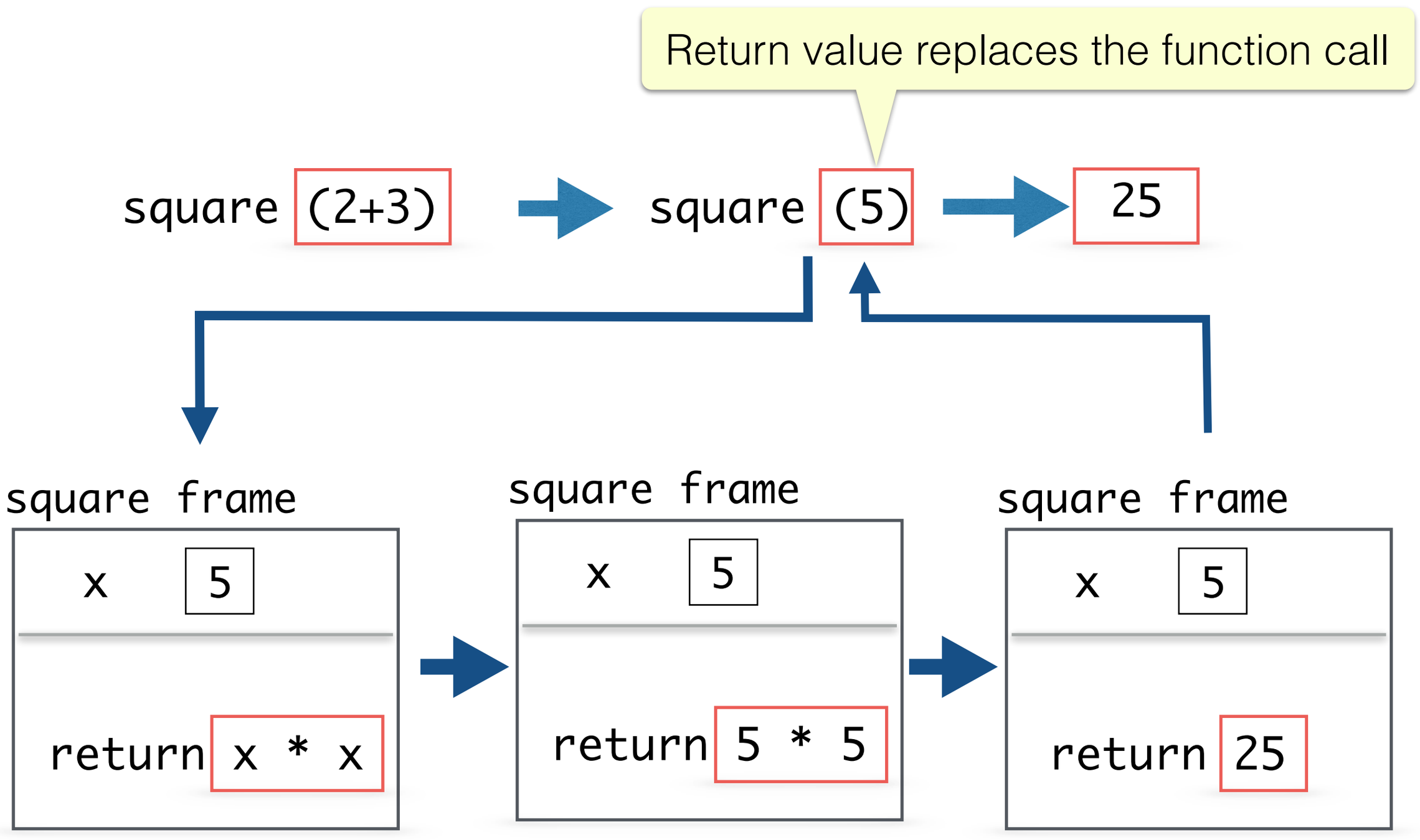
```
def square(x):
    return x*x
```

```
def square(apple):
    return apple*apple
```

```
def square(num):
    return num*num
```

Review: Function Call Model

- **Function frame.** Model to understanding how a function call works



Review: Return Statement

- When a function returns a value, where does it “end up”?
- Can a function have **multiple return** statements?
    - How many of them will ever be reached during a particular invocation of the function?
- What happens to the **“control flow” of a program when we hit a return statement** inside a function frame (invocation of a function)
    - Is any code after a return that is reached executed?
- What happens to the **the function frame** (the state of the local variables inside it) **after we hit return**?
- How can a function **return a sequence of multiple values**?
- Is any information that was computed within a function, that is not returned, remembered?

Recall: Variable Scope

- **Local variables.** An assignment to a variable within a function definition creates/changes a local variable
- Local variables exist only within a functions body, and cannot be referred outside of it
- **Parameters** are also local variables that are assigned a value when the function is invoked

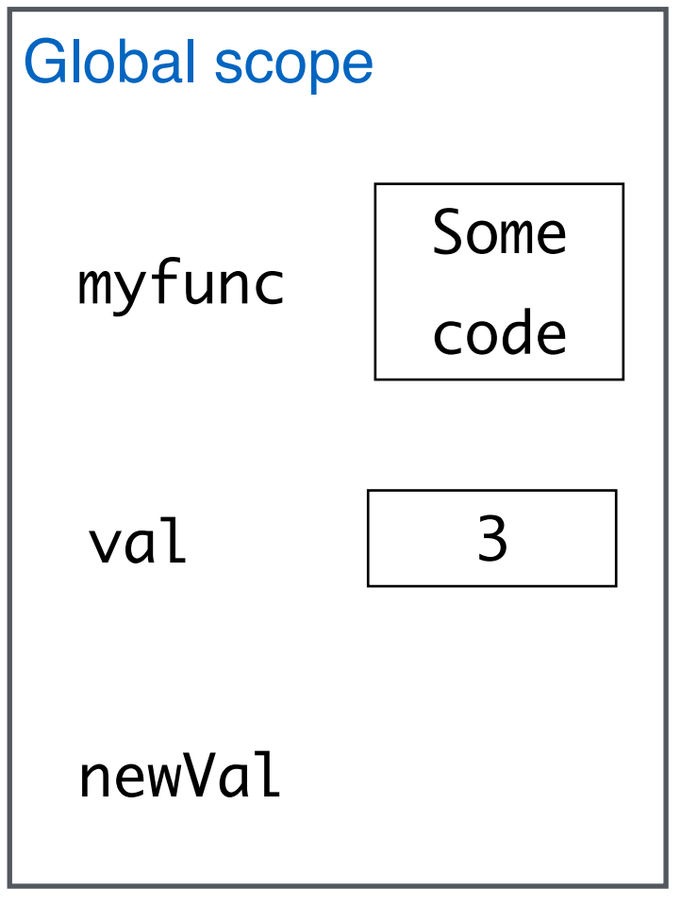
```
def square(num):
    return num*num
```

```
In [1] square (5)
Out [1] 25
In [2] num
NameError: name ‘num’ is not defined
```

Recall: Variable Scope

```
def myfunc (val):
    val = val + 1
    print('val = ', val)
    return val

val = 3
newVal = myfunc(val)
```



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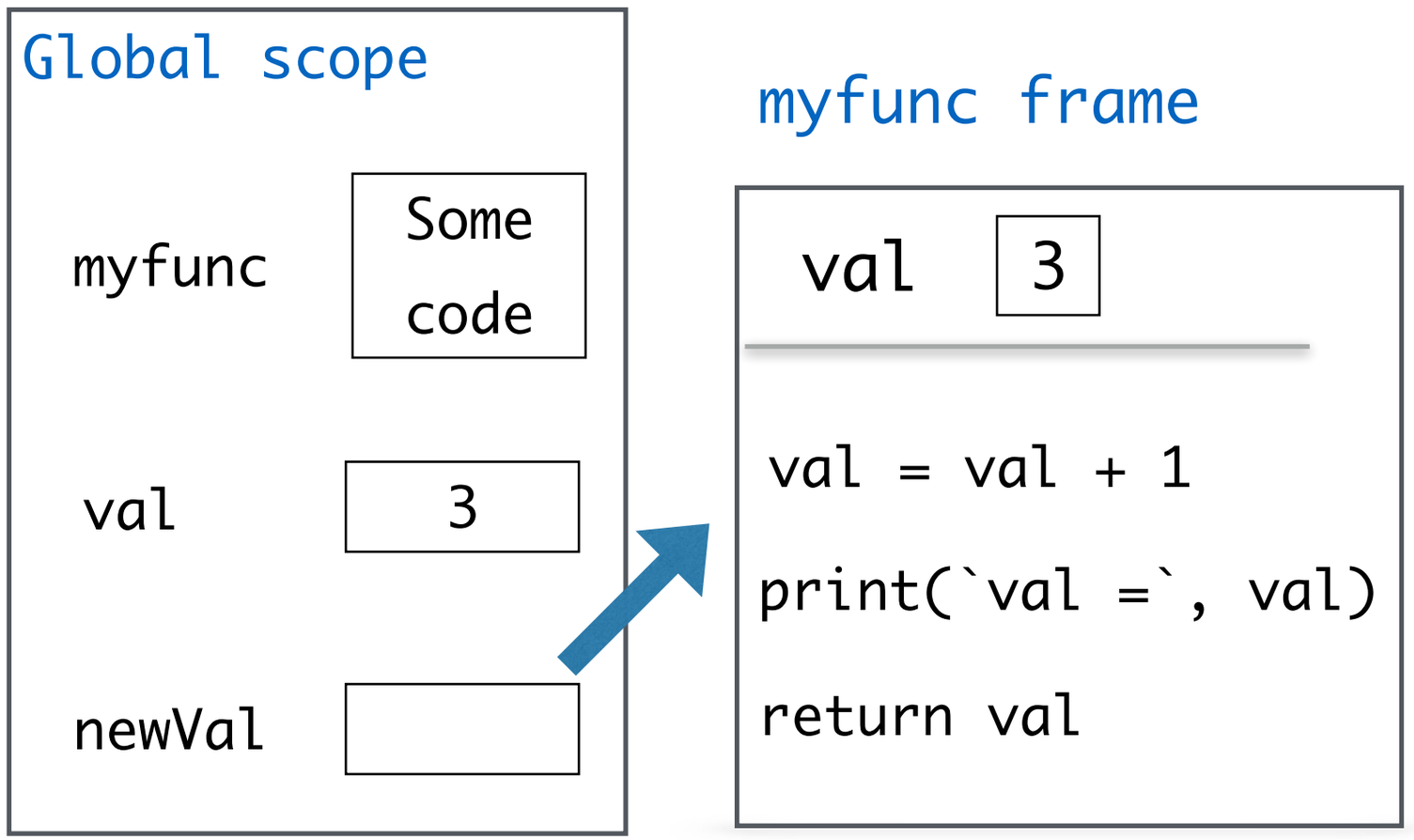

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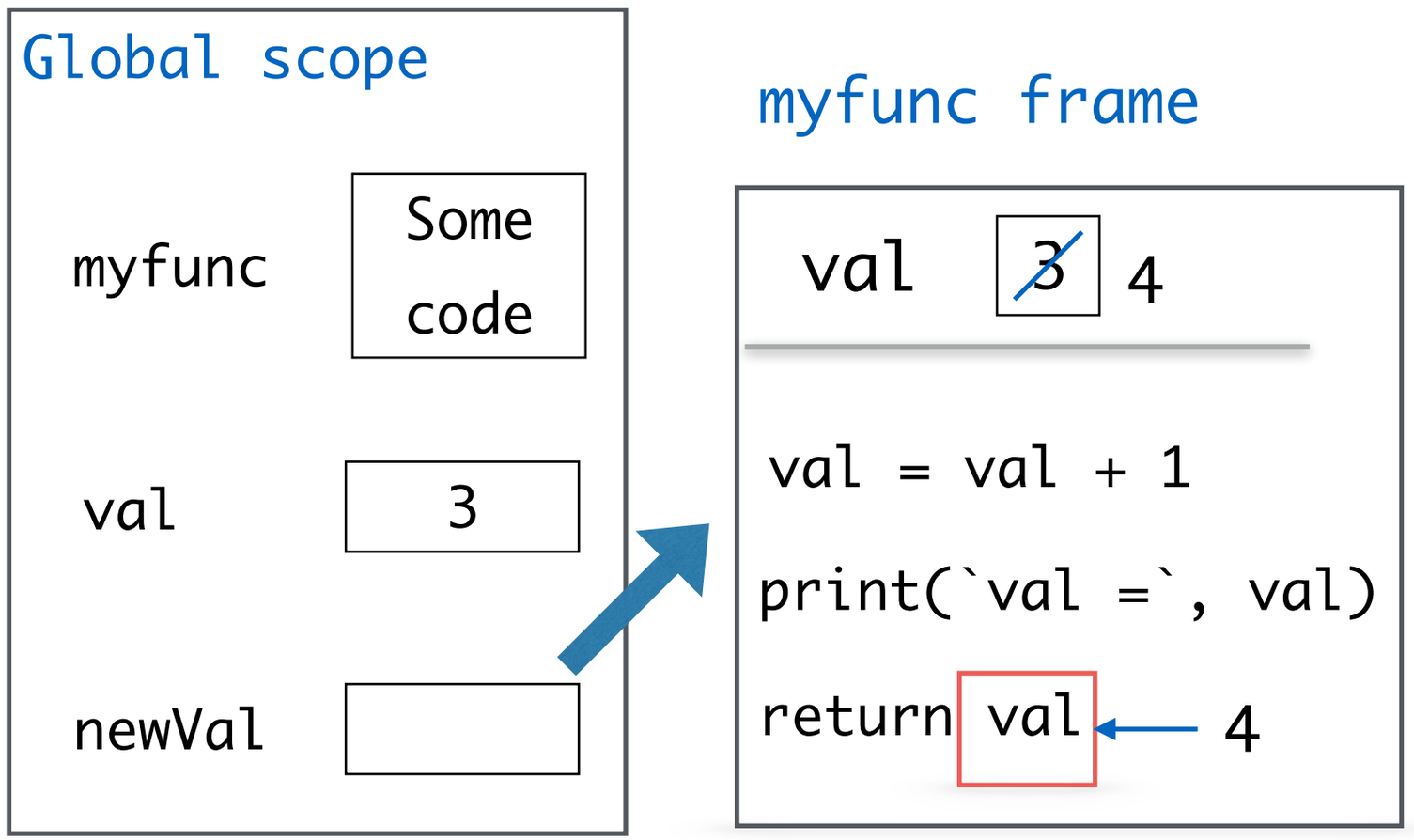
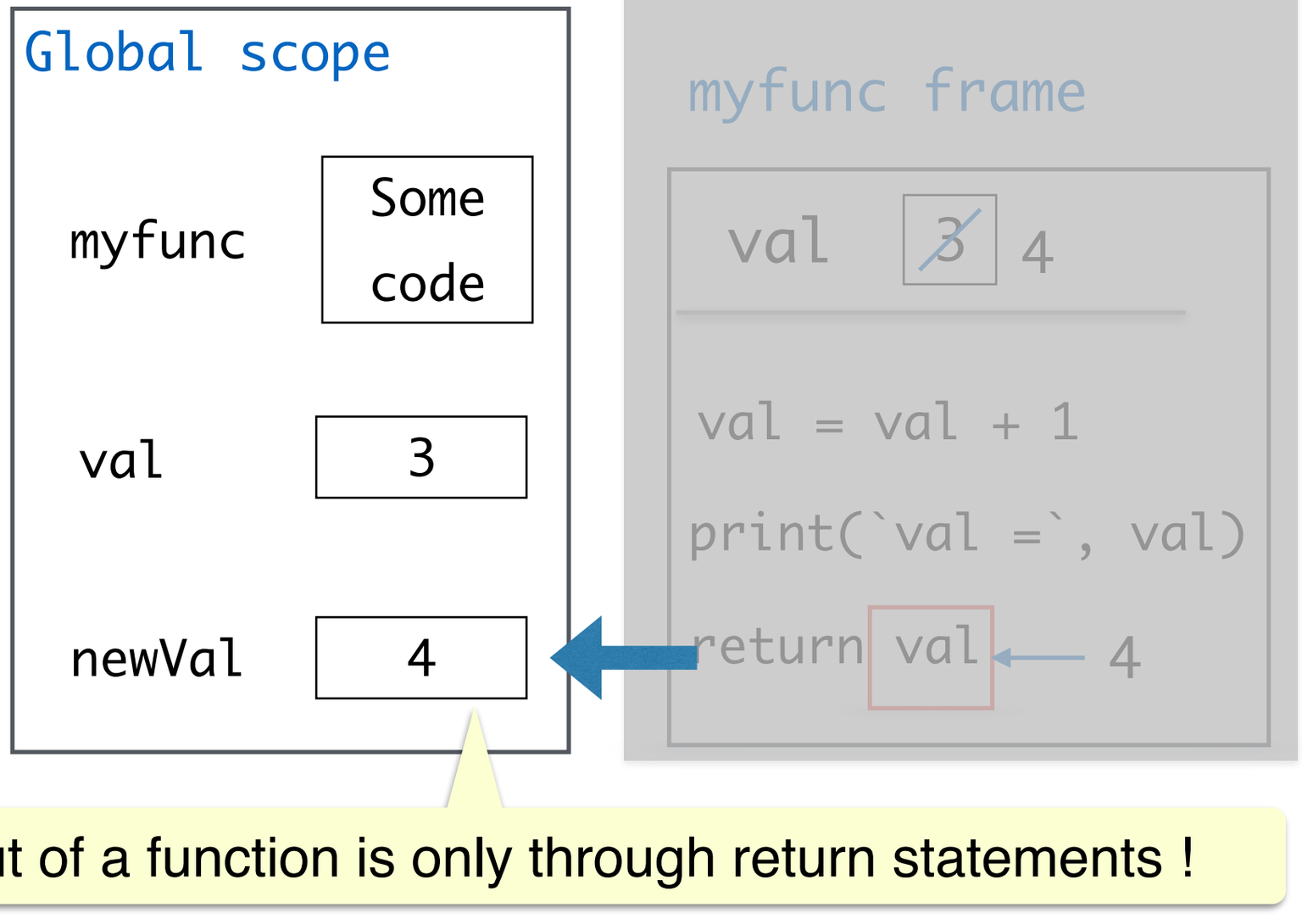


Recall: Variable Scope

```
def myfunc (val):
    val = val + 1
    print(`val =`, val)
    return val

val = 3
newVal = myfunc(val)
```

Function frame destroyed (and all local variables lost) after return from call



Information flow out of a function is only through return statements !

New Type of Functions with `Yield`

- A function that has a **`yield`** statement in it is called a **generator function**
- **`yield`** statement completely changes the behavior of the function

A generator function

```
def genF(num):
    yield num
```

```
>>> g = genF(10)
>>> g
<generator object genF at 0x10a55ac50>
```

Invoking a generator function creates a **generator object**

A "normal" function

```
def simpleF(num):
    return num
```

```
>>> f = simpleF(10)
>>> f
10
```

Invoking a regular (non-generator) function **returns the output**

Generator Functions

- `genF` does nothing other than `yield` the value that is passed as an argument. Invoking it like a "normal" function does not produce a returned value but results in a **generator object**
- If we call the `next()` method on the generator object `g`, it "yields" or "produces" a value. After it, the generator `g` is exhausted

A generator function

```
def genF(num):

    yield num
```

A "normal" function

```
def simpleF(num):

    return num
```

```
>>> g = genF(10)
>>> g
<generator object genF at 0x10a55ac50>
>>> next(g)
10
>>> next(g)
  File "<stdin>", line 1, in <module>
StopIteration
```

```
>>> f = simpleF(10)
>>> f
10
```

Calling next on it again throws a `StopIteration` exception

Understanding `Yield`

- If a `yield exp` statement is reached, the function's state is frozen, and the value of the expression `exp` is returned to the `.next()` call
- That is, all local state of variables is retained, and then function execution is "resumed" when `.next()` is invoked again, and the control flow proceeds exactly where it left off
- A function can contain multiple `yield` (along with `return`) statements

Yield vs Return

- **Similarity.** Both `yield` and `return` will return some value from a function to the caller
- **Difference:** while a return statement terminates the function entirely, the yield statement **pauses** the function (saving all its state) and later continues from there on successive calls

Mechanics of Generator Functions

- Generator function contains one or more **`yield`** statement
- When called returns an object (iterator) but does not start execution immediately
- When a generator function yields a value, it is paused and the control is transferred to the caller
- Local variables and their states are remembered between successive calls
- Finally, when the function terminates (either by reaching a return statement or reaching the end of function body), a **StopIteration** is raised automatically on further `.next()` calls
- Such exceptions are handled automatically if iterating over the generator object in a for loop

Generator Functions: Examples

In [1]:
```
def ourSecondGen():
    yield "a"
    yield "b"
    yield "c"
```

In [2]:
```
genObj = ourSecondGen()
```

In [3]:
```
next(genObj)
```

Out[3]: 'a'

In [4]:
```
next(genObj)
```

Out[4]: 'b'

In [5]:
```
next(ourSecondGen())  #predict the answer!
```

Out[5]: 'a'

In [6]:
```
next(ourSecondGen())
```

Out[6]: 'a'

Creates and calls `next()` on new generator object!

CountTo(n) : Three Versions!

```
In [7]: def countToPart1(n):
            i = 0
            while i <= n:
                print(i)
                i += 1

In [8]: countToPart1(6)

0
1
2
3
4
5
6
```

```
In [9]: def countToPart2(n):
            i = 0
            while i <= n:
                return i
                i += 1

In [10]: countToPart2(12)

Out[10]: 0
```

```
In [12]: def countToPart3(n):
             i = 1
             while i <= n:
                 yield i
                 i += 1

In [13]: gObj = countToPart3(6)

In [14]: gObj

Out[14]: <generator object countToPart3 at 0x10858f250>

In [15]: next(gObj)

Out[15]: 1

In [16]: next(gObj)

Out[16]: 2

In [17]: next(gObj)

Out[17]: 3

In [18]: next(gObj)

Out[18]: 4
```

Generating Infinite Sequences

In [7]:
```
def count(start = 0, step = 1): # optional parameters
    i = start
    while True: # read: forever!
        yield i
        print("Now incrementing i=", i)
        i += step
```

In [8]:
```
g = count()
```

In [9]:
```
next(g)
```

Out[9]: 0

In [10]:
```
next(g)
```

```
Now incrementing i= 0
```

Out[10]: 1

In [11]:
```
next(g)
```

```
Now incrementing i= 1
```

Out[11]: 2

In [12]:
```
next(g)
```

```
Now incrementing i= 2
```

Out[12]: 3

Can keep going on forever!

Fibonacci Sequence

- Can use generators to generate “infinite series” in **a lazy manner**
- For example, the **fibonacci sequence**
  - The fibonacci numbers F_n form a sequence, called the Fibonacci sequence, such that each number is the sum of the two preceding ones, starting from 0 and 1. That is,
    - $F_0 = 0$, $F_1 = 1$, and $F_n = F_{n-2} + F_{n-2}$ for all $n \geq 2$.
- Named after mathematician Pisa (later called Fibonacci), although it appears in early Indian mathematical texts
- These sequences occur in nature (such as the arrangement of leaves on a steam), the flowering of an artichoke, etc

Generator Function for Fibonacci

- Lets write a generator function that yields the next fibonacci number in the sequence when called

```
In [1]: def fibo(a = 0, b = 1):
            yield a
            yield b
            while True:
                a,b = b,a+b
                yield b
```

Optional parameters (by default first parameter `a` is `0`, second `b` is `1`)

Fibonacci sequence on demand

```
In [2]: fibN = fibo()

In [3]: next(fibN)
Out[3]: 0

In [4]: next(fibN)
Out[4]: 1

In [5]: next(fibN)
Out[5]: 1

In [6]: next(fibN)
Out[6]: 2

In [7]: next(fibN)
Out[7]: 3

In [8]: next(fibN)
Out[8]: 5
```

Acknowledgments

These slides have been adapted from:

- http://cs111.wellesley.edu/spring19 and
- https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-0001-introduction-to-computer-science-and-programming-in-python-fall-2016/