MASTER IN ENTREPRENEURSHIP INNOVATION MANAGEMENT IN COLLABORATION WITH MIT SLOAN

IN COLLABORATION WITH MIT MANAGEMENT SLOAN SCHOOL

UNIVERSITÀ DEGLI STUDI DI NAPOLI PARTHENOPE

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Python Programming Course Lesson 5

Funcitons and Data Structures

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OVERVIEW

- structuring programs and hiding details
- functions
- specifications
- keywords: `return` vs `print`
- scope

HOW DO WE WRITE CODE?

- so far…
  - covered language mechanisms
  - know how to write different files for each computation
  - each file is some piece of code
  - each code is a sequence of instructions
- problems with this approach
  - easy for small-scale problems
  - messy for larger problems
  - hard to keep track of details
  - how do you know the right info is supplied to the right part of code

GOOD PROGRAMMING

- more code not necessarily a good thing
- measure good programmers by the amount of functionality
- introduce **functions**
- mechanism to achieve **decomposition** and **abstraction**

EXAMPLE – PROJECTOR

- a projector is a black box
- don't know how it works
- know the interface: input/output
- connect any electronic to it that can communicate with that input
- black box somehow converts image from input source to a wall, magnifying it
- **ABSTRACTION IDEA**: do not need to know how projector works to use it

EXAMPLE – PROJECTOR

- projecting large image for Olympics decomposed into separate tasks for separate projectors
- each projector takes input and produces separate output
- all projectors work together to produce larger image
- **DECOMPOSITION IDEA**: different devices work together to achieve an end goal

…..APPLY THESE CONCEPTS TO PROGRAMMING!

Create Structures with DECOMPOSITION

- in projector example, separate devices
- in programming, divide code into **modules**
  - are **self-contained**
  - used to **break up** code
  - intended to be **reusable**
  - keep code **organized**
  - **keep code coherent**
- this lecture, achieve decomposition with **functions**
- in a few weeks, achieve decomposition with **classes**

Suppress Details with ABSTRACTION

- in projector example, instructions for how to use it are sufficient, no need to know how to build one
- in programming, think of a piece of code as a **black box**
  - cannot see details
  - do not need to see details
  - do not want to see details
  - hide tedious coding details
- achieve abstraction with **function specifications** or **docstrings**

FUNCTIONS

- write reusable pieces/chunks of code, called **functions**
- functions are not run in a program until they are "**called**" or "**invoked**" in a program
- function characteristics:
  - has a **name**
  - has **parameters** (0 or more)
  - has a **docstring** (optional but recommended)
  - has a **body**
  - **returns** something

HOW TO WRITE and CALL/INVOKE A FUNCTION

keyword

name

parameters or arguments

```
def is_even( i ):
```

specification, docstring

```
    """
    Input: i, a positive int
    Returns True if i is even, otherwise False
    """
```

body

```
    print("inside is_even")
    return i%2 == 0
```

```
is_even(3)
```

later in the code, you call the function using its name and values for parameters

IN THE FUNCTION BODY

```
def is_even( i ):
    """
    Input: i, a positive int
    Returns True if i is even, otherwise False
    """
    print("inside is_even")
    return i%2 == 0
```

run some commands

keyword

expression to evaluate and return

VARIABLE SCOPE

- **formal parameter** gets bound to the value of **actual parameter** when function is called
- new **scope/frame/environment** created when enter a function
- **scope** is mapping of names to objects

```
def f( x ):
    x = x + 1
    print('in f(x): x =', x)
    return x

x = 3
z = f( x )
```

formal parameter

Function definition

actual parameter

Main program code
* initializes a variable x
* makes a function call f(x)
* assigns return of function to variable z

VARIABLE SCOPE

```
def f( x ):
    x = x + 1
    print('in f(x): x =', x)
    return x

x = 3
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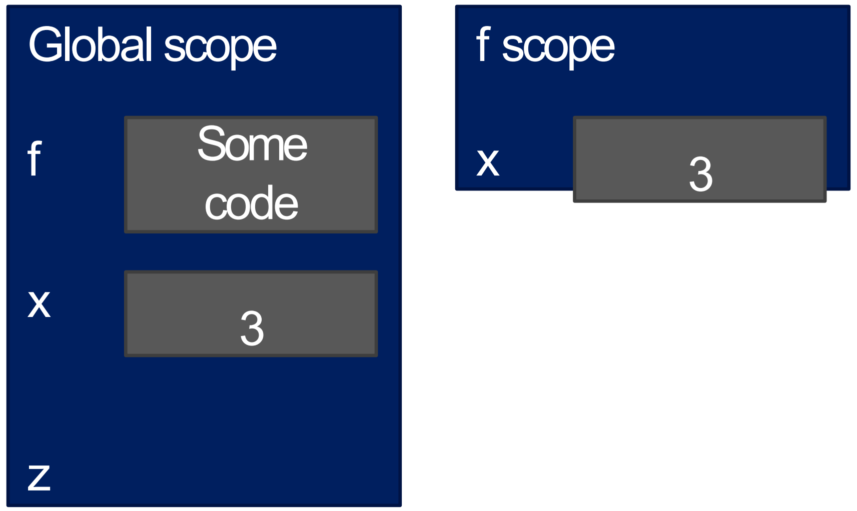
```



VARIABLE SCOPE

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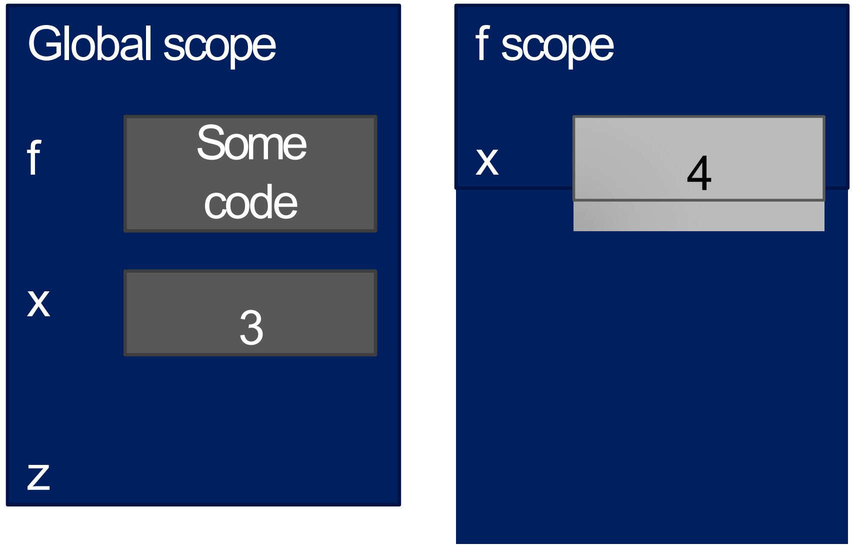

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x = 3
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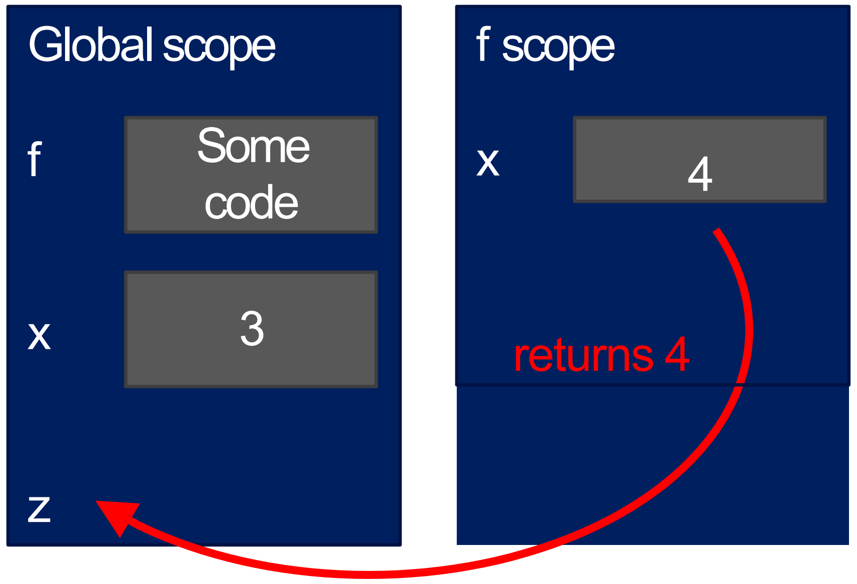

VARIABLE SCOPE

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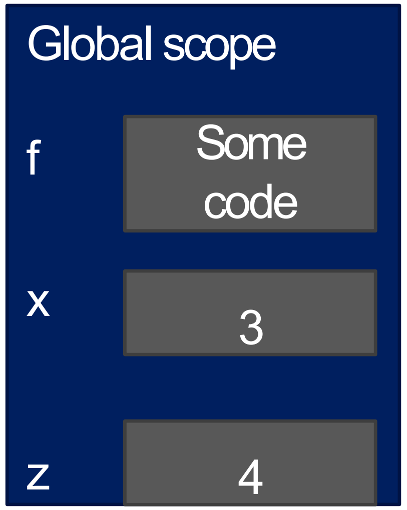

ONE WARNING IF NO `return` STATEMENT

```
def is_even( i ):
    """
    Input: i, a positive int
    Does not return anything
    """
    i%2 == 0
```

without a return statement

- Python returns the value **None, if no `return` given**
- represents the absence of a value

ONE WARNING IF NO `return` STATEMENT

```
def is_even( i ):
    """
    Input: i, a positive int
    Does not return anything
    """
    i%2 == 0
```

without a return statement

- Python returns the value **None, if no `return` given**
- represents the absence of a value

`return` vs `print`

- return only has meaning **inside** a function
- only **one** return executed inside a function
- code inside function but after return statement not executed
- has a value associated with it, **given to function caller**

- print can be used **outside**
- functions
- can execute **many** print statements inside a function
- code inside function can be executed after a print statement
- has a value associated with it, **outputted** to the console

FUNCTIONS AS ARGUMENTS

- arguments can take on any type, even functions

```
def func_a():
    print 'inside func_a'
def func_b(y):
    print 'inside func_b'
    return y
def func_c(z):
    print 'inside func_c'
    return z()
print func_a()
print 5 + func_b(2)
print func_c(func_a)
```

call `func_a`, takes no parameters

call `func_b`, takes one parameter

call `func_c`, takes one parameter, another function

FUNCTIONS AS ARGUMENTS

```
def func_a():
    print 'inside func_a'
def func_b(y):
    print 'inside func_b'
    return y
def func_c(z):
    print 'inside func_c'
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print func_a()
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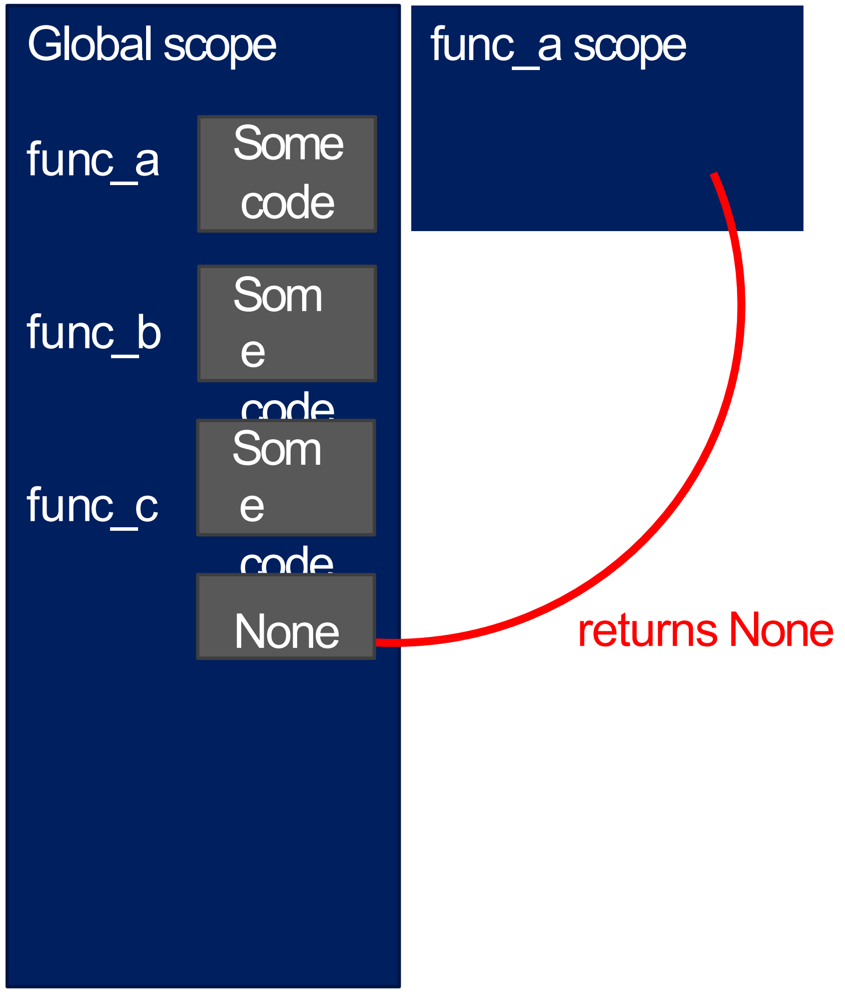
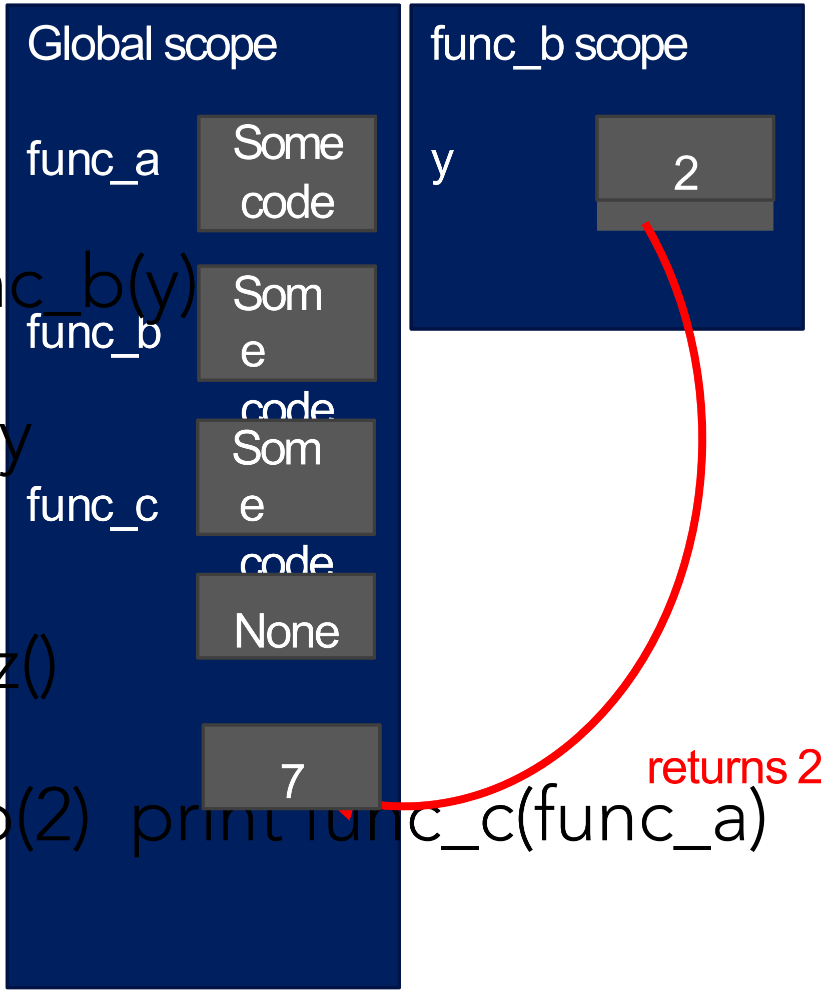
print func_c(func_a)
```



FUNCTIONS AS ARGUMENTS

- def func_a():
- print 'inside func_a' def func_b(y):
  - print 'inside func_b' return y
- def func_c(z):
  - print 'inside func_c' return z()
- print func_a() print 5 + func_b(2) print func_c(func_a)



FUNCTIONS AS ARGUMENTS

```
def func_a():
    print 'inside func_a'
def func_b(y):
    print 'inside func_b'
    return y
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    print 'inside func_c'
    return z()
print func_a()
print 5 + func_b(2)
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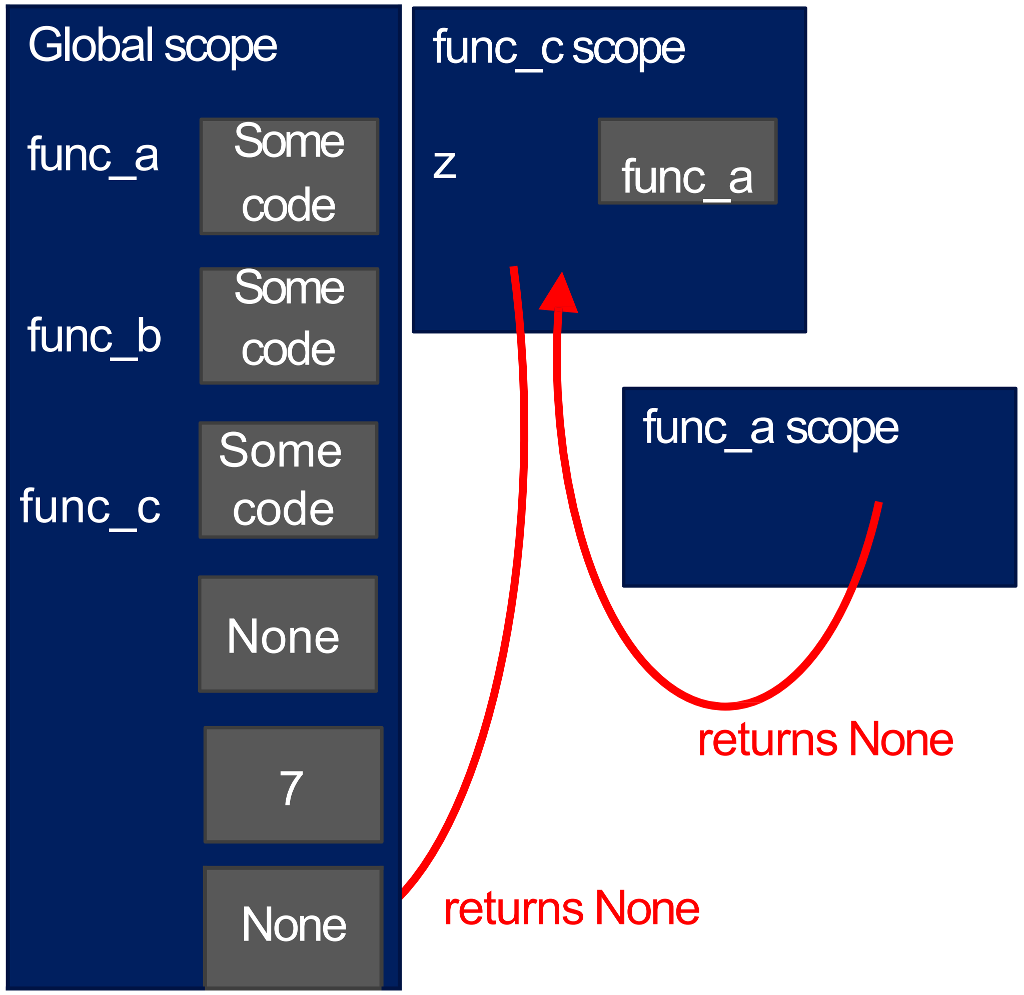
```



SCOPE EXAMPLE

- inside a function, **can access** a variable defined outside
- inside a function, **cannot modify** a variable defined outside -- can using **global variables**, but frowned upon

```
def f(y):
    x = 1
    x += 1
    print(x)

x = 5
f(x)
print(x)
```

x is re-defined in scope of f

different x objects

```
def g(y):
    print(x)
    print(x + 1)

x = 5
g(x)
print(x)
```

x from outside g

x inside g is picked up from scope that called function g

```
def h(y):
    x += 1

x = 5
h(x)
print(x)
```

UnboundLocalError: local variable 'x' referenced before assignment

SCOPE EXAMPLE

- inside a function, **can access** a variable defined outside
- inside a function, **cannot modify** a variable defined outside -- can using **global variables**, but frowned upon

```
def f(y):
    x = 1
    x += 1
    print(x)

x = 5
f(x)
print(x)
```

```
def g(y):
    print(x)


x = 5
g(x)
print(x)
```

```
def h(y):
    x += 1

x = 5
h(x)
print(x)
```

x from global/main program scope

HARDER SCOPE EXAMPLE

IMPORTANT and TRICKY!

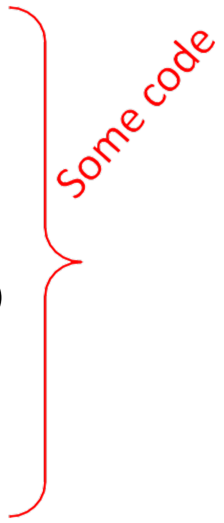
Python Tutor is your best friend to help sort this out!

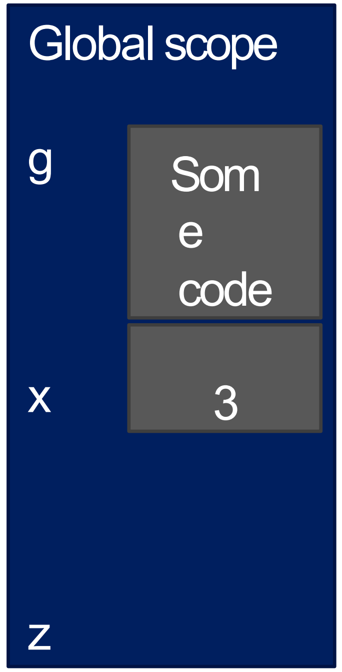
http://www.pythontutor.com/

SCOPE DETAILS

```
def g(x):
    def h():
        x = 'abc'
    x = x + 1
    print('g: x =', x)
    h()
    return x

x = 3
z = g(x)
```





SCOPE DETAILS

```
def g(x):
    def h():
        x = 'abc'
    x = x + 1
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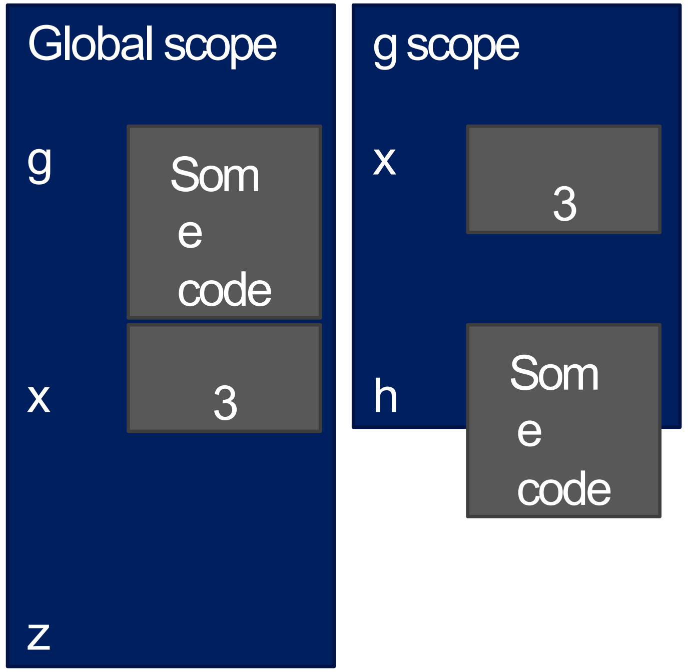

SCOPE DETAILS

```
def g(x):
    def h():
        x = 'abc'
    x = x + 1
    print('g: x =', x)
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    return x

x = 3
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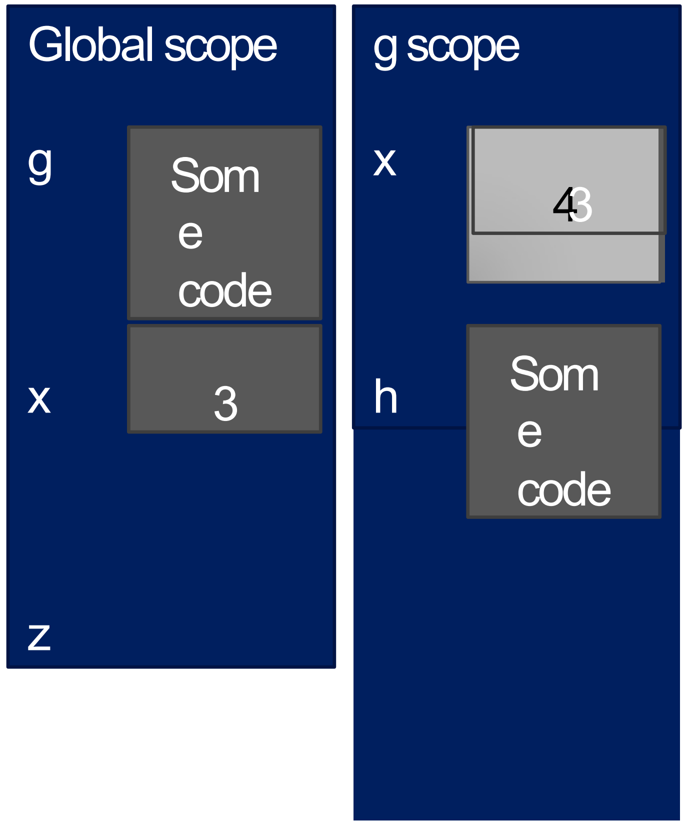
```



SCOPE DETAILS

```
def g(x):
    def h():
        x = 'abc'
    x = x + 1
    print('g: x =', x)
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x = 3
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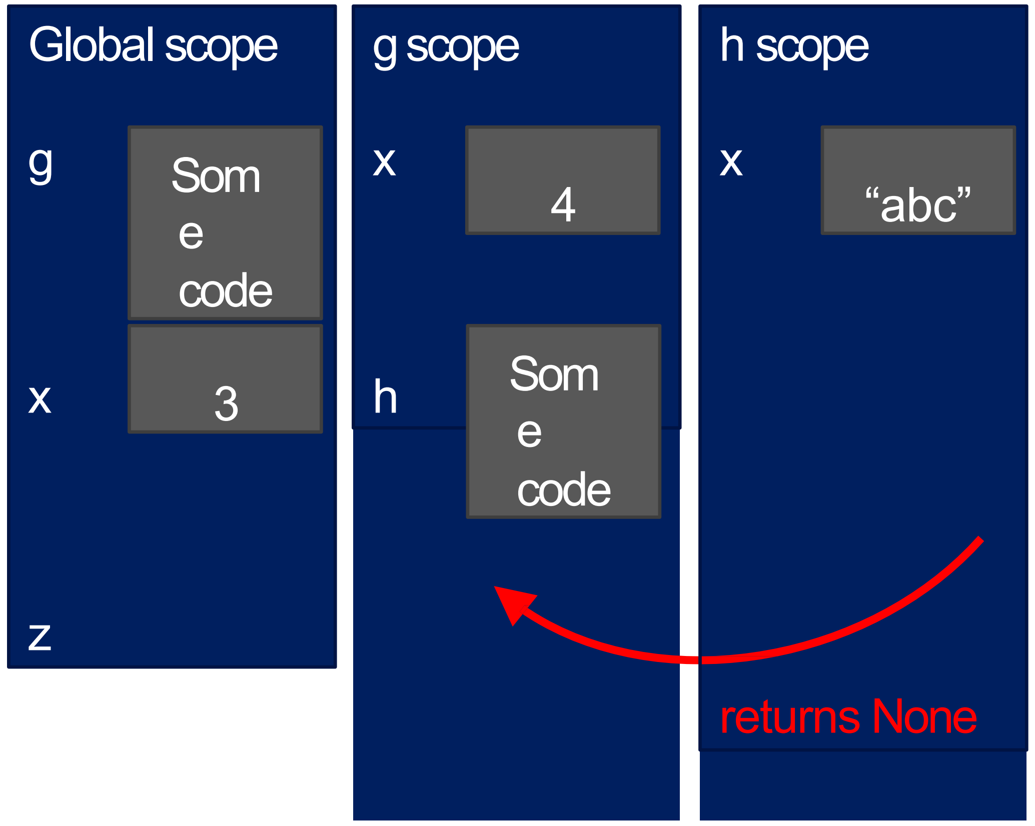
```



SCOPE DETAILS

```
def g(x):
    def h():
        x = 'abc'
    x = x + 1
    print('g: x =', x)
    h()
    return x

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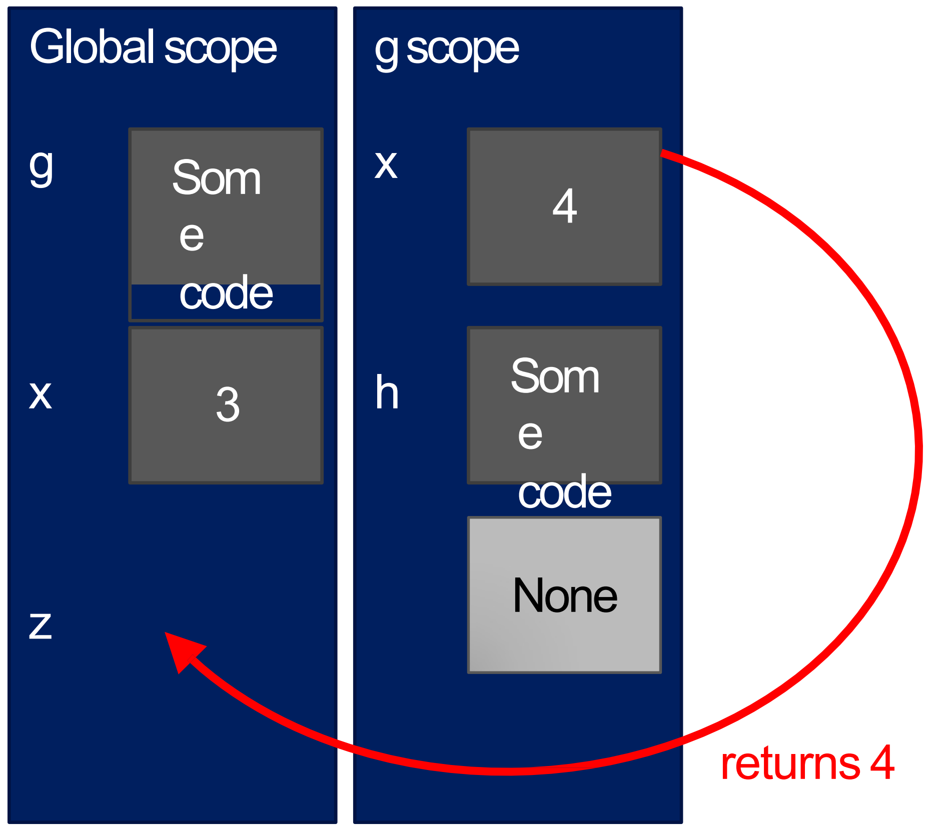
```



SCOPE DETAILS

```
def g(x):
    def h():
        x = 'abc'
    x = x + 1
    print('g: x =', x)
    h()
    return x

x = 3
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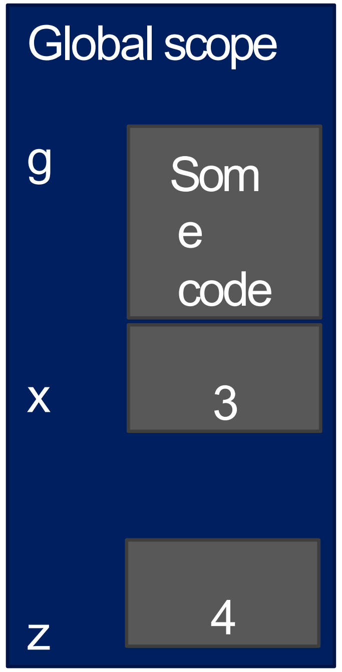
```



DECOMPOSITION & ABSTRACTION

- powerful together
- code can be used many times but only has to be debugged once!

Data Structures

OVERVIEW

- have seen variable types: `int`, `float`, `bool`, `string`
- introduce new **compound data types**
    - tuples
    - lists
- idea of aliasing
- idea of mutability
- idea of cloning

TUPLES

- an ordered sequence of elements, can mix element types
- cannot change element values, immutable
- represented with parentheses

remember strings?

```
te = ()
```

empty tuple

```
t = (2,"mit",3)
t[0]                     → evaluates to 2
(2,"mit",3) + (5,6)      → evaluates to (2,"mit",3,5,6)
t[1:2]       → slice tuple, evaluates to ("mit",)
t[1:3]       → slice tuple, evaluates to ("mit",3)
len(t)       → evaluates to 3
t[1] = 4     → gives error, can't modify object
```

extra comma means a tuple with one element

TUPLES

- conveniently used to **swap** variable values

```
x = y
y = x
```
✗

```
temp = x
x = y
y = temp
```
✓

```
(x, y) = (y, x)
```
✓

- used to **return more than one value** from a function

```
def quotient_and_remainder(x, y):
    q = x // y
    r = x % y
    return (q, r)
(quot, rem) = quotient_and_remainder(4,5)
```

integer division

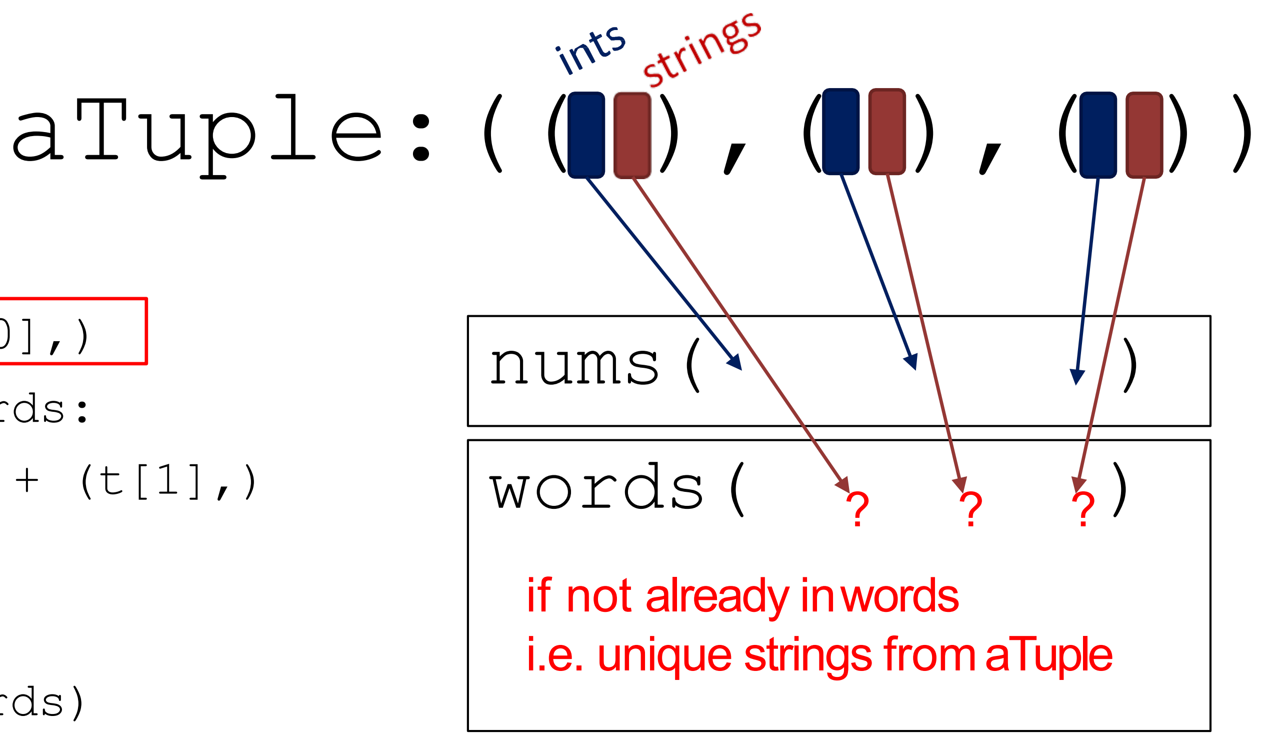
MANIPULATING TUPLES

- can **iterate** over tuples

```
def get_data(aTuple):
    nums = ()
    words = ()
    for t in aTuple:
        nums = nums + (t[0],)
        if t[1] not in words:
            words = words + (t[1],)
    min_n = min(nums)
    max_n = max(nums)
    unique_words = len(words)
    return (min_n, max_n, unique_words)
```

empty tuple

singleton tuple



LISTS

- **ordered sequence** of information, accessible by index
- a list is denoted by **square brackets**, `[ ]`
- a list contains **elements**
  - usually homogeneous (ie, all integers)
  - can contain mixed types (not common)
- list elements can be changed so a list is **mutable**

INDICES AND ORDERING

`a_list = []` empty list

`L = [2, 'a', 4, [1,2]]`

`len(L)` → evaluates to 4

`L[0]` → evaluates to 2

`L[2]+1` → evaluates to 5

`L[3]` → evaluates to `[1,2]`, another list!

`L[4]` → gives an error

`i = 2`

`L[i-1]` → evaluates to ‘a’ since `L[1]='a'` above

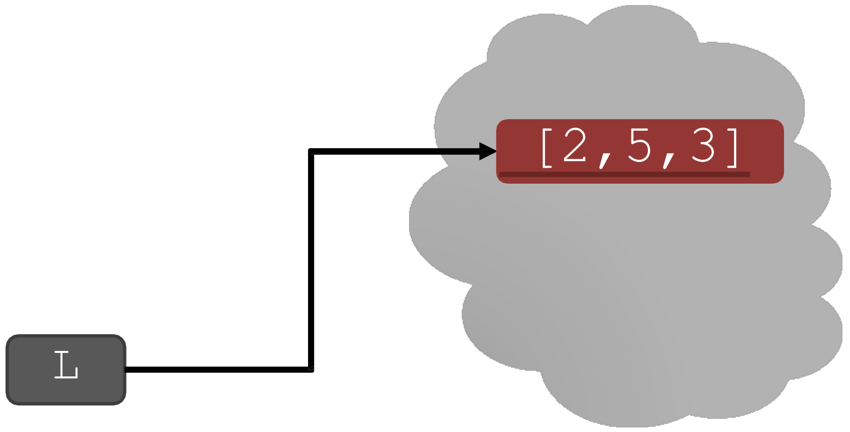
CHANGING ELEMENTS

- lists are **mutable**!
- assigning to an element at an index changes the value

```
L = [2, 1, 3]

L[1] = 5
```

- `L` is now `[2, 5, 3]`, note this is the **same object** `L`



ITERATING OVER A LIST

- compute the **sum of elements** of a list
- common pattern, iterate over list elements

```
total = 0
  for i in range(len(L)):
      total += L[i]
  print total
```

```
total = 0
  for i in L:
      total += i
  print total
```

like strings, can iterate over list elements directly

- notice
  - list elements are indexed `0` to `len(L)-1`
  - `range(n)` goes from `0` to `n-1`

OPERATIONS ON LISTS - ADD

- **add** elements to end of list with `L.append(element)`
- **mutates** the list!

```
L = [2,1,3]
L.append(5)
```

→ L is now `[2,1,3,5]`

- what is the dot?
  - lists are Python objects, everything in Python is an object
  - objects have data
  - objects have methods and functions
  - access this information by `object_name.do_something()`
  - will learn more about these later

OPERATIONS ON LISTS - ADD

- to combine lists together use **concatenation**, + operator, to give you a new list
- **mutate** list with `L.extend(some_list)`

```
L1 = [2,1,3]

L2 = [4,5,6]

L3 = L1 + L2
```

→ `L3` is `[2,1,3,4,5,6]`
`L1, L2` unchanged

```
L1.extend([0,6])
```

→ mutated `L1` to `[2,1,3,0,6]`

OPERATIONS ON LISTS- REMOVE

- delete element at a **specific index** with `del(L[index])`
- remove element at **end of list** with `L.pop()`, returns the removed element
- remove a **specific element** with `L.remove(element)`
  - looks for the element and removes it
  - if element occurs multiple times, removes first occurrence
  - if element not in list, gives an error

```
L = [2,1,3,6,3,7,0] # do below in order
L.remove(2)  → mutates L = [1,3,6,3,7,0]
L.remove(3)  → mutates L = [1,6,3,7,0]
del(L[1])    → mutates L = [1,3,7,0]
L.pop()      → returns 0 and mutates L = [1,3,7]
```

all these operations mutate the list

CONVERT LISTS TOSTRINGS AND BACK

- convert **string to list** with `list(s)`, returns a list with every character from `s` an element in `L`
- can use `s.split()`, to **split a string on a character** parameter, splits on spaces if called without a parameter
- use `''.join(L)` to turn a **list of characters into a string**, can give a character in quotes to add char between every element

```
s = "I<3 cs"          → s is a string
list(s)               → returns ['I','<','3',' ','c','s']
s.split('<')          → returns ['I', '3 cs']
L = ['a','b','c']     → L is a list
''.join(L)            → returns "abc"
'_'.join(L)           → returns "a_b_c"
```

OTHER LIST OPERATIONS

- sort() and sorted()
- reverse()
- and many more! https://docs.python.org/3/tutorial/datastructures.html

```
L=[9,6,0,3]
sorted(L)       → returns sorted list, does not mutate L
L.sort()        → mutates L=[0,3,6,9]
L.reverse()     → mutates L=[9,6,3,0]
```

LISTS IN MEMORY

- lists are **mutable**
- behave differently than immutable types
- is an object in memory
- variable name points to object
- any variable pointing to that object is affected
- key phrase to keep in mind when working with lists is **side effects**

AN ANALOGY

- attributes of a person
  - singer, rich
- he is known by many names
- all nicknames point to the **same person**
  - add new attribute to **one nickname**…

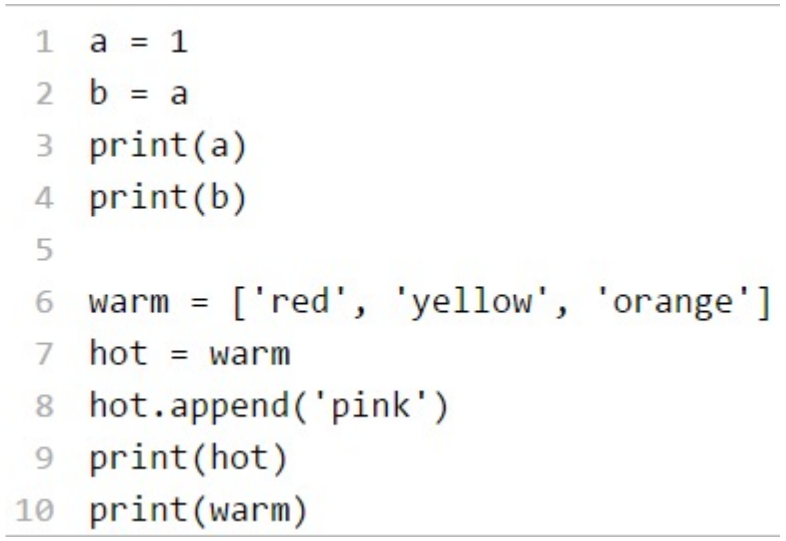
Justin Bieber	singer	rich	troublemaker

- …**all his nicknames** refer to old attributes AND all new ones

The Bieb	singer	rich	troublemaker
JBeebs	singer	rich	troublemaker

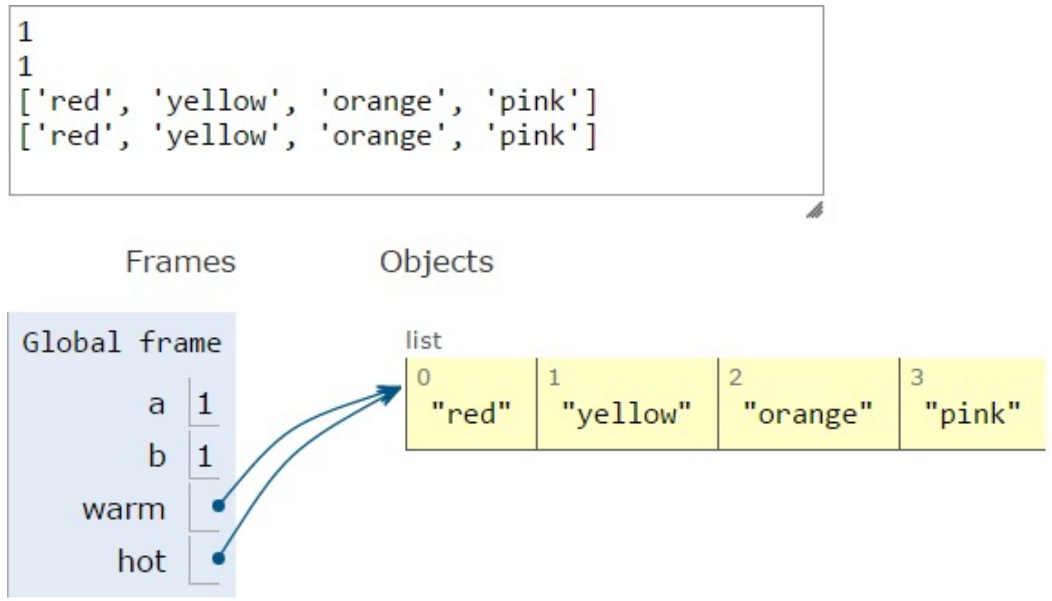
ALIASES

- `hot` is an **alias** for `warm` – changing one changes the other!
- `append()` has a side effect



```
a = 1
b = a
print(a)
print(b)

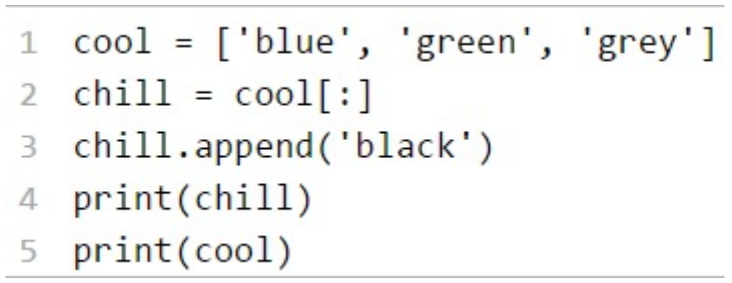
warm = ['red', 'yellow', 'orange']
hot = warm
hot.append('pink')
print(hot)
print(warm)
```



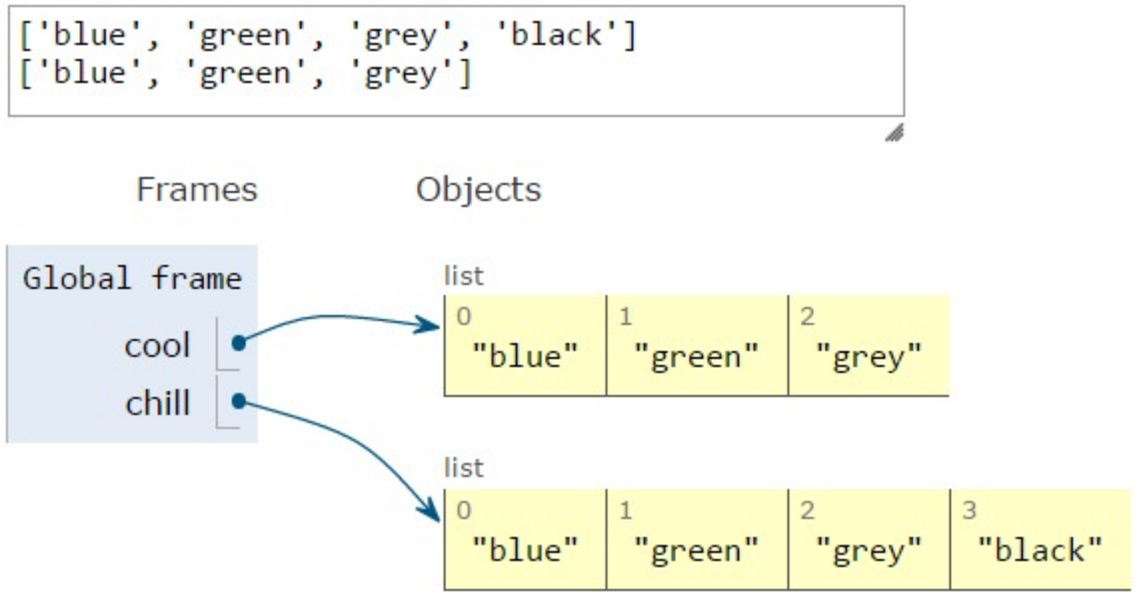
```
1
1
['red', 'yellow', 'orange', 'pink']
['red', 'yellow', 'orange', 'pink']
```

CLONING A LIST

- create a new list and **copy every element** using
  `chill = cool[:]`



```
cool = ['blue', 'green', 'grey']
chill = cool[:]
chill.append('black')
print(chill)
print(cool)
```



```
['blue', 'green', 'grey', 'black']
['blue', 'green', 'grey']
```

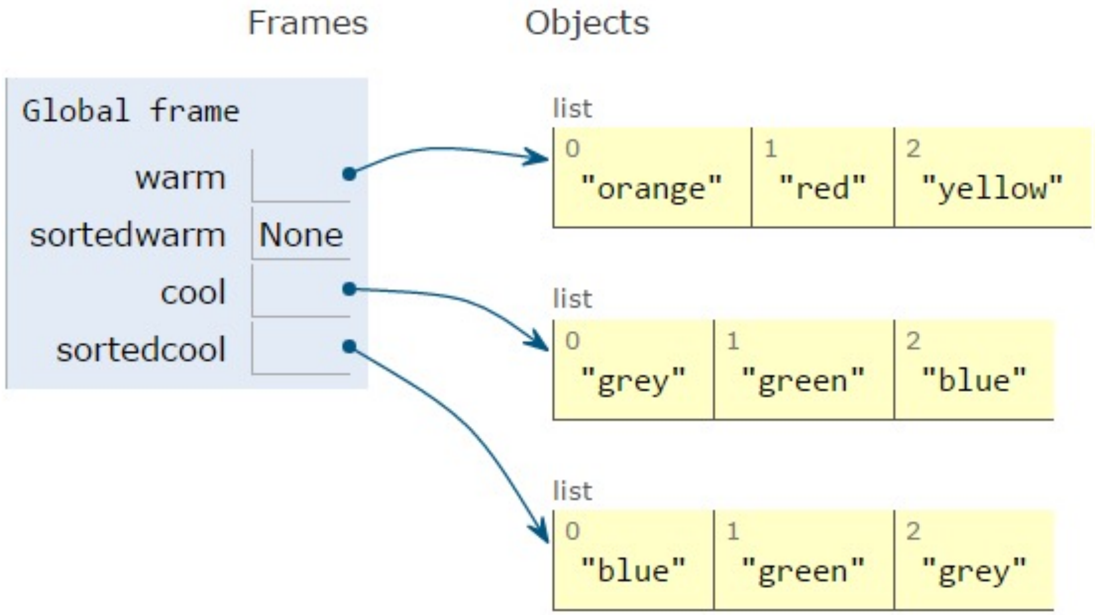
SORTING LISTS

- calling `sort()` **mutates** the list, returns nothing
- calling `sorted()` **does not mutate** list, must assign result to a variable

```
warm = ['red', 'yellow', 'orange']
sortedwarm = warm.sort()
print(warm)
print(sortedwarm)

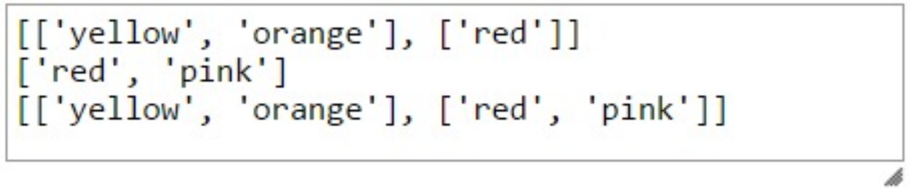
cool = ['grey', 'green', 'blue']
sortedcool = sorted(cool)
print(cool)
print(sortedcool)
```

```
['orange', 'red', 'yellow']
None
['grey', 'green', 'blue']
['blue', 'green', 'grey']
```

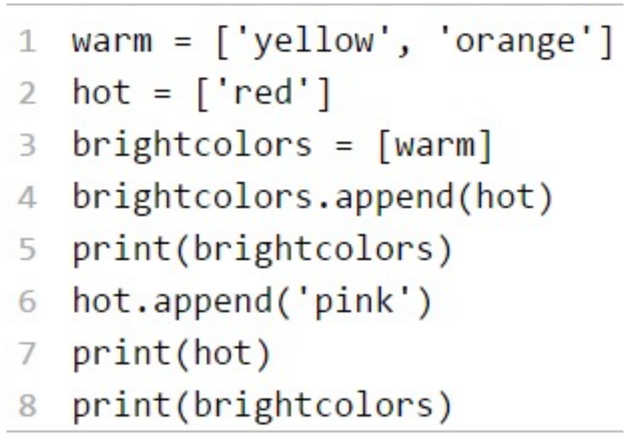


LIST OF LIST OF LIST OF…

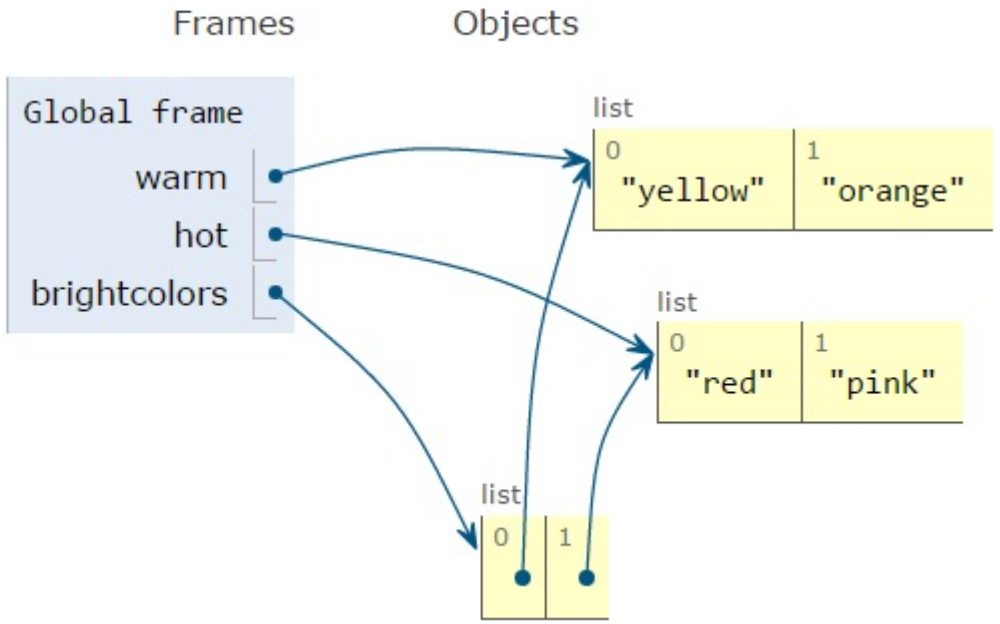
- can have **nested** lists
- side effects still possible after mutation



```
[['yellow', 'orange'], ['red']]
['red', 'pink']
[['yellow', 'orange'], ['red', 'pink']]
```



```
warm = ['yellow', 'orange']
hot = ['red']
brightcolors = [warm]
brightcolors.append(hot)
print(brightcolors)
hot.append('pink')
print(hot)
print(brightcolors)
```



MUTATION AND ITERATION

- avoid mutating a list as you are iterating over it

```
def remove_dups(L1, L2):
    for e in L1:
        if e in L2:
            L1.remove(e)
```

✗

```
def remove_dups(L1, L2):
    L1_copy = L1[:]
    for e in L1_copy:
        if e in L2:
            L1.remove(e)
```

✓

```
L1 = [1, 2, 3, 4]
L2 = [1, 2, 5, 6]
remove_dups(L1, L2)
```

clone list first, note that `L1_copy = L1` does NOT clone

- `L1` is `[2,3,4]` not `[3,4]` Why?
  - Python uses an internal counter to keep track of index it is in the loop
  - mutating changes the list length but Python doesn't update the counter
  - loop never sees element 2

Dictionaries

HOW TO STORE STUDENT INFO

- so far, can store using separate lists for every info

```
names = ['Ana', 'John', 'Denise', 'Katy']
grade = ['B', 'A+', 'A', 'A']
course = [2.00, 6.0001, 20.002, 9.01]
```

- a **separate list** for each item
- each list must have the **same length**
- info stored across lists at **same index**, each index refers to info for a different person

HOW TO UPDATE/RETRIEVE STUDENT INFO

```
def get_grade(student, name_list, grade_list, course_list):   i     =

name_list.index(student)

   grade = grade_list[i]

   course = course_list[i]  return (course, grade)
```

messy if have a lot of different info to keep track of

must maintain **many lists** and pass them as arguments

must **always index** using integers

must remember to change multiple lists

A BETTER AND CLEANER WAY – A DICTIONARY

- nice to **index item of interest directly** (not always int)
- nice to use **one data structure**, no separate lists

0	Elem 1
1	Elem 2
2	Elem 3
3	Elem 4
…	…
index	element

Key 1	Val 1
Key 2	Val 2
Key 3	Val 3
Key 4	Val 4
…	…
custom index by label	element

A PYTHON DICTIONARY

- store pairs of data
  - key
  - value

'Ana'	'B'
'Denise'	'A'
'John'	'A+'
'Katy'	'A'

custom index by label

element

empty dictionary

```
my_dict = {}

grades = {'Ana':'B', 'John':'A+', 'Denise':'A', 'Katy':'A'}
```

key1 val1 key2 val2 key3 val3 key4 val4

DICTIONARY LOOKUP

- similar to indexing into a list
- looks up the key
- returns the value associated with the key
- if key isn't found, get an error

'Ana'	'B'
'Denise'	'A'
'John'	'A+'
'Katy'	'A'

```
grades = {'Ana':'B', 'John':'A+', 'Denise':'A', 'Katy':'A'}
grades['John']         → evaluates to 'A+'
grades['Sylvan']       → gives a KeyError
```

DICTIONARY OPERATIONS

```
grades = {'Ana':'B', 'John':'A+', 'Denise':'A', 'Katy':'A'}
```

- **add** an entry

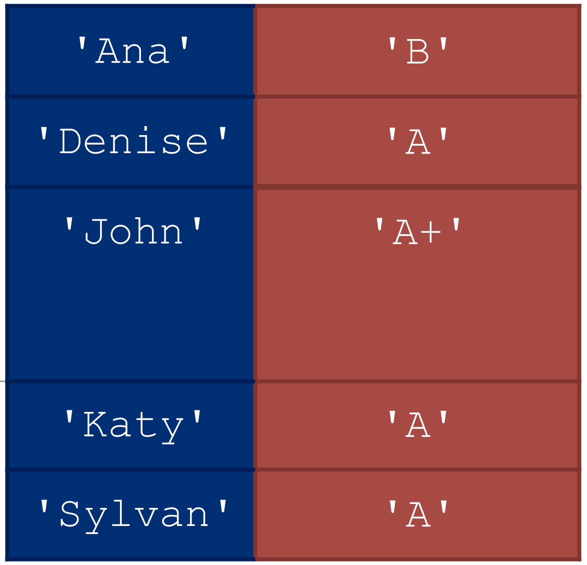
```
grades['Sylvan'] = 'A'
```

- **test** if key in dictionary

```
'John' in grades      → returns True
'Daniel' in grades    → returns False
```

- **delete** entry

```
del(grades['Ana'])
```



'Ana'	'B'
'Denise'	'A'
'John'	'A+'
'Katy'	'A'
'Sylvan'	'A'

DICTIONARY OPERATIONS

```
grades = {'Ana':'B', 'John':'A+', 'Denise':'A', 'Katy':'A'}
```

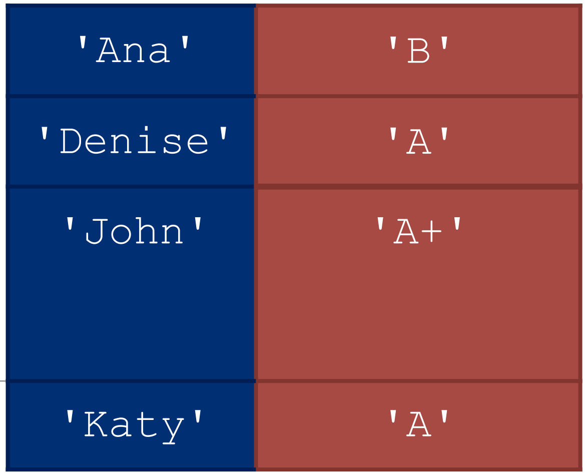
- get an **iterable that acts like a tuple of all keys** no guaranteed order

  `grades.keys()` → returns `['Denise','Katy','John','Ana']`

- get an **iterable that acts like a tuple of all values**

  `grades.values()` → returns `['A', 'A', 'A+', 'B']`

  no guaranteed order



'Ana'	'B'
'Denise'	'A'
'John'	'A+'
'Katy'	'A'

DICTIONARY KEYS and VALUES

- values
  - any type (**immutable and mutable**)
  - can be **duplicates**
  - dictionary values can be lists, even other dictionaries!
- keys
  - must be **unique**
  - **immutable** type (`int`, `float`, `string`, `tuple`, `bool`)
    - actually need an object that is **hashable,** but think of as immutable as all immutable types are hashable
  - careful with `float` type as a key
- **no order** to keys or values!

```
d = {4:{1:0}, (1,3):"twelve",
'const':[3.14,2.7,8.44]}
```

`list` vs `dict`

- **ordered** sequence of elements
- look up elements by an integer index
- indices have an **order**
- index is an **integer**

- **matches** "keys" to "values"
- look up one item by another item
- **no order** is guaranteed
- key can be any **immutable** type

EXAMPLE: 3 FUNCTIONS TO ANALYZE SONG LYRICS

1) create a **frequency dictionary** mapping `str:int`
2) find **word that occurs the most** and how many times
   - use a list, in case there is more than one word
   - return a tuple `(list,int)` for (words_list, highest_freq)
3) find the **words that occur at least X times**
   - let user choose "at least X times", so allow as parameter
   - return a list of tuples, each tuple is a `(list, int)` containing the list of words ordered by their frequency
   - IDEA: From song dictionary, find most frequent word. Delete most common word. Repeat. It works because you are mutating the song dictionary.

CREATING A DICTIONARY

```
def lyrics_to_frequencies(lyrics):
    myDict = {}
    for word in lyrics:
        if word in myDict:
            myDict[word] += 1
        else:
            myDict[word] = 1
    return myDict
```

can iterate over list

can iterate over keys in dictionary

update value associated with key

USING THE DICTIONARY

```
def most_common_words(freqs):
    values = freqs.values()
    best = max(values)
    words = []
    for k in freqs:
        if freqs[k] == best:
            words.append(k)
    return (words, best)
```

this is an iterable, so can apply built-in function

can iterate over keys in dictionary

LEVERAGING DICTIONARY PROPERTIES

```
def words_often(freqs, minTimes):
    result = []
    done = False
    while not done:
        temp = most_common_words(freqs)
        if temp[1] >= minTimes:
            result.append(temp)
            for w in temp[0]:
                del(freqs[w])
        else:
            done = True
    return result


print(words_often(beatles, 5))
```

can directly mutate dictionary; makes it easier to iterate

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Thank you for your attention