Comprehension

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Comprehension

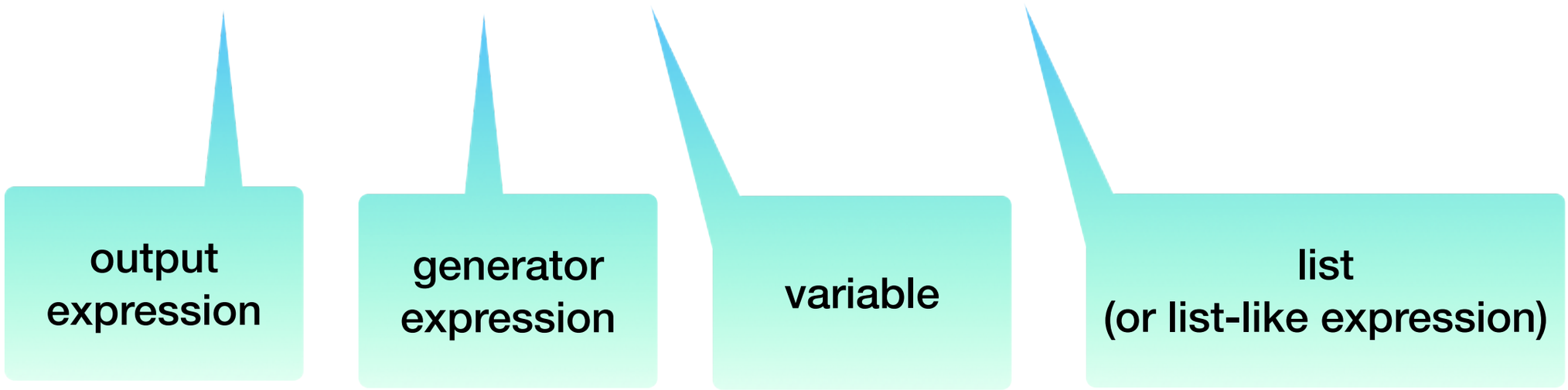
- List comprehension is used in functional programming but it becomes handy
  - We define a list with a for clause within the brackets that define the list.
- Here are two ways to construct a list consisting of squares

```
lista = []
for i in range(100):
    lista.append(i**2)
```

```
lista = [i**2 for i in range(100)]
```

Comprehension

```
[x**2 for x in range(100)]
```



Self Test

- The following code fragment defines a list of elements
- Use list comprehension in order to generate the same list
- Use the interactive window in IDLE

```
>>> lista = []
>>> for i in range(10):
        lista.append(i**3-i**2+i-1)


>>> lista
[-1, 0, 5, 20, 51, 104, 185, 300, 455, 656]
```

Self Test Solution

```
>>> lista = [i**3-i**2+i-1 for i in range(10)]
>>> lista
[-1, 0, 5, 20, 51, 104, 185, 300, 455, 656]
```

Comprehension

- List comprehension can add an if-condition
  - Result is now all even squares.

```
[x**2 for x in range(100) if x%2 == 0 ]
```

Comprehension

- List comprehension can be quite involved
  - Remember that we can check for types of variables
  - We use the built-in function `isinstance( )`
  - Example: `isinstance(345, int)` is True
  - Application to list comprehension: Squaring the elements of a list (a_list) that are integers

```
>>> a_list = [1, "4", 9, "a", 0, 4]
>>> [e**2 for e in a_list if isinstance(e, int)]
[1, 81, 0, 16]
```

Comprehension

- We can nest comprehensions
- A list of all composite numbers between 2 and 100.
  - A composite number is a product of two integers *i* and *j* that are larger than 1.

```
[i*j for i in range(2,51) for j in range(2,101) if i*j < 100]
```

- However, the result contains many repeated numbers

```
[4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66,
68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51,
54, 57, 60, 63, 66, 69, 72, 75, 78, 81, 84, 87, 90, 93, 96, 99, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68,
72, 76, 80, 84, 88, 92, 96, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 12, 18, 24, 30, 36, 42,
48, 54, 60, 66, 72, 78, 84, 90, 96, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 84, 91, 98, 16, 24, 32, 40, 48, 56, 64, 72, 80,
88, 96, 18, 27, 36, 45, 54, 63, 72, 81, 90, 99, 20, 30, 40, 50, 60, 70, 80, 90, 22, 33, 44, 55, 66, 77, 88, 99, 24, 36, 48,
60, 72, 84, 96, 26, 39, 52, 65, 78, 91, 28, 42, 56, 70, 84, 98, 30, 45, 60, 75, 90, 32, 48, 64, 80, 96, 34, 51, 68, 85, 36,
54, 72, 90, 38, 57, 76, 95, 40, 60, 80, 42, 63, 84, 44, 66, 88, 46, 69, 92, 48, 72, 96, 50, 75, 52, 78, 54, 81, 56, 84, 58,
87, 60, 90, 62, 93, 64, 96, 66, 99, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98]
```

Comprehensions

- Luckily, we can use a set instead:

```
{i*j for i in range(2,51) for j in range(2,51) if i*j < 100}
```

- The difference is just curly brackets instead of rectangular brackets
- The result is now simpler:

```
{4, 6, 8, 9, 10, 12, 14, 15, 16, 18, 20, 21, 22, 24, 25,
26, 27, 28, 30, 32, 33, 34, 35, 36, 38, 39, 40, 42, 44,
45, 46, 48, 49, 50, 51, 52, 54, 55, 56, 57, 58, 60, 62,
63, 64, 65, 66, 68, 69, 70, 72, 74, 75, 76, 77, 78, 80,
81, 82, 84, 85, 86, 87, 88, 90, 91, 92, 93, 94, 95, 96,
98, 99}
```

Comprehensions

- We can now get all of the prime numbers between 2 and 100 by using this set, using comprehension on top of comprehension

```
{i for i in range(2,100) if i not in
{i*j for i in range(2,51) for j in range(2,51) if i*j < 100}}
```

- This is cool but will not win any price for clarity
- You can make it more comprehensible if you define a set of composite numbers before using it

Self Test

- Use the previous example to generate a set of all numbers between 1 and 100 (included) that are **not** squares

Self Test Solution

```
seta = {i for i in range(1,101) if i not in {i*i for i in range(11)}}
```

Comprehensions

- You can also use comprehension on dictionaries
- Here is how you create a dictionary that associates integers up to 100*100 to their square root
  - `{i*i: i  for i in range(101)}`

```
>>> {i*i: i for i in range(101)}
{0: 0, 1: 1, 4: 2, 9: 3, 16: 4, 25: 5, 36: 6, 49: 7, 64: 8, 81: 9, 100: 10, 121:
 11, 144: 12, 169: 13, 196: 14, 225: 15, 256: 16, 289: 17, 324: 18, 361: 19, 400
: 20, 441: 21, 484: 22, 529: 23, 576: 24, 625: 25, 676: 26, 729: 27, 784: 28, 84
1: 29, 900: 30, 961: 31, 1024: 32, 1089: 33, 1156: 34, 1225: 35, 1296: 36, 1369:
 37, 1444: 38, 1521: 39, 1600: 40, 1681: 41, 1764: 42, 1849: 43, 1936: 44, 2025:
 45, 2116: 46, 2209: 47, 2304: 48, 2401: 49, 2500: 50, 2601: 51, 2704: 52, 2809:
 53, 2916: 54, 3025: 55, 3136: 56, 3249: 57, 3364: 58, 3481: 59, 3600: 60, 3721:
 61, 3844: 62, 3969: 63, 4096: 64, 4225: 65, 4356: 66, 4489: 67, 4624: 68, 4761:
 69, 4900: 70, 5041: 71, 5184: 72, 5329: 73, 5476: 74, 5625: 75, 5776: 76, 5929:
 77, 6084: 78, 6241: 79, 6400: 80, 6561: 81, 6724: 82, 6889: 83, 7056: 84, 7225:
 85, 7396: 86, 7569: 87, 7744: 88, 7921: 89, 8100: 90, 8281: 91, 8464: 92, 8649:
 93, 8836: 94, 9025: 95, 9216: 96, 9409: 97, 9604: 98, 9801: 99, 10000: 100}
```

Comprehensions

- And here is how you can try to “invert” a dictionary where the roles of keys and values are swapped

```
drev = {d[key]:key for key in d}
```

- This one works well, because the values are different for different keys

```
>>> d = {1:4, 2:5, 3:7, 4:8, 5:9}
>>> {d[key]:key for key in d}
{4: 1, 5: 2, 7: 3, 8: 4, 9: 5}
```

- And this one inverts with some arbitrariness

```
>>> d = {1:4, 2:5, 3:4, 4:5, 6:7, 7:6}
>>> {d[key]:key for key in d}
{4: 3, 5: 4, 7: 6, 6: 7}
```

Self Test

- You are given a function `func` that takes one integer argument
- You want to create a memoization dictionary that associates `i` for `i` in `range(100)` with `func(i)`

Self Test Answer

```
mem_func = {i: func(i) for i in range(101)}
```

```
func = lambda x: 3*x+4
```

gives

```
>>> func = lambda x: 3*x+4
>>> mem = {x: func(x) for x in range(101)}
>>> mem
{0: 4, 1: 7, 2: 10, 3: 13, 4: 16, 5: 19, 6: 22, 7: 25, 8: 28, 9: 31, 10: 34, 11:
 37, 12: 40, 13: 43, 14: 46, 15: 49, 16: 52, 17: 55, 18: 58, 19: 61, 20: 64, 21:
 67, 22: 70, 23: 73, 24: 76, 25: 79, 26: 82, 27: 85, 28: 88, 29: 91, 30: 94, 31:
 97, 32: 100, 33: 103, 34: 106, 35: 109, 36: 112, 37: 115, 38: 118, 39: 121, 40:
 124, 41: 127, 42: 130, 43: 133, 44: 136, 45: 139, 46: 142, 47: 145, 48: 148, 49
: 151, 50: 154, 51: 157, 52: 160, 53: 163, 54: 166, 55: 169, 56: 172, 57: 175, 5
8: 178, 59: 181, 60: 184, 61: 187, 62: 190, 63: 193, 64: 196, 65: 199, 66: 202,
67: 205, 68: 208, 69: 211, 70: 214, 71: 217, 72: 220, 73: 223, 74: 226, 75: 229,
 76: 232, 77: 235, 78: 238, 79: 241, 80: 244, 81: 247, 82: 250, 83: 253, 84: 256
, 85: 259, 86: 262, 87: 265, 88: 268, 89: 271, 90: 274, 91: 277, 92: 280, 93: 28
3, 94: 286, 95: 289, 96: 292, 97: 295, 98: 298, 99: 301, 100: 304}
```

Map, Filter

Map

- Map allows you to apply a function to all elements of a list
- Example:

```
func = lambda x: x+3
list(map(func, [2,3,4])
```

- Why the list? map returns an iterator (so that it does not waste memory on values that are not used)

```
>>> func = lambda x: x+3
>>> list(map(func, [2,3,4]))
[5, 6, 7]
```

Filter

- You filter a list by applying a condition
- The result is the list formed by all elements that satisfy the condition
    - You need to have a boolean function, i.e. a function that returns True or False
    - Here is an example of such a function:

```
lambda x: x%2==0
```

    - Returns True if x is divisible by 2
    - Returns False otherwise
    - x%2 is zero if and only if x is even

Filter

- The function `filter(function, sequence)` return an iterable of all elements in the sequence t that render the function True.

```
>>> fibonacci = [0, 1, 1, 2, 3, 5, 8, 13, 21, 44, 65, 109, 174, 283]
>>> list(filter(lambda x: x%2==0, fibonacci))
[0, 2, 8, 44, 174]
>>> list(filter(lambda x: x%2==1, fibonacci))
[1, 1, 3, 5, 13, 21, 65, 109, 283]
```

Comprehension in Action

Python

Getting the listing of a directory

- Task: Generate a listing of all files in a directory that end in ".py"
  - Tool: import the os module and use listdir

```
[filename for filename in os.listdir(directoryname)
     if filename.endswith(".py")]
```

Creating sub-directories

- Task: We want to create a sub-dictionary of a dictionary where the keys are restricted by a condition
  - Use dictionary comprehension

```
def evenkeys(dictionary):
    return { i:dictionary[i] for i in dictionary if i%2==0}
```

Filtering a list

- We want to filter a list using a criterion

  1. We can use the filter function

  2. We can use list comprehension, which is often simpler

- Example: Only display the positive elements of this large list

```
>>> rlist
[20, -1, 3, 0, 17, 1, 20, 19, 24, 4, 21, 0, 4, 7, 20, 2, 1, 13, 0, 21, 23, 6, 2,
 22, 4, 3, 6, 2, 13, -5, 3, 13, 20, 23, 14, 13, 13, 20, 10, 24, 9, -1, -4, 22, 1
5, 21, 18, -1, 16, 13, 1, 3, 12, 21, 0, 9, 4, 24, -3, 4, 10, 8, 1, 19, 3, 20, 4,
 5, 25, 8, 8, 14, -5, 23, 24, 14, 1, 0, -5, -3, 3, -4, 11, 1, 8, 17, 2, 2, 23, 6
, 2, 25, 15, 4, 23, 20, 5, -3, 11, 16]
>>> list(filter(lambda x: x>0, rlist))
[20, 3, 17, 1, 20, 19, 24, 4, 21, 4, 7, 20, 2, 1, 13, 21, 23, 6, 2, 22, 4, 3, 6,
 2, 13, 3, 13, 20, 23, 14, 13, 13, 20, 10, 24, 9, 22, 15, 21, 18, 16, 13, 1, 3,
12, 21, 9, 4, 24, 4, 10, 8, 1, 19, 3, 20, 4, 5, 25, 8, 8, 14, 23, 24, 14, 1, 3,
11, 1, 8, 17, 2, 2, 23, 6, 2, 25, 15, 4, 23, 20, 5, 11, 16]
>>> [x for x in rlist if x>0]
[20, 3, 17, 1, 20, 19, 24, 4, 21, 4, 7, 20, 2, 1, 13, 21, 23, 6, 2, 22, 4, 3, 6,
 2, 13, 3, 13, 20, 23, 14, 13, 13, 20, 10, 24, 9, 22, 15, 21, 18, 16, 13, 1, 3,
12, 21, 9, 4, 24, 4, 10, 8, 1, 19, 3, 20, 4, 5, 25, 8, 8, 14, 23, 24, 14, 1, 3,
11, 1, 8, 17, 2, 2, 23, 6, 2, 25, 15, 4, 23, 20, 5, 11, 16]
```

Mapping a list

- We want to apply a function to all elements in a list

```
>>> rlist =[random.randint(-10,20) for _ in range(20)]
>>> rlist
[-2, -9, 20, -10, -9, 19, -4, 1, 16, 3, 8, -10, 4, -2, 11, 8, 11, -7, -2, -3]
>>> list(map(lambda x: (x-6)**2, rlist))
[64, 225, 196, 256, 225, 169, 100, 25, 100, 9, 4, 256, 4, 64, 25, 4, 25, 169, 64
, 81]
>>> [(x-6)**2 for x in rlist]
[64, 225, 196, 256, 225, 169, 100, 25, 100, 9, 4, 256, 4, 64, 25, 4, 25, 169, 64
, 81]
>>>
```

Zip

Zip

- Often we have related data in a number of lists
  - Example: list of student names, list of grades, list of high school
    - [“Frankieboy”, “Violet”, “Kumar”, “Dshenghis”]
    - [“D”, “A”, “B”, “C”]
    - [“MPS1”, “MH”, “MH”, “MPS59”]
- Zipping will create a zip object that generates the tuples (“Frankieboy”, “D”, “MPS1”), (“Violet”,“A”,”MH”), (“Kumar”, “B”, “MH”), (“Dshenghis”,”C”, “MPS59”)

Zip

- We can reach the same effect with list comprehension, but since we cannot enumerate in parallel through several iterables, we need to use indices.

```
>>> names = ["Albertina", "Bertram", "Chris", "David"]
>>> grades = ["A", "B", "C", "D"]
>>> highschools = ["MH", "SHH", "LGH", "MHT"]
>>> zip(names, grades, highschools)
<zip object at 0x1153e8bc8>
>>> list(zip(names, grades, highschools))
[('Albertina', 'A', 'MH'), ('Bertram', 'B', 'SHH'), ('Chris', 'C', 'LGH'), ('David', 'D', 'MHT')]
>>> [ (names[i], grades[i], highschools[i]) for i in range(len(names))]
[('Albertina', 'A', 'MH'), ('Bertram', 'B', 'SHH'), ('Chris', 'C', 'LGH'), ('David', 'D', 'MHT')]
>>>
```

Zip

- What happens if you give zip iterables of different length
  - E.g. a list of 5, a list of 4 and a list of 3 elements?
  - The result is a zip object of length the minimum of the lengths.

Zip

- Undoing a zip:
  - If you make a list `alist` out of a zip object, you can break it apart with the `zip(*alist)` command

```
>>> names = ["Albertina", "Bertram", "Chris", "David"]
>>> grades = ["A", "B", "C", "D"]
>>> highschools = ["MH", "SHH", "MPS57", "LGH"]
>>> alist = list(zip(names, grades, highschools))
>>> alist
[('Albertina', 'A', 'MH'), ('Bertram', 'B', 'SHH'), ('Chris', 'C', 'MPS57'), ('D
avid', 'D', 'LGH')]
>>> list(zip(*alist))
[('Albertina', 'Bertram', 'Chris', 'David'), ('A', 'B', 'C', 'D'), ('MH', 'SHH',
 'MPS57', 'LGH')]
>>> names, grades, highschools = tuple(list(zip(*alist)))
>>> names
('Albertina', 'Bertram', 'Chris', 'David')
>>> grades
('A', 'B', 'C', 'D')
>>> highschools
('MH', 'SHH', 'MPS57', 'LGH')
```

Exercises

Exercise

- Use list comprehension:
  - Flatten a matrix
    - Example: [[1, 2, 3], [4, 5, 6], [7, 8, 9]] —> [1,2,3,4,5,6,7,8,9]

Solution

- Loop Solution:
  - Using extend

```
def flatten1(matrix):
    result = []
    for row in matrix:
        result.extend(row)
    return result
```

- But this cannot be translated

Solution

- A loop solution that can be translated

```
def flatten2(matrix):
    result = []
    for row in matrix:
        for item in row:
            result.append(item)
return result
```

- This is not english, but Python: for row in matrix for item in row

Solution

- Now we can do comprehension with the same order of for loops

```
def flatten3(matrix):
    return [ item for row in matrix for item in row]
```

Exercise

- Given a list, subtract its reverse from itself
  - [10, 7, 5, 4, 2, 1] —> [10-1, 7-2, 5-4, 4-5, 2-7, 1-10]

Solution

- Loop version:
  - Use a slice to get the reverse of the list

```
def clw(lista):
    result = []
    for first, second in zip(lista, lista[::-1]):
        result.append(first-second)
    return result
```

Solution

- Translated into comprehension

```
def clwc(lista):
    return [first - sec for first, sec in zip(lista, lista[::-1])]
```

Exercise

- Given a matrix, calculate its negative

```
[ [1,2,4],
  [2,5,8],
  [3,3,3],
  [5,4,2]
]
```

Solution

- A double loop

```
def neg1(matrix):
    result = []
    for row in matrix:
        new_row = [ ]
        for item in row:
            new_row.append(-item)
        result.append(new_row)
    return result
```

Solution

- A single loop with one interior comprehension

```
def neg2(matrix):
    result = []
for row in matrix:
    result.append([-item for item in row])
return result
```

Solution

- A double comprehension (which shows that you might not want to overdo comprehension)

```
def neg3(matrix):
    return [ [-item for item in row] for row in matrix]
```

Generator Comprehension

- We can use comprehension on generators
- Called **generator expressions**
  - Generators are defined with round parentheses

```
squares = (n**2 for n in range(1, 100))
```

```
>>> next(squares)
1
>>> next(squares)
4
>>> next(squares)
9
>>> next(squares)
16
>>> next(squares)
Traceback (most recent call last):
  File "<pyshell#36>", line 1, in <module>
    next(squares)
StopIteration
```

Generator Comprehension

- The generator expression can be called with next( )
  - However, what if we want an infinite generator?
    - Could define a generator the old fashioned way

```
def squares1():
    n=0
    while True:
        n+=1
        yield(n**2)
```

```
>>> a = squares1()
>>> while(True):
        print(next(a))


1
4
9
16
25
36
49
```

Generator Comprehension

- Or use generators defined in itertools

```
import itertools
squares2 = (n**2 for n in itertools.count(1,1))
```

```
>>> while True:
        print(next(squares2))


1
4
9
16
25
36
49
64
81
```

Generator Comprehension

- **WHY?**
  - Assume you want to process a huge set of data
  - You need to create intermediate results
  - If you use lists, they eat up memory
  - If you use generators, they don't

And now for something completely different

Copying Data Structures

- Copying and assignment are two different things

Copying Data Structures

- Copying and assignment are two different things
  - We have an object a

```
a = set(1, 2, “one”)
```

  - We assign a to b
  - But the two objects are still linked:

Copying Data Structures

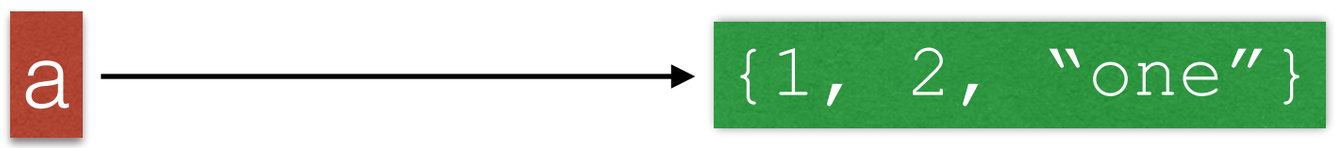
- Copying and assignment are two different things

```
a = set([1, 2, "one"])
print(a)
b = a
print(b)
# Now we change set a
a.remove("one")
# Which also changes set b
print(b)
```

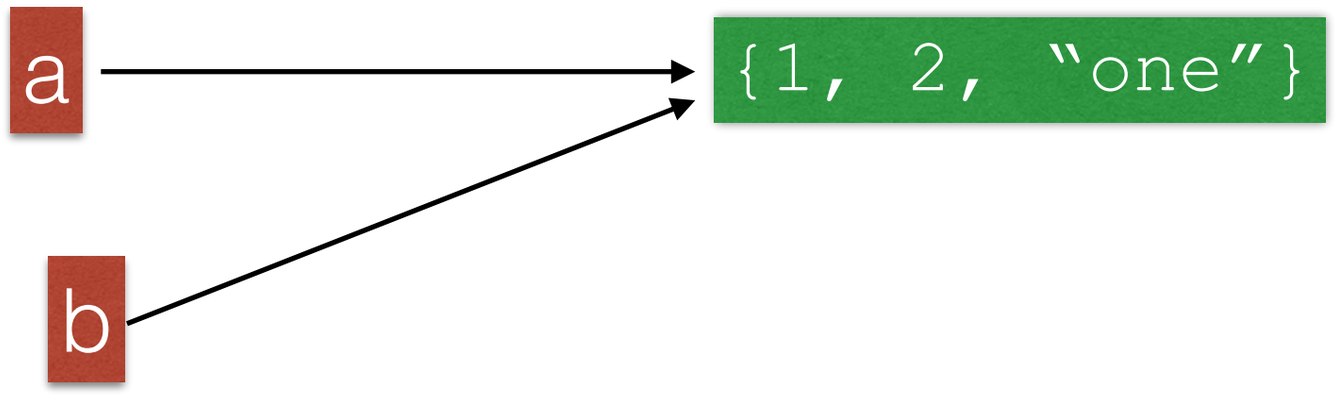
```
>>> a = {1,2,"one"}
>>> a
{1, 2, 'one'}
>>> b = a
>>> a.remove("one")
>>> a
{1, 2}
>>> b
{1, 2}
```

Copying Data Structures

- Copying and assignment are two different things
  - Here is what happens
    - In Python, names point to objects

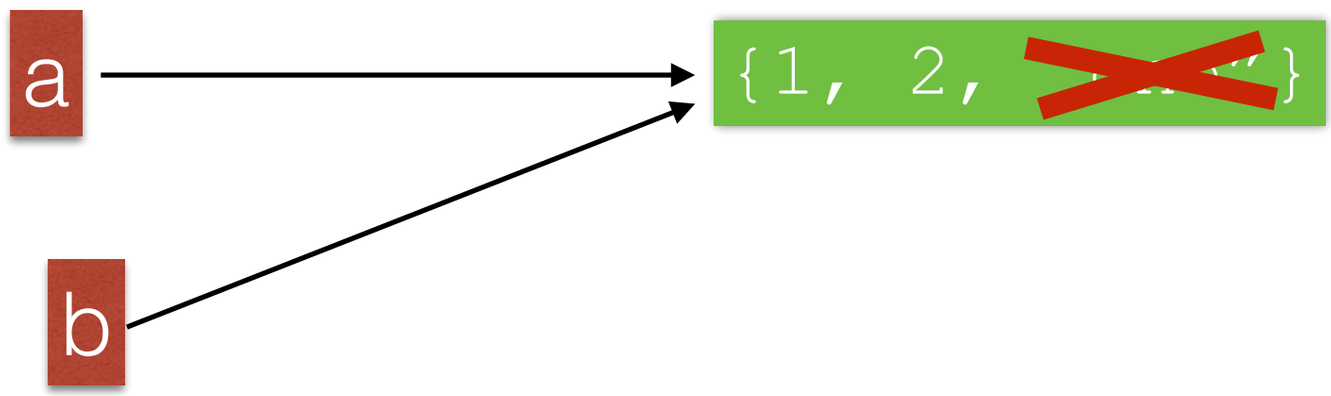


- Assigning adds a name to the same object



Copying Data Structures

- Copying and assignment are two different things
  - Since there is only one object, I can manipulate the object through either name



Copying Data Structures

- Copying and assignment are two different things
  - If I want to copy, I need to do so explicitly

```
lista = [1, 2, "three", [4,5]]
listb = [x for x in lista]
lista[2] = 3
print(lista)
print(listb)
```

```
>>> lista = [1, 2, "three", [4,5]]
>>> listb = [x for x in lista]
>>> lista[2] = 3
>>> lista
[1, 2, 3, [4, 5]]
>>> listb
[1, 2, 'three', [4, 5]]
```

- Now changes to one do not change the other!

Copying Data Structures

- Copying and assignment are two different things
  - One can use slices to copy lists
  - `listb = lista[0:4]`

Copying Data Structures

- Copying becomes difficult if we have compound objects
  - E.g.: A list which contains lists, sets, …
- Shallow copy:
  - Resulting copies have shared elements

Copying Data Structures

- Example: A matrix as a list of rows
  - Create zero row by multiplying list with an integer

```
matrix = 3*[ 4*[0]]
```

- One might think it creates a structure like

```
[ [0, 0, 0, 0],
  [0, 0, 0, 0],
  [0, 0, 0, 0]]
```

  - which is not entirely false

Copying Data Structures

- We can get the elements as we should

```
matrix = 3*[ 4*[0]]
print(matrix[3][2])
```

- And we can set elements

```
matrix = 3*[ 4*[0]]
matrix[3][2] = 5
```

- But now we see that we got three times the same row

Copying Data Structures

```
matrix = 3*[ 4*[0] ]
print(matrix)
matrix[2][3] = 5
print(matrix)
```

```
RESTART: /Users/tjschwarzsj/Google Drive/AATeaching/Python/Programs/copying.py
[[0, 0, 0, 0], [0, 0, 0, 0], [0, 0, 0, 0]]
[[0, 0, 0, 5], [0, 0, 0, 5], [0, 0, 0, 5]]
```

Copying Data Structures

- How can we do this:
  - Need to construct the zero rows independently
    - Use e.g. list comprehension

```
matrix = [ [0 for _ in range(4)] for i in range(3)]
```

Copying Data Structures

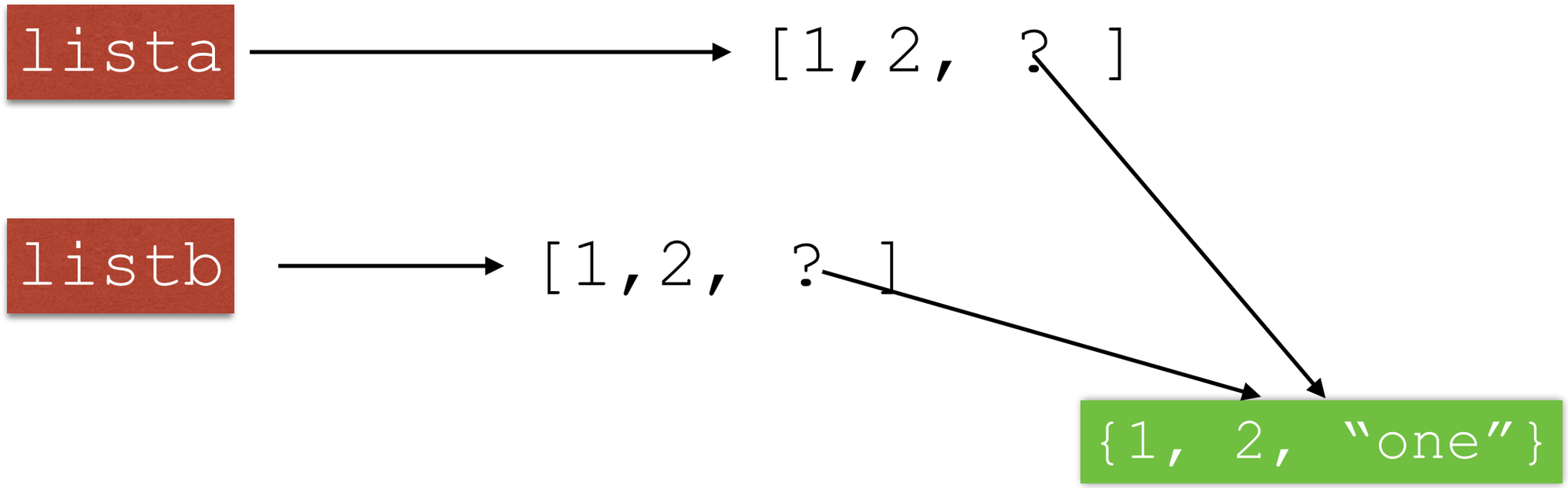
- Shallow copy: Assume we have

```
lista = [1, 2, [3,4,5]]
```

- We create a shallow copy by

```
lista = [1, 2, [3, 4, 5]]
listb = lista[:]
```

- But here is what is happening

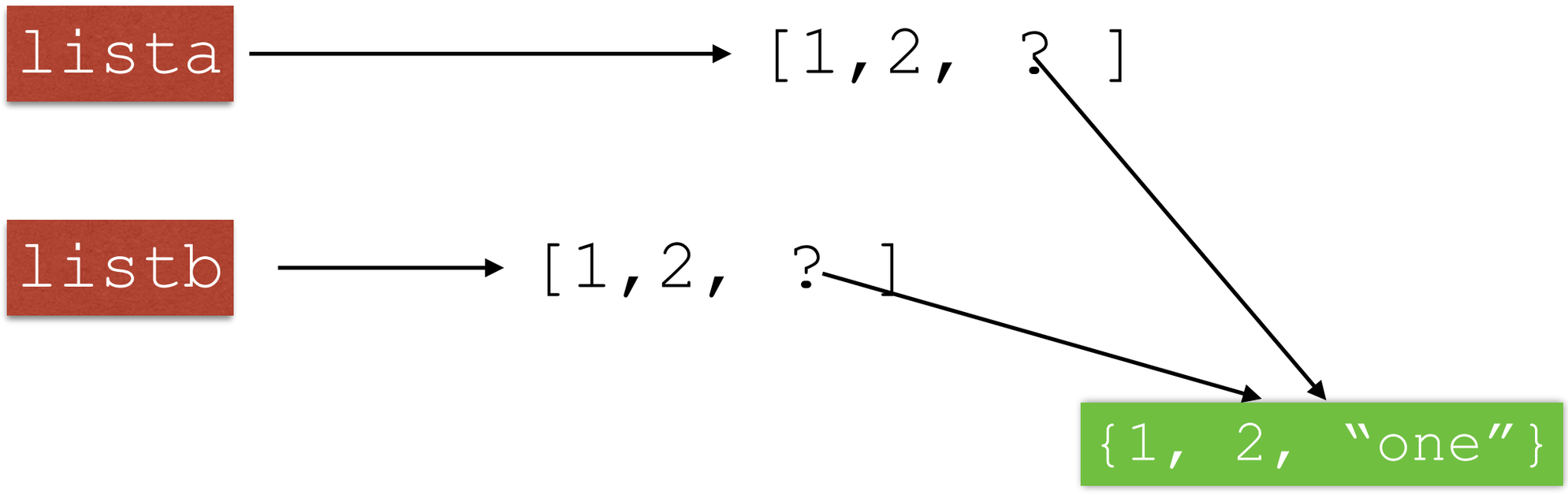



```
lista = [1, 2, [3, 4, 5]]
listb = lista[:]
```

The two lists still share a component. We can change this component in one list and change it in the other one as well.

Copying Data Structures

- We have two copies of the list, but the third element are two different names for the same object




```
lista = [1, 2, [3, 4, 5]]
listb = lista[:]
```

Copying Data Structures

- In consequence, I can alter the same element in the list which is element number 2

```
lista = [1, 2, [3, 4, 5]]
listb = lista[:]
lista[2][0] = 6
print(lista)
print(listb)
```

- prints out

```
[1, 2, [6, 4, 5]]
[1, 2, [6, 4, 5]]
```

Copying Data Structures

- I need to use a deep copy
  - Easiest:
    - Use the module `copy`
    - Use `copy.deepcopy(object)` for deep copying
    - Use `copy.copy(object)` for shallow copying

Copying Data Structures

- This is a famous Python gotcha
    - Behavior is not intuitive.