

Sequences and Higher Order Functions

Scaling a Sequence

- Given a sequence of numbers, how to scale every element?
- Let's say, scale by 2

[5, 1, 4, 9, 11, 22, 12, 55]



[10, 2, 8, 18, 22, 44, 24, 110]

Scaling a Sequence

- Given a sequence of numbers, how to scale every element?

```
def seqScaleI(seq,n):  
    output = []  
    for i in seq:  
        output.append(i*n)  
    return output
```

```
def seqScaleR(seq,n):  
    if not seq:  
        return seq  
    return [seq[0]*n]+seqScaleR(seq[1:],n)
```

Squaring a Sequence

- Given a sequence of numbers, how to square every element?

[5, 1, 4, 9, 11, 22, 12, 55]



[25, 1, 16, 81, 121, 484, 144, 3025]

```
def seqSquareI(seq):  
    output = []  
    for i in seq:  
        output.append(i*i)  
    return output
```

Squaring/Scaling a Sequence

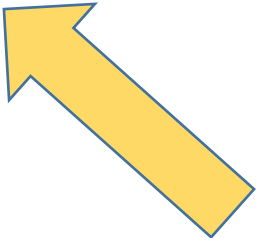
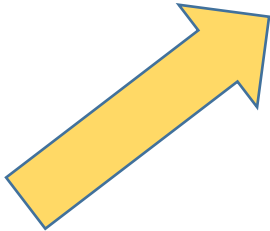
- Other than the function name (that can change to anything), what is the different?

```
def seqScaleI(seq,n):  
    output = []  
    for i in seq:  
        output.append(i*n)  
    return output
```

```
def seqSquareI(seq):  
    output = []  
    for i in seq:  
        output.append(i*i)  
    return output
```

- What should we do with other operations to a sequence?
 - E.g. cube, abs, etc.?

```
def map(f, seq):  
    output = []  
    for i in seq:  
        output.append(f(i))  
    return output
```



```
def seqScaleI(seq, n):  
    output = []  
    for i in seq:  
        output.append(i*n)  
    return output
```

are

```
def seqSquareI(seq):  
    output = []  
    for i in seq:  
        output.append(i*i)  
    return output
```

Difference Operations on a Sequence

```
>>> lst = [5,1,4,9,11,22,12,55]
>>> map(square,lst)
[25, 1, 16, 81, 121, 484, 144, 3025]
>>> map(scale2,lst)
[10, 2, 8, 18, 22, 44, 24, 110]
>>> map(lambda x:x*x,lst)
[25, 1, 16, 81, 121, 484, 144, 3025]
>>> map(lambda x:2*x,lst)
[10, 2, 8, 18, 22, 44, 24, 110]
>>> map(lambda x:-x,lst)
[-5, -1, -4, -9, -11, -22, -12, -55]
```

Our map()

- However, our map() can only process list
 - Cannot work on other sequences like tuples, strings, etc.
- However, Python does have its original version of map()
 - But it will return a type “map” object
 - You can convert that object into other sequences like list or tuples

```
>>> tup = (1,-2,3)
>>> map1 = map(abs,tup)
>>> map1
<map object at 0x112e61438>
>>> type(map1)
<class 'map'>
>>> map1Tuple = tuple(map1)
>>> map1Tuple
(1, 2, 3)
>>> map1List = list(map1)
>>> map1List
[]
```


Python's map()

```
>>> tup = (1,-2,3)
>>> map1 = map(abs,tup)
>>> map1
<map object at 0x112e61358>
>>> type(map1)
<class 'map'>
>>> map1List = list(map1)
>>> map1List
[1, 2, 3]
>>> map1Tuple = tuple(map1)
>>> map1Tuple
()
```

```
>>> tup = (1,-2,3)
>>> map1 = map(abs,tup)
>>> map1
<map object at 0x112e61438>
>>> type(map1)
<class 'map'>
>>> map1Tuple = tuple(map1)
>>> map1Tuple
(1, 2, 3)
>>> map1List = list(map1)
>>> map1List
[]
```

Python's map()

- The map object is actually an “iterable”
 - After you “took out” items from the map object, the items will be “gone”
- Conclusion
 - Conversion from a map object to a tuple or list only once

```
>>> tup = (1,-2,3)
>>> map1 = map(abs,tup)
>>> map1
<map object at 0x112e61438>
>>> type(map1)
<class 'map'>
>>> map1Tuple = tuple(map1)
>>> map1Tuple
(1, 2, 3)
>>> map1List = list(map1)
>>> map1List
[]
```

Python's Filter

Python's Filter

- Python's map()
 - Apply a function f to every item x in the sequence
- Python's filter()
 - Apply a **predicate** function f to every item x in the sequence
 - A predicate is a function that return True or False
 - Return a iterable that
 - Keep the item if $f(x)$ returns True
 - Remove the item otherwise

Python's `filter()`

```
>>> l = [1,2,3,'a',(1,2),('b',3)]
>>> filter(lambda x:type(x)==int,l)
<filter object at 0x112e618d0>
>>> list(filter(lambda x:type(x)==int,l))
[1, 2, 3]
>>> l = [1,2,'a',(1,2),6,('b',3),999]
>>> list(filter(lambda x:type(x)==int,l))
[1, 2, 6, 999]
>>> list(filter(lambda x:type(x)==str,l))
['a']
>>> l2 = [1,4,5,-4,9,-99,0,32,-9]
>>> list(filter(lambda x: x < 0 , l2))
[-4, -99, -9]
```

Counting a Sequence Shallowly or Deeply

How to Count the Number of Element in a Sequence?

```
>>> lst = [5,1,4,9,11,22,12,55]
>>> seqCountI(lst)
8
```

- Of course we can use `len()`
- But what if we want to implement it ourselves?

```
def seqCountR(seq):
    if not seq:
        return 0
    return 1 + seqCountR(seq[1:])
```

However, it's Shallow

```
>>> lst2 = [1,2,3,[4,5,6,7]]
```

```
>>> seqCountR(lst2)
```

```
4
```

- How to count "deeply"?

```
>>> deepcount(lst2)
```

```
7
```

- And what about a list like this

```
>>> lst3 = [1, 4, 9, [1, 4], [4, 9, 16, [1, 4, 9]], [9, 16, 25]]
```

```
>>> deepcount(lst3)
```

```
14
```


Counting Logic? **Shallow** Count

- Total count = count of the **first** item + count of the rest
 - But the count of the first item is always 1

```
def seqCountR(seq):  
    if not seq:  
        return 0  
    return 1 + seqCountR(seq[1:])
```

- Can we do the same thing for deep count?
- What is the difference between deep and shallow count?
 - In deep count, the “length” of the first item may not be 1

Counting Logic? Deep Count

- Total count = count of the **first** item + count of the rest
 - But the count of the first item is only 1 if it's not a sequence
- [**1**, 2, 3, 4, [2, 3, 4], [1]]
 - The first item has a count 1
- [**[1, 2]**, 3, 4, 5]
 - The first item does not has a count 1
- Two questions:
 - How to tell the first item is a sequence or not?
 - What to do if the first item is a sequence?

First Question

- How to tell the first item is a list or not a list
 - Assuming we only have list
 - Not difficult to extend to tuples
- Check

`type(seq[0])==list`

- E.g.

```
>>> l1 = [1,2,3,4,[2,3,4],[1]]
```

```
>>> type(l1[0])==list
```

```
False
```

```
>>> l2 = [[1,2],3,4,5]
```

```
>>> type(l2[0])==list
```

```
True
```

Second Question

- If the first item is NOT a list, e.g. [**1**, 2, 3, 4, [2, 3, 4], [1]]
 - count of the first item is 1
- If the first item IS a list, e.g. [**[1, 2]**, 3, 4, 5]
 - recursively compute `deepcount()` of the first item!
- And this can handle if the first item is a list of a list of a list of
- e.g.
 - [**[[[[1, 2], 2], 4], 2]**, 3, 4, 5]

Second Question

- If the first item is NOT a list, e.g. [**1**, 2, 3, 4, [2, 3, 4], [1]]
 - count of the first item is 1
- If the first item IS a list, e.g. [**[1, 2]**, 3, 4, 5]
 - recursively compute `deepcount()` of the first item!

```
def deepcount(seq):  
    if seq == []:  
        return 0  
    elif type(seq) != list:  
        return 1  
    else:  
        return deepcount(seq[0]) + deepcount(seq[1:])
```

Simple Test

deepcount([1])



1 deepcount(1) + deepcount([])

```
def deepcount(seq):  
    if seq == []:  
        return 0  
    elif type(seq) != list:  
        return 1  
    else:  
        return deepcount(seq[0]) + deepcount(seq[1:])
```

Whenever we
reached this line
Count + 1

Simple Test

deepcount([1,2,3])



deepcount(1) + deepcount([2,3])

1



1

deepcount(2) + deepcount([3])



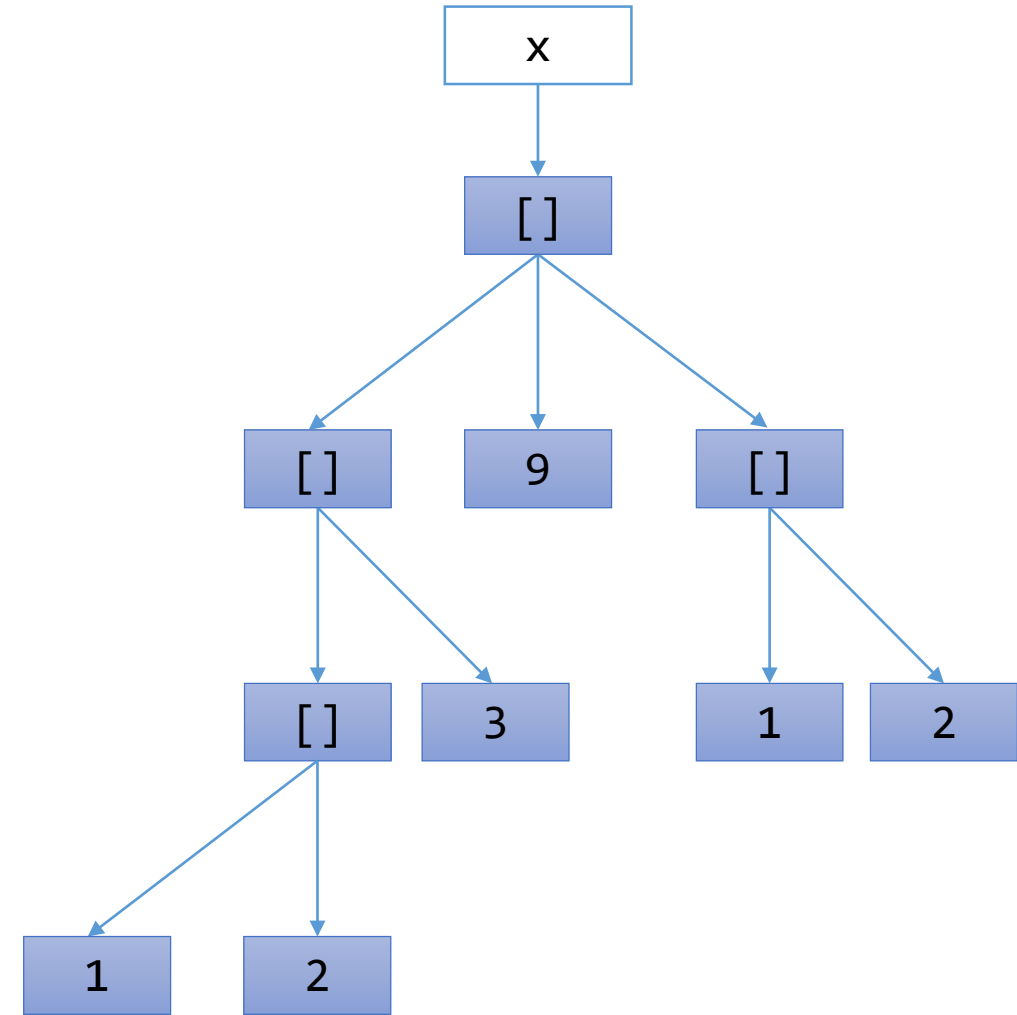
1

deepcount(3) + deepcount([])

Tracing the Code

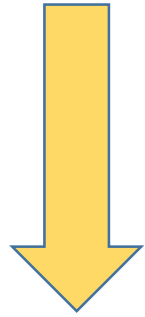
- `x = [[[1,2],3],9,[1,2]]`

```
def deepcount(seq):  
    if seq == []:  
        return 0  
    elif type(seq) != list:  
        return 1  
    else:  
        return deepcount(seq[0]) + deepcount(seq[1:])
```

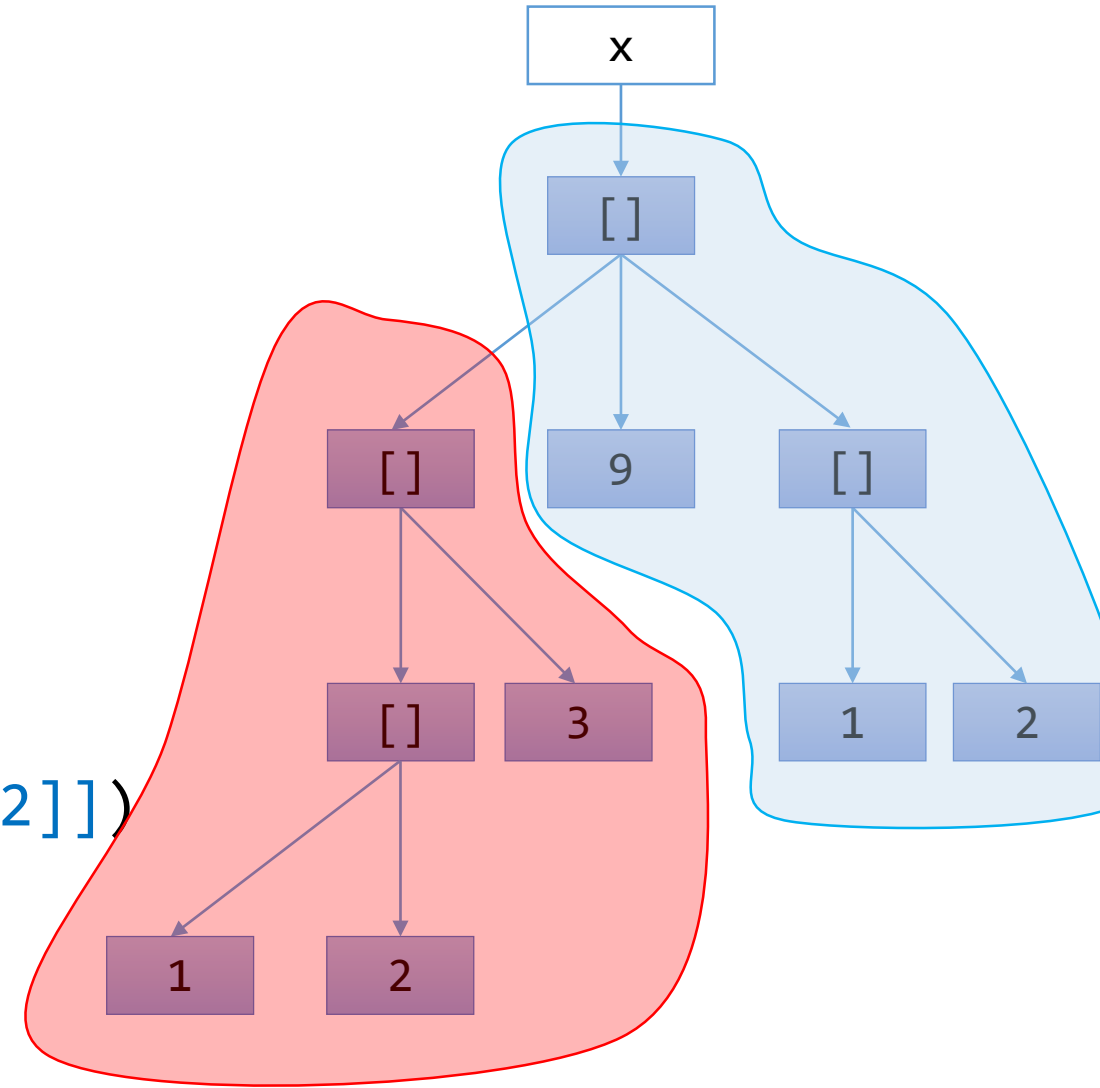


Tracing the Code

deepcount([[1,2],3],9,[1,2])



deepcount([1,2],3)+deepcount([9,[1,2]])



Let's Consider the Left Term

deepcount([**1**,**2**],3[])



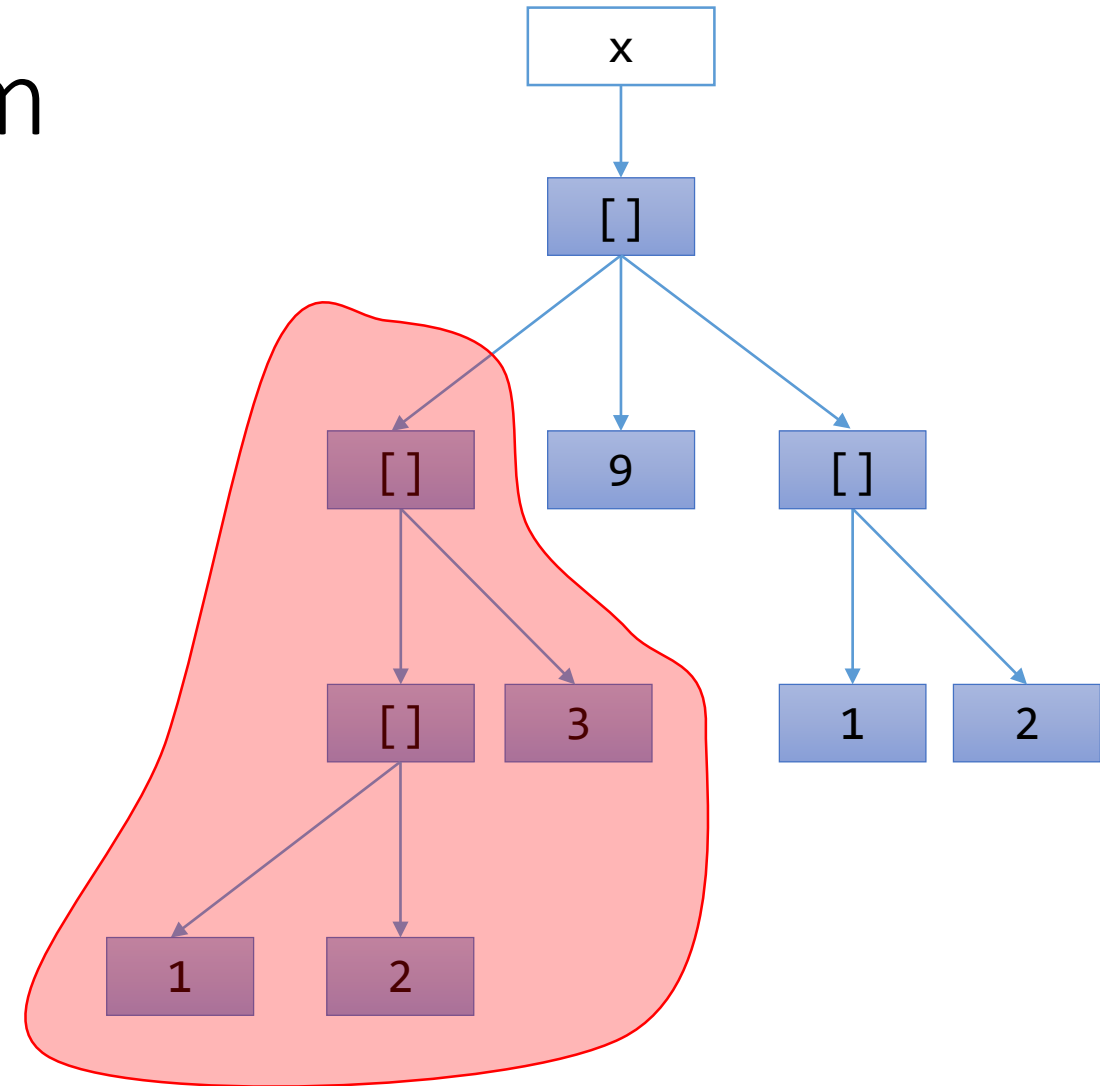
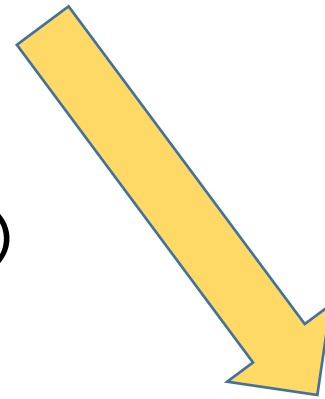
deepcount(**1**,**2**) + deepcount([3])



deepcount(**1**) + deepcount([2])



deepcount(2)+deepcount([])



deepcount(3)+deepcount([])

Let's Consider the Left Term

deepcount([**1**,**2**],3[])



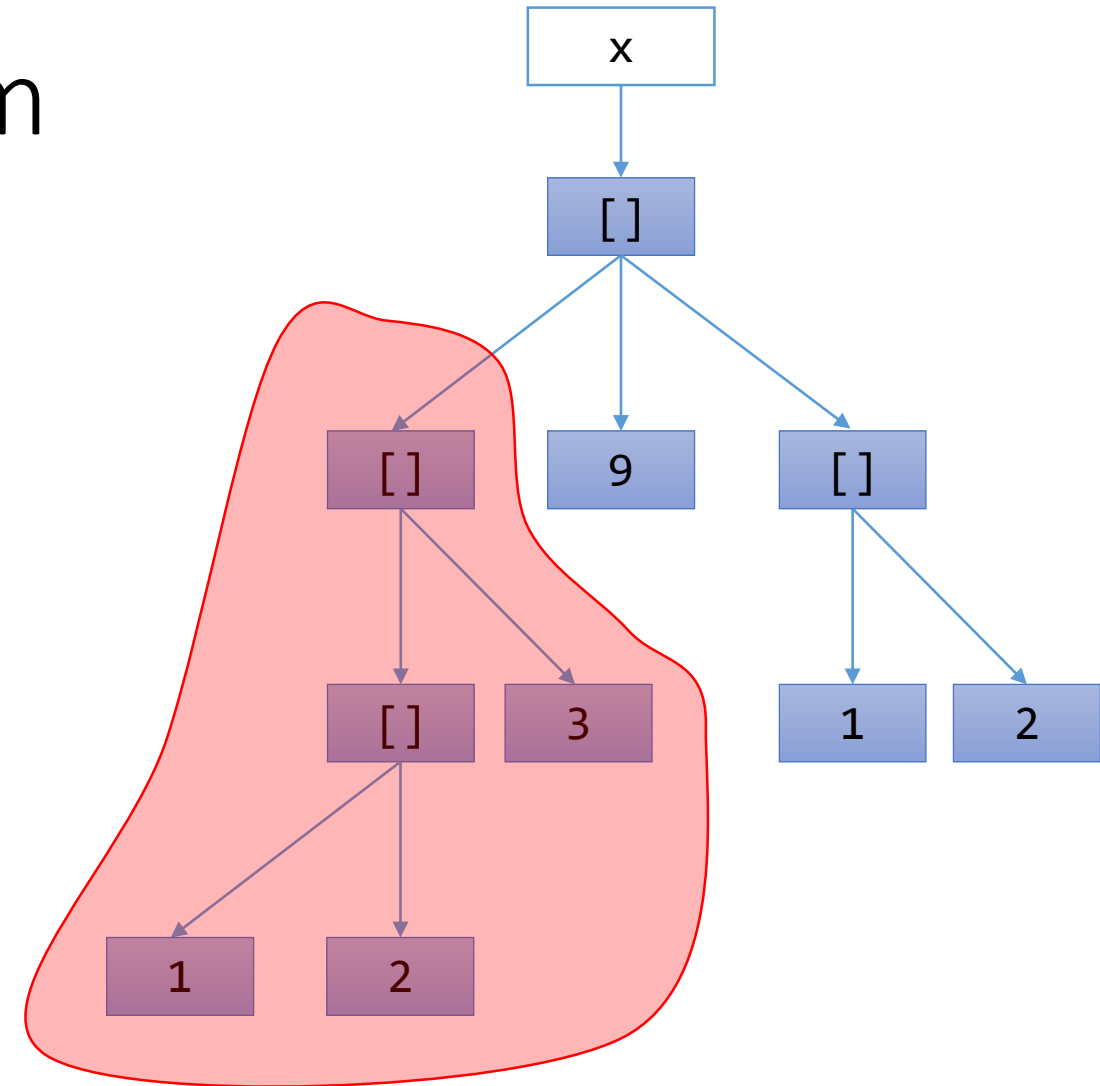
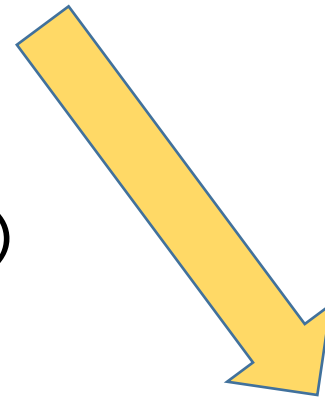
deepcount(**1**,**2**) + deepcount([3])



1 deepcount(**1**) + deepcount([2])



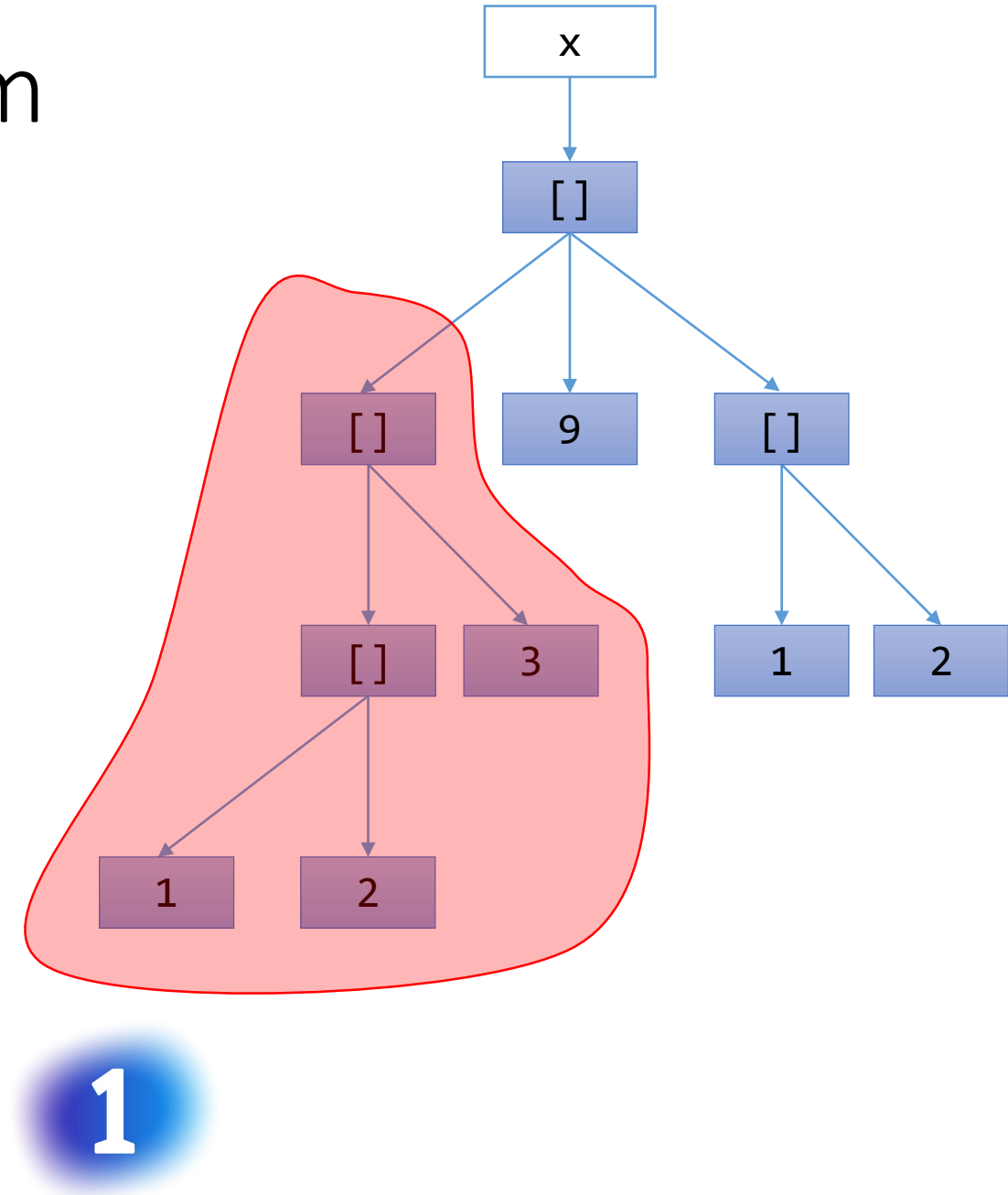
deep**1**count(2)+deepcount([])



deep**1**count(3)+deepcount([])

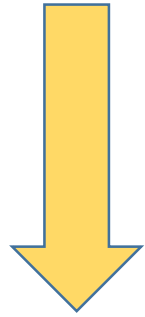
Let's Consider the Left Term

deepcount([**[1,2]**,3]) ➡ 3



Tracing the Code

deepcount([[1,2],3],9,[1,2])

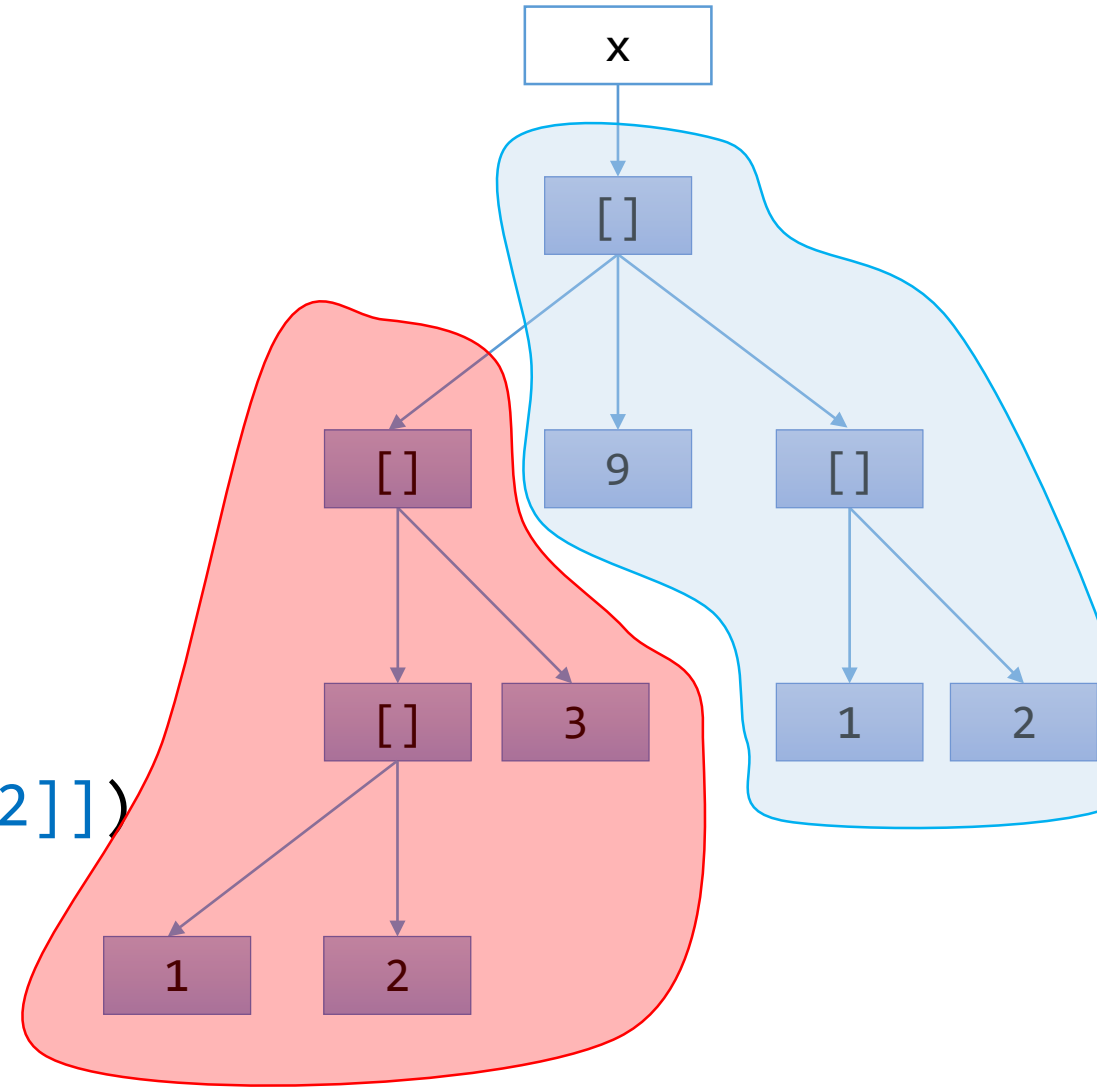


deepcount([1,2],3)+deepcount([9,[1,2]])



3

+deepcount([9,[1,2]])



Tracing the Code

deepcount([9,[1,2]])



deepcount(**9**)+deepcount(**[1,2]**)



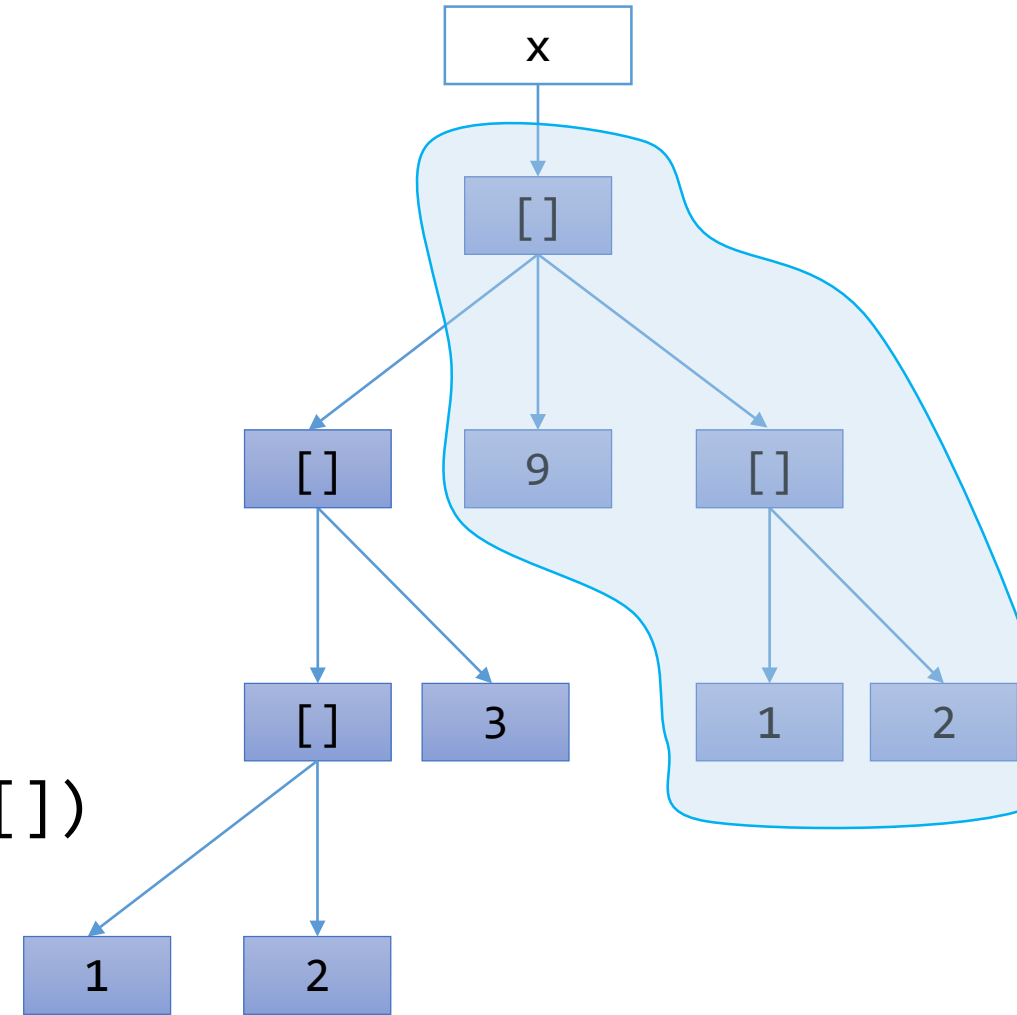
deepcount(**[1,2]**) + deepcount([])



deepcount(1) + deepcount([2])



deepcount(2) + deepcount([])



Tracing the Code

deepcount([9,[1,2]])



deepcount(**9**)+deepcount(**[1,2]**)

1



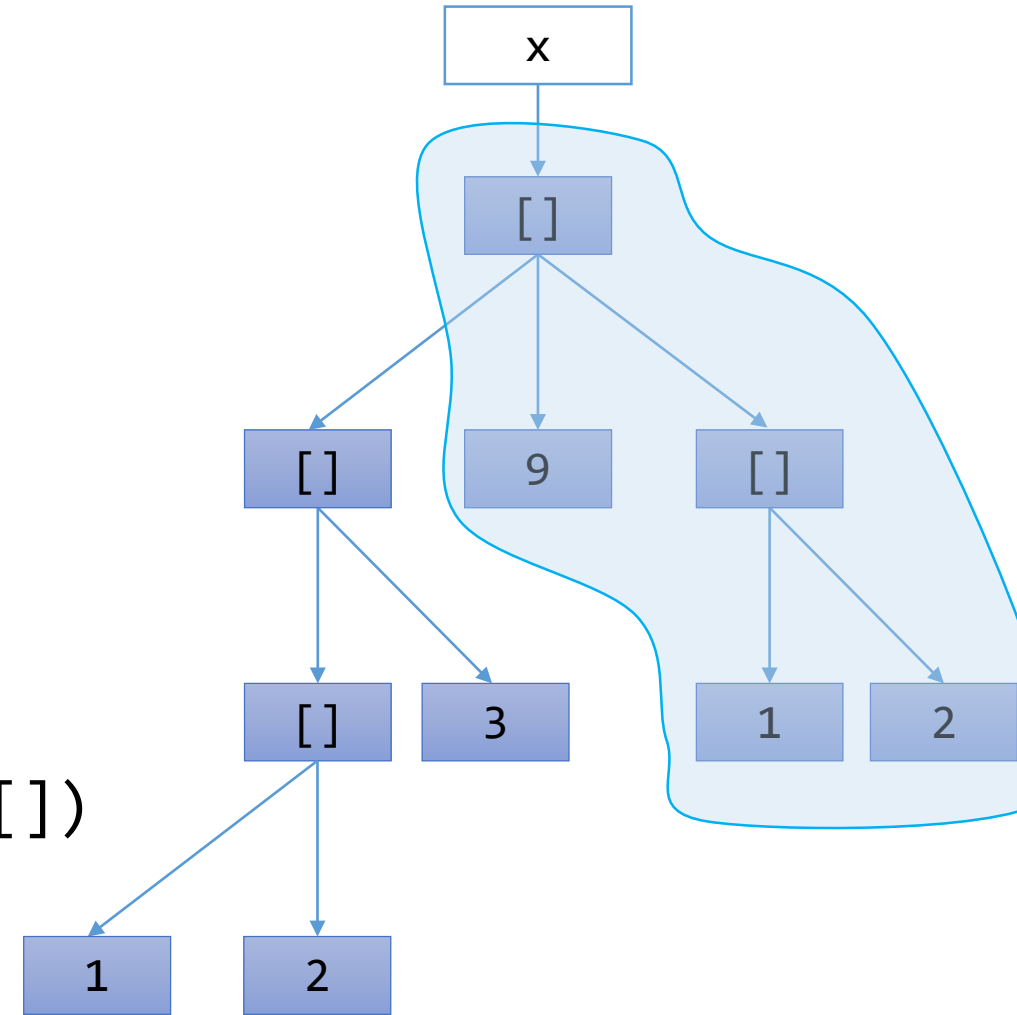
deepcount(**[1,2]**) + deepcount([])



deepcount(1) + deepcount([2])

1

deepcount(**1**) + deepcount([])



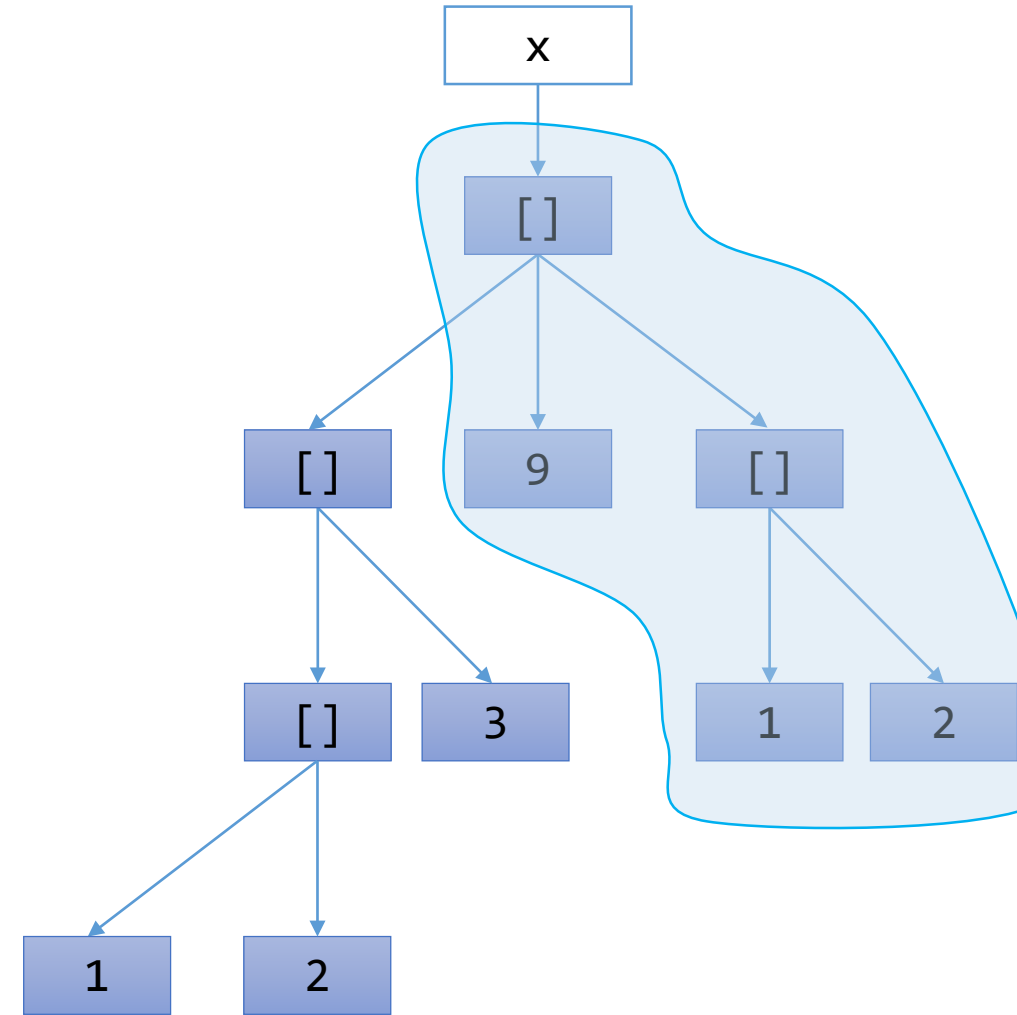
Tracing the Code

deepcount([9,[1,2]]) ➡ 3

1

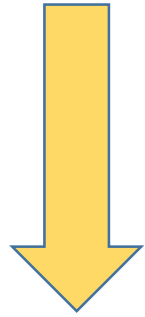
1

1



Tracing the Code

`deepcount([[1,2],3],9,[1,2])`



`deepcount([1,2],3)+deepcount([9,[1,2]])`

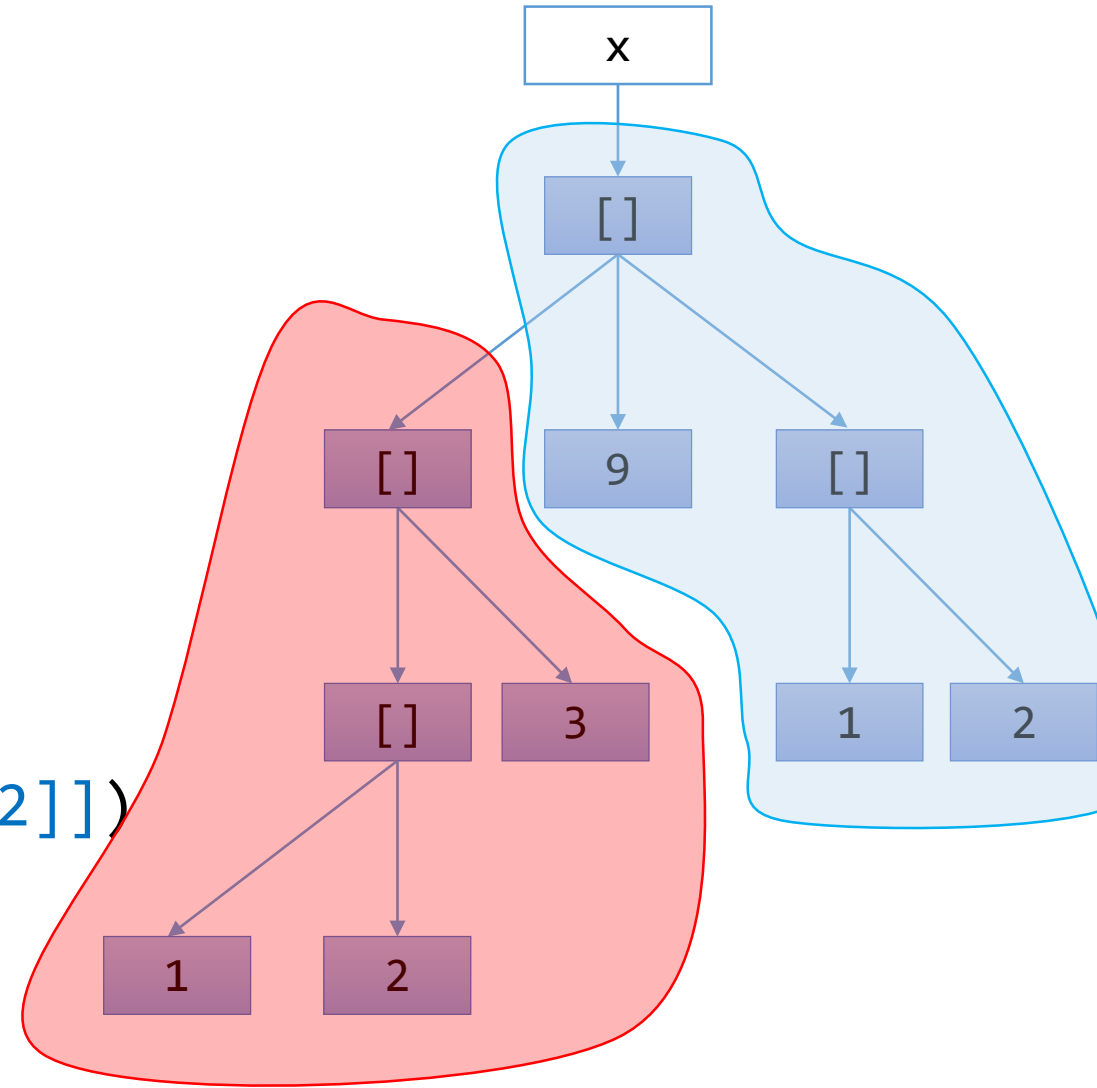


3

+

3

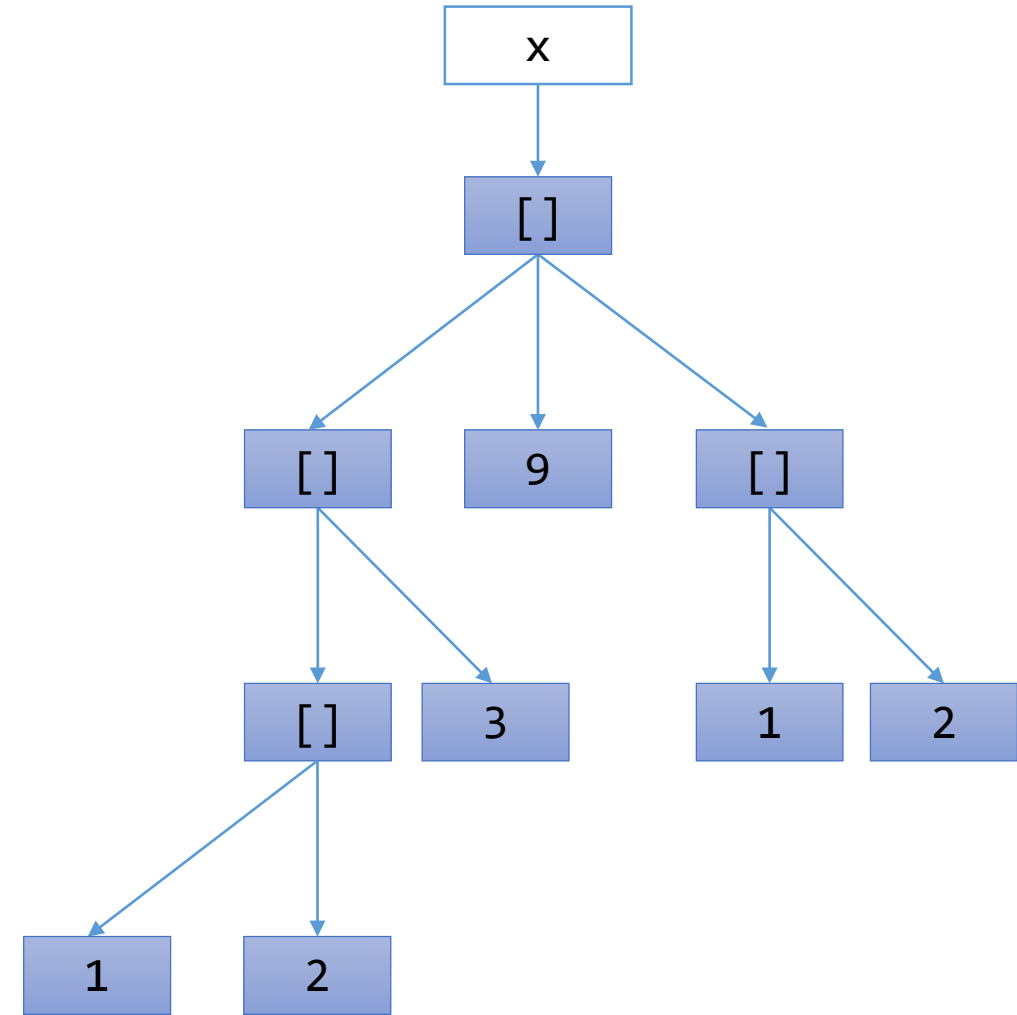
= 6



Tracing the Code

- `x = [[[1,2],3],9,[1,2]]`

```
def deepcount(seq):  
    if seq == []:  
        return 0  
    elif type(seq) != list:  
        return 1  
    else:  
        return deepcount(seq[0]) + deepcount(seq[1:])
```



How about

- DeepSquare?

```
>>> l = [1, 4, 9, [1, 4], [4, 9, 16, [1, 4, 9]], [9, 16, 25]]
>>> deepSquare(l)
[1, 16, 81, [1, 16], [16, 81, 256, [1, 16, 81]], [81, 256, 625]]
```

- Deep Increment (by 1)?

```
>>> deepInc(l)
[2, 3, 4, [2, 3], [3, 4, 5, [2, 3, 4]], [4, 5, 6]]
>>> deepInc(deepInc(deepInc(l)))
[4, 5, 6, [4, 5], [5, 6, 7, [4, 5, 6]], [6, 7, 8]]
```

Get Some Insight from DeepCount?

```
def deepcount(seq):  
    if seq == []:  
        return 0  
    elif type(seq) != list:  
        return 1  
    else:  
        return deepcount(seq[0]) + deepcount(seq[1:])
```

DeepSquare

- Spot the difference?

```
def deepSquare(seq):  
    if seq == []:  
        return seq  
    elif type(seq) != list:  
        return seq*seq  
    else:  
        return [deepSquare(seq[0])]+ deepSquare(seq[1:])
```

DeepSquare

- Base case is different
 - If seq is reduced to an empty list, return it as it is

```
def deepSquare(seq):  
    if seq == []:  
        return seq  
    elif type(seq) != list:  
        return seq*seq  
    else:  
        return [deepSquare(seq[0])]+ deepSquare(seq[1:])
```

DeepSquare

- The leaf case
 - If the item is not a list, return its square instead of 1

```
def deepSquare(seq):  
    if seq == []:  
        return seq  
    elif type(seq) != list:  
        return seq*seq  
    else:  
        return [deepSquare(seq[0])]+ deepSquare(seq[1:])
```

DeepSquare

- Otherwise
 - Return the list of recursive call of the first item
 - Huh? Why not return the “recursive call of the first item”? Why an extra “layer” of list?
 - And concatenate with the recursive call of the “rest” of the list

```
def deepSquare(seq):  
    if seq == []:  
        return seq  
    elif type(seq) != list:  
        return seq*seq  
    else:  
        return [deepSquare(seq[0])]+ deepSquare(seq[1:])
```


deepSquare([2])



[deepSquare(2)] + deepSquare([])



[2*2]

+



[]



[4]

```
def deepSquare(seq):  
    if seq == []:  
        return seq  
    elif type(seq) != list:  
        return seq*seq  
    else:  
        return [deepSquare(seq[0])] + deepSquare(seq[1:])
```

DeepInc

- How different from DeepSquare?

```
def deepInc(seq):  
    if seq == () or seq == []:  
        return seq  
    elif type(seq) != list:  
        return seq+1  
    else:  
        return [deepInc(seq[0])] + deepInc(seq[1:])
```



ARE YOU THINKING...

WHAT I'M THINKING???

```
def deepInc(seq):  
    if seq == () or seq == []:  
        return seq  
    elif type(seq) != list:  
        return seq+1  
    else:  
        return [deepInc(seq[0])] + deepInc(seq[1:])  
  
def deepSquare(seq):  
    if seq == []:  
        return seq  
    elif type(seq) != list:  
        return seq*seq  
    else:  
        return [deepSquare(seq[0])] + deepSquare(seq[1:])
```

deepMap !!!!

```
def deepMap(func, seq):  
    if seq == []:  
        return seq  
    elif type(seq) != list:  
        return func(seq)  
    else:  
        return [deepMap(func, seq[0])] + deepMap(func, seq[1:])
```

deepMap!!!

```
>>> l = [1, 2, 3, [1, 2], [2, 3, 4, [1, 2, 3]], [3, 4, 5]]
>>> deepMap(square,l)
[1, 4, 9, [1, 4], [4, 9, 16, [1, 4, 9]], [9, 16, 25]]
>>> deepMap(str,l)
['1', '2', '3', ['1', '2'], ['2', '3', '4', ['1', '2', '3']],
['3', '4', '5']]
>>> deepMap(lambda x:x/2,l)
[0.5, 1.0, 1.5, [0.5, 1.0], [1.0, 1.5, 2.0, [0.5, 1.0, 1.5]],
[1.5, 2.0, 2.5]]
```

Remember List Copy by copy()?

```
>>> l2 = l.copy()
>>> l2
[1, 2, 3, [1, 2], [2, 3, 4, [1, 2, 3]], [3, 4, 5]]
>>> l[3][0] = 999
>>> l2
[1, 2, 3, [999, 2], [2, 3, 4, [1, 2, 3]], [3, 4, 5]]
>>> l
[1, 2, 3, [999, 2], [2, 3, 4, [1, 2, 3]], [3, 4, 5]]
```

- Shallow copy!!!!!!! (Please refer to tutorials)

deepCopy()

```
>>> l2 = deepMap(lambda x: x.copy() if type(x)==list else x, l)
>>> l2
[1, 2, 3, [1, 2], [2, 3, 4, [1, 2, 3]], [3, 4, 5]]
```

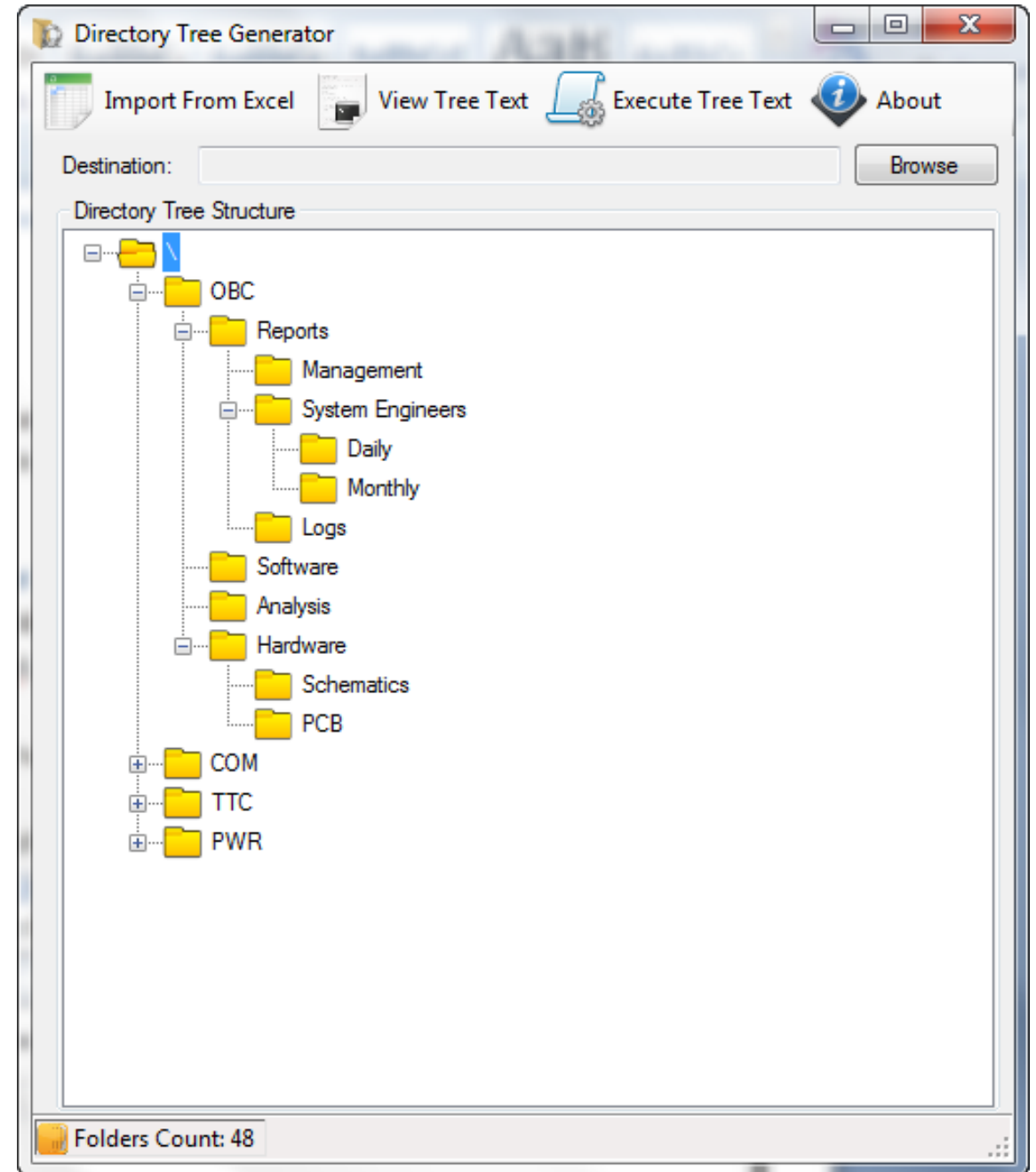
- And it works!

```
>>> l[3][0] = 999
>>> l
[1, 2, 3, [999, 2], [2, 3, 4, [1, 2, 3]], [3, 4, 5]]
>>> l2
[1, 2, 3, [1, 2], [2, 3, 4, [1, 2, 3]], [3, 4, 5]]
```


Why Do I Want to Go
“Deep”?

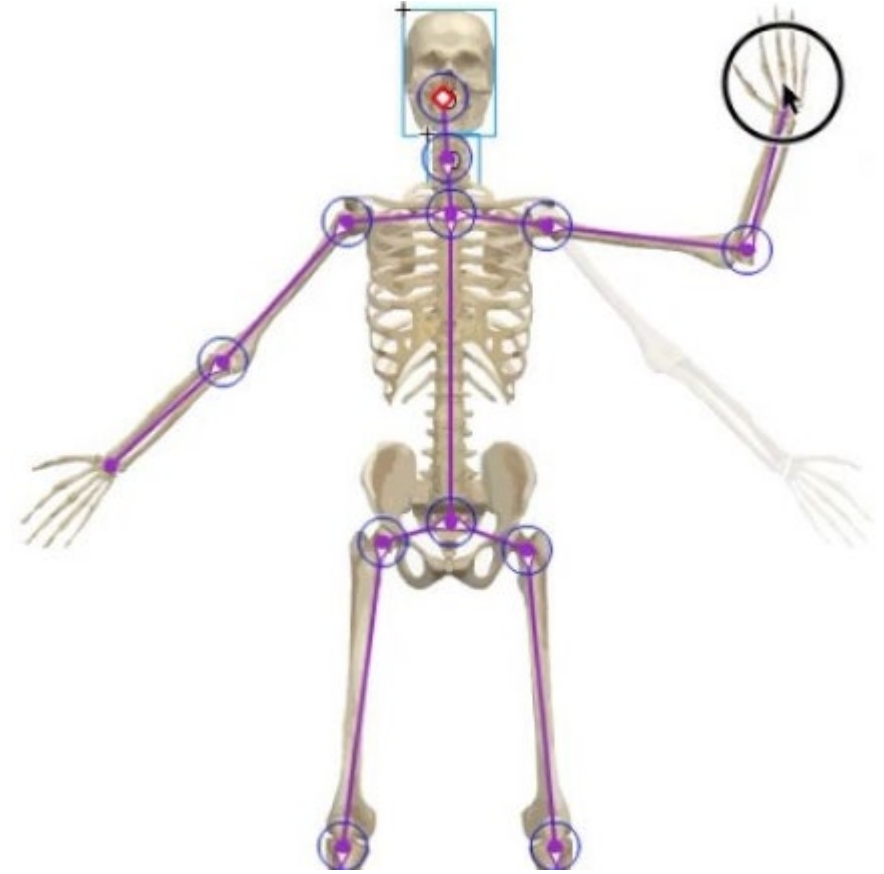
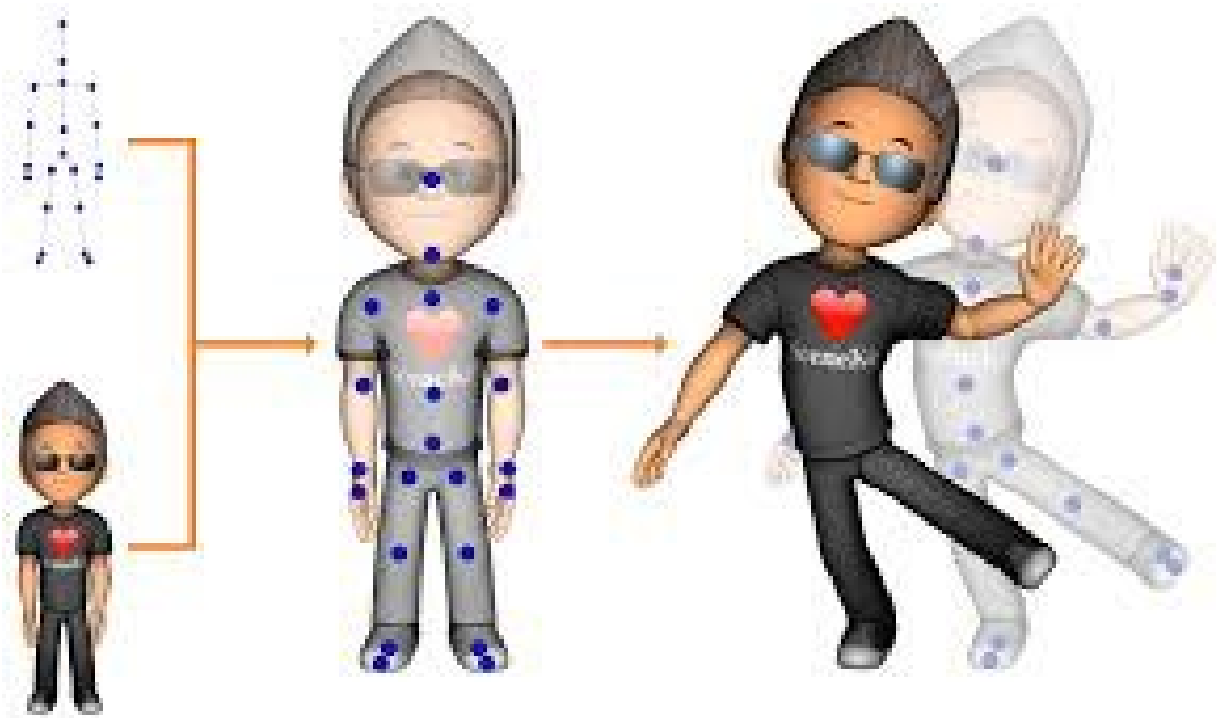
Copying a Directory

- When the directory contains a lot of files in many subdirectories



Computer Animation

- Skeleton animation



Shortest Path Tree

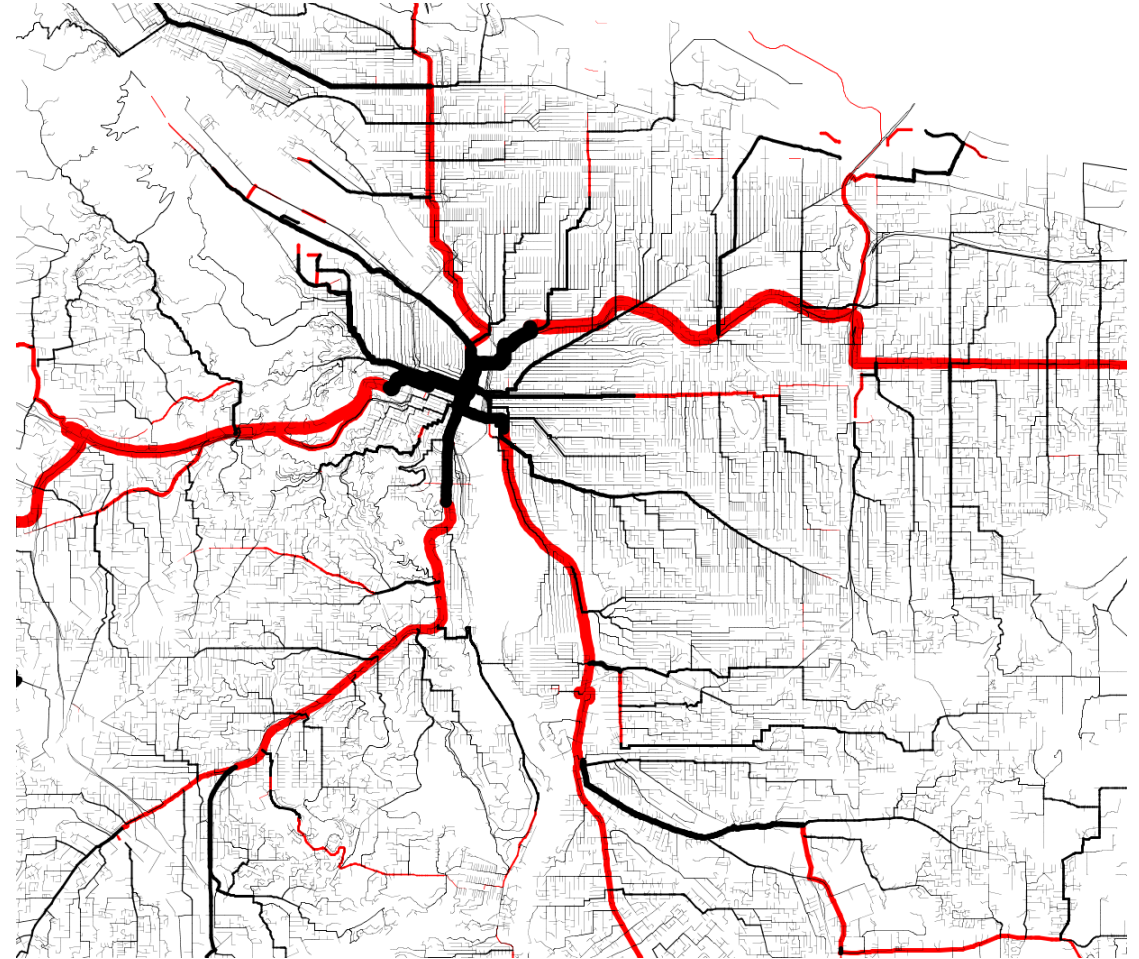
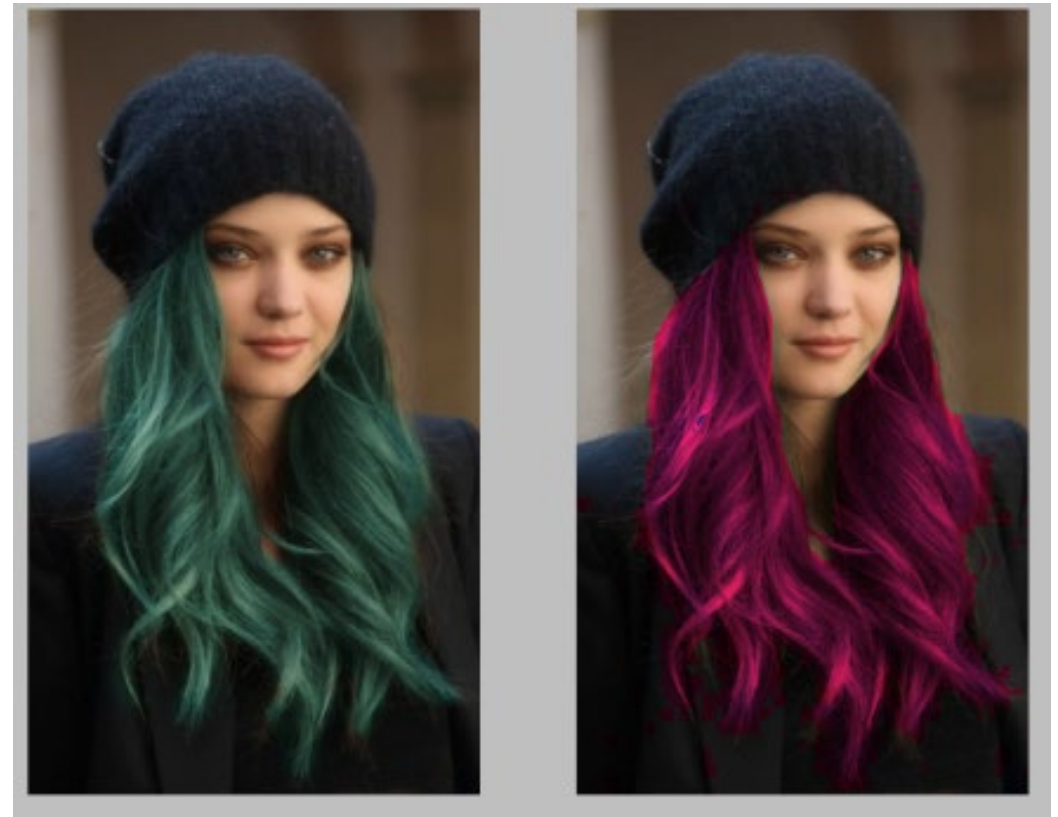


Image Processing

- An image is a list of lists of lists
 - The first level list: rows
 - The second level of lists: column
 - The third level of lists: RGB values
- Map a function to change certain values
 - E.g. change colors



How about if I just want to
be shallow?



How about if I just want to be shallow?

- Given a nested list, output a list with all the elements but without any

```
>>> l = [1, 2, 3, [1, 2], [2, 3, 4, [1, 2, 3]], [3, 4, 5]]  
>>> flatten(l)  
[1, 2, 3, 1, 2, 2, 3, 4, 1, 2, 3, 3, 4, 5]
```

Flatten()

```
def flatten(seq):  
    if seq == []:  
        return seq  
    elif type(seq) != list:  
        return [seq]  
    else:  
        return flatten(seq[0]) + flatten(seq[1:])
```

flatten([[[1]]])

flatten([[1]]) + flatten([])

flatten([1]) + flatten([]) + flatten([])

flatten(1) + flatten([]) + flatten([]) + flatten([])

[1] + flatten([]) + flatten([]) + flatten([])

Conclusions

- `map()` is a powerful tools in Python
 - Allows you to perform a lot of operations with less redundant code
- Deep operations are useful to solve problems with non-linear data
 - E.g. Trees, n-dim arrays, graphs
- Using recursive functions wisely is the key for algorithms
 - Higher level of coding