CSc 120
Introduction to Computer Programming II

Adapted from slides
by Dr. Saumya Debray

09: Python lists (aka “arrays”)

some performance puzzlers

Example 1: insert vs append

insert: adds an element into the middle of a list

```
>>> list0 = [1,2,3,4]
>>> list0
[1, 2, 3, 4]
>>> list0.insert(2, 'aaa')
>>> list0
[1, 2, 'aaa', 3, 4]
>>> list0.insert(3, 'bbb')
>>> list0
[1, 2, 'aaa', 'bbb', 3, 4]
>>> 
```

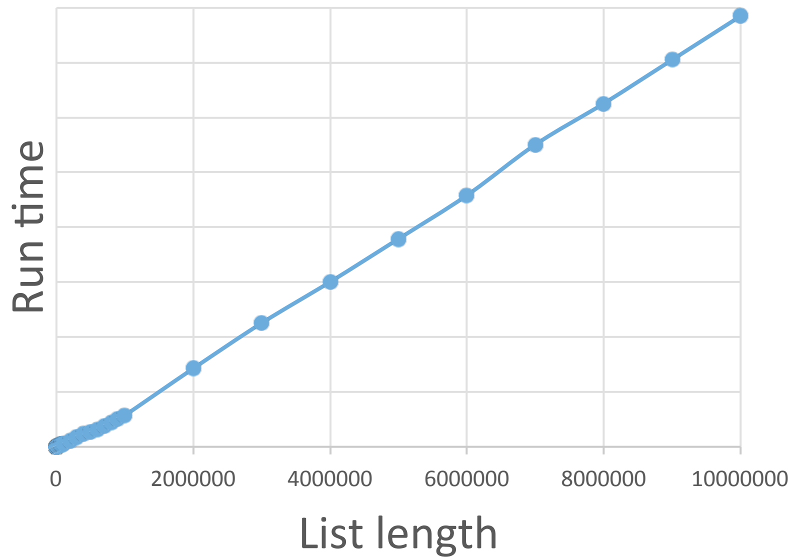
append: adds an element at the end of a list

```
>>> list0 = [1,2,3,4]
>>> list0
[1, 2, 3, 4]
>>> list0.append('aaa')
>>> list0
[1, 2, 3, 4, 'aaa']
>>> list0.append('bbb')
>>> list0
[1, 2, 3, 4, 'aaa', 'bbb']
>>> 
```

Example 1: insert vs append

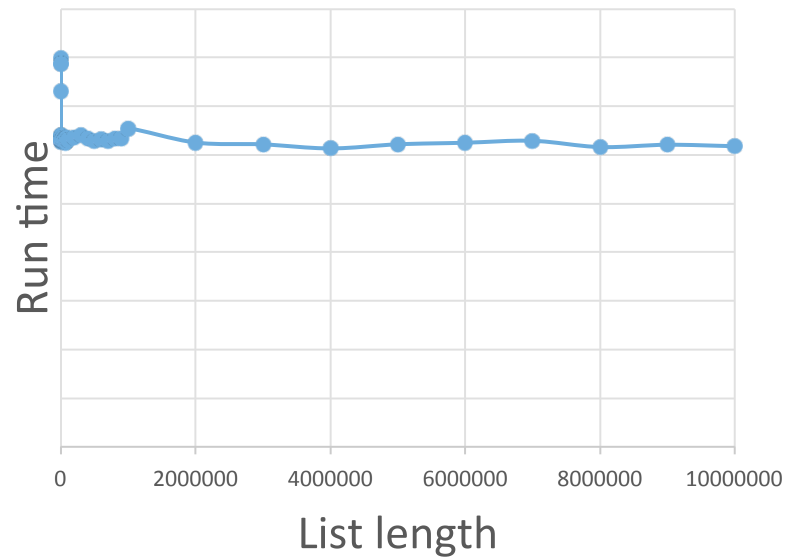
insert: adds an element into the middle of a list

```
list0 = mklist(n)         # length of list0 == n
list0.insert(n//2, 0)  # insert at midpoint
```



append: adds an element at the end of a list

```
list0 = mklist(n)
list0.append(0)  # add at the end
```



Why this difference?

Example 2: mk_nxn_list

 # given a number n > 0, return an n x n list-of-lists of n

Version 1

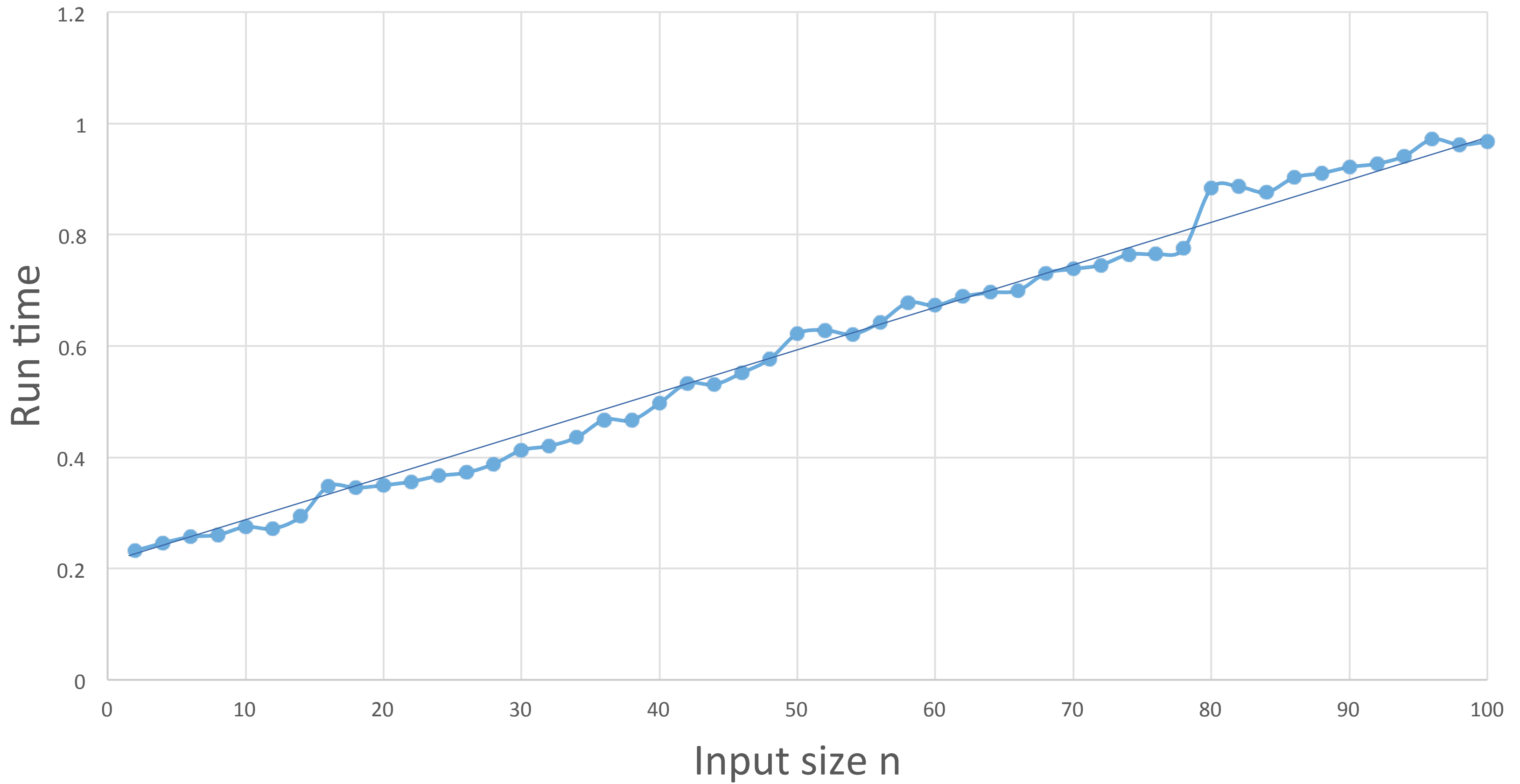
```
def mk_nxn_list(n):
    return [[n]*n]*n
```

Version 2

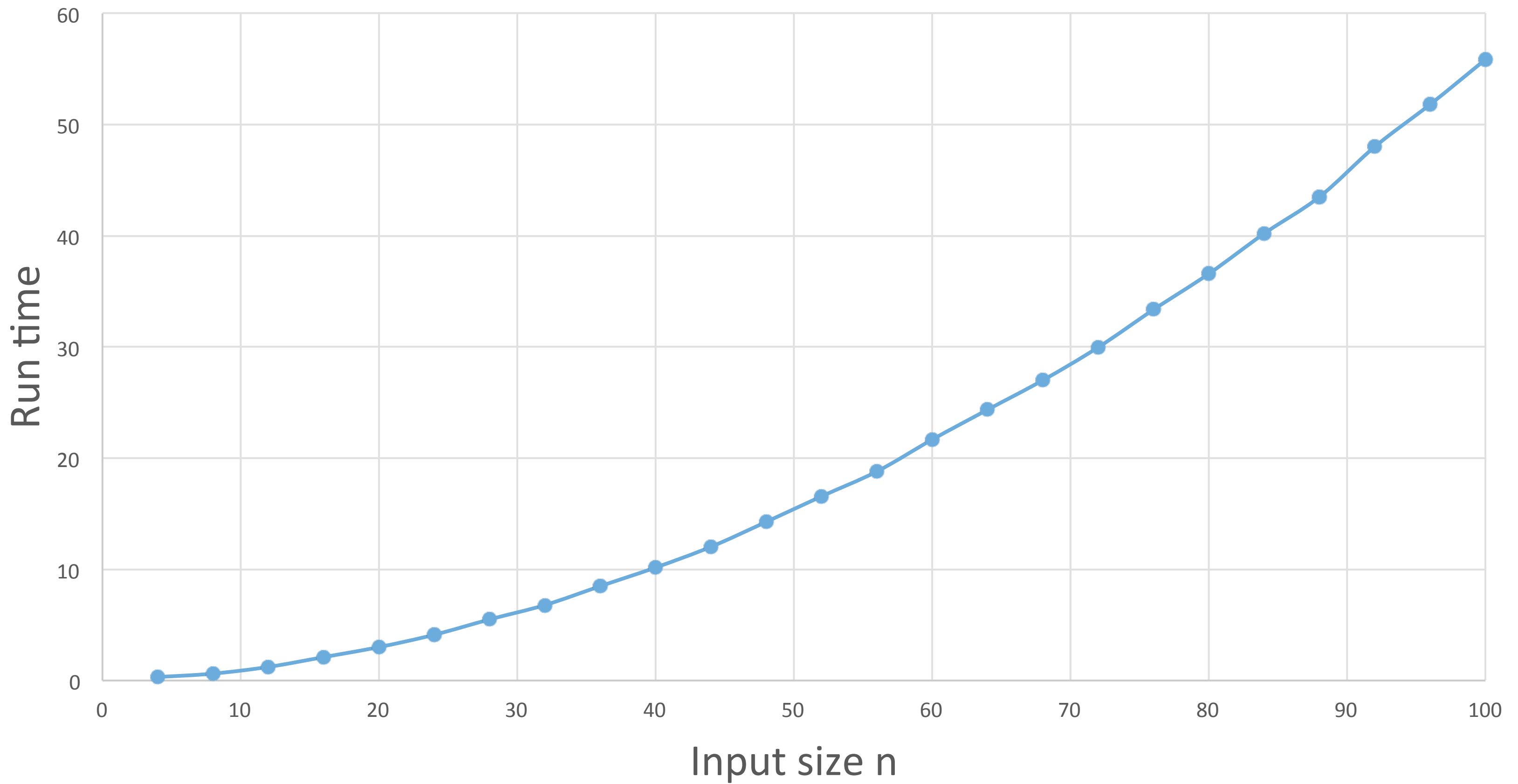
```
def mk_nxn_list(n):
    outlist = []
    for i in range(n):
        row_i = []
        for j in range(n):
            row_i.append(n)
        outlist.append(row_i)
    return outlist
```

```
>>> mk_nxn_list(2)
[[2, 2], [2, 2]]
>>> mk_nxn_list(3)
[[3, 3, 3], [3, 3, 3], [3, 3, 3]]
>>> mk_nxn_list(4)
[[4, 4, 4, 4], [4, 4, 4, 4], [4, 4, 4, 4],
 [4, 4, 4, 4]]
>>> |
```

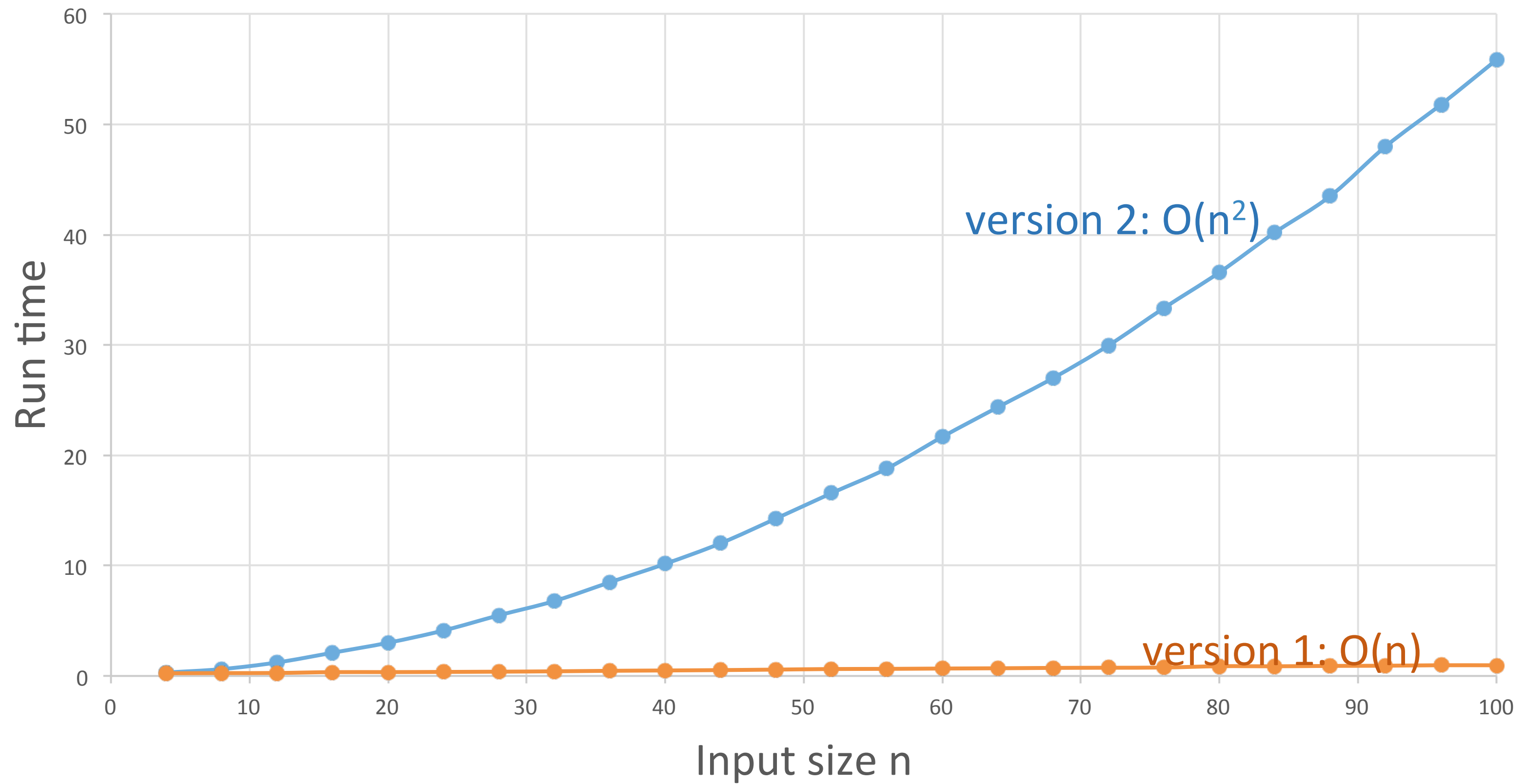
mk_nxn_list(n) version 1



mk_nxn_list(n) version 2



mk_nxn_list(n) both versions



Why this difference?

data organization in memory

Data organization in memory

insert: adds an element into the middle of a list

```
>>> list0 = [1,2,3,4]
>>> list0
[1, 2, 3, 4]
>>> list0.insert(2, 'aaa')
>>> list0
[1, 2, 'aaa', 3, 4]
>>> list0.insert(3, 'bbb')
>>> list0
[1, 2, 'aaa', 'bbb', 3, 4]
>>> 
```

append: adds an element at the end of a list

```
>>> list0 = [1,2,3,4]
>>> list0
[1, 2, 3, 4]
>>> list0.append('aaa')
>>> list0
[1, 2, 3, 4, 'aaa']
>>> list0.append('bbb')
>>> list0
[1, 2, 3, 4, 'aaa', 'bbb']
>>> 
```

- The organization of lists in memory affects the implementation of primitive operations

Data organization in memory

Consider list insertion

```
>>> list0 = [1,2,3,4]
>>> list0
[1, 2, 3, 4]
>>> list0.insert(2, 'aaa')
>>> list0
[1, 2, 'aaa', 3, 4]
>>> list0.insert(3, 'bbb')
>>> list0
[1, 2, 'aaa', 'bbb', 3, 4]
>>> |
```

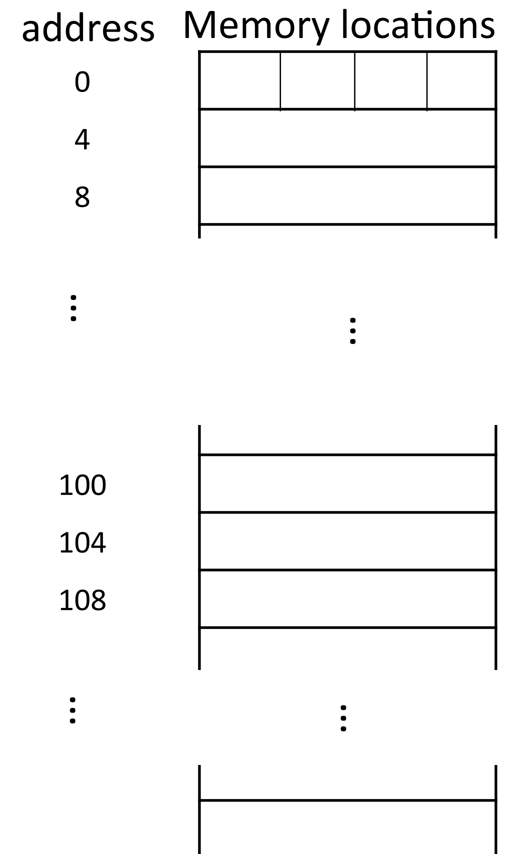
- The organization of this data in memory affects the primitive operations

- This affects the complexity of algorithms that work on the data

Data organization in memory

- Computer memory is organized as a sequence of *locations*
  - each location is identified by its *address* (a number)
  - a location typically consists of 8 bits (a "byte")
  - bytes are often grouped into "words" (32 or 64 bits)

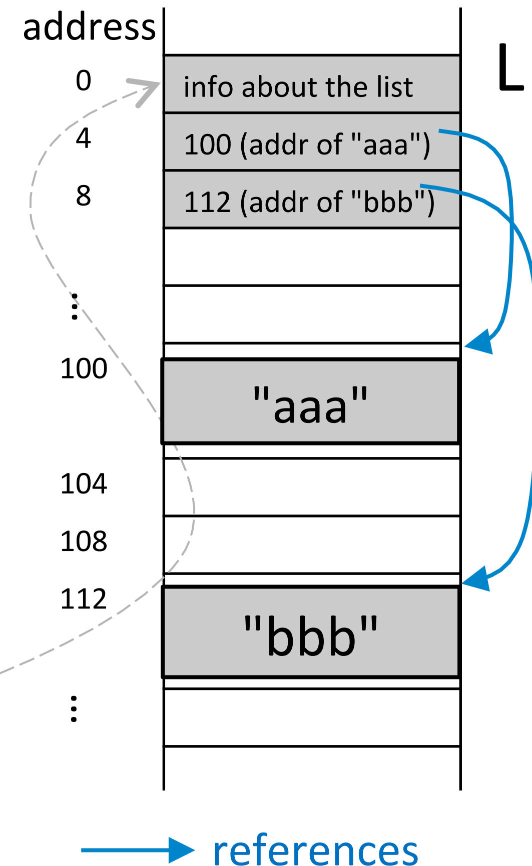
⇒ A location (or word) can only hold a limited amount of data



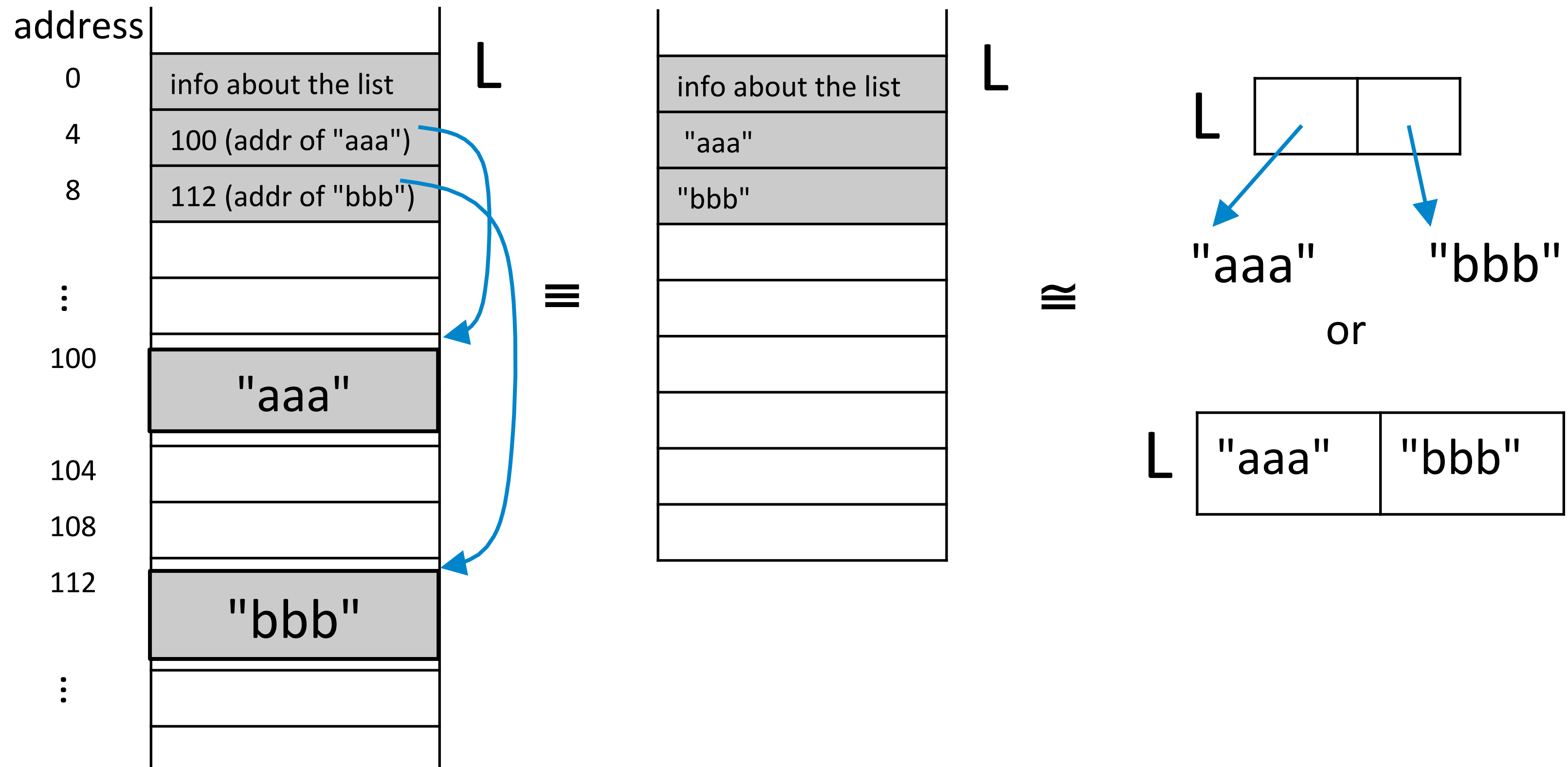
Data organization in memory

- A memory location can hold only a limited amount of data
- An object typically spans multiple memory locations
- Data are organized as follows:
  - objects and values are placed where memory is available
  - the object's memory address is used as a *reference* to it

E.g.: for L = ["aaa", "bbb"]



Data organization in memory

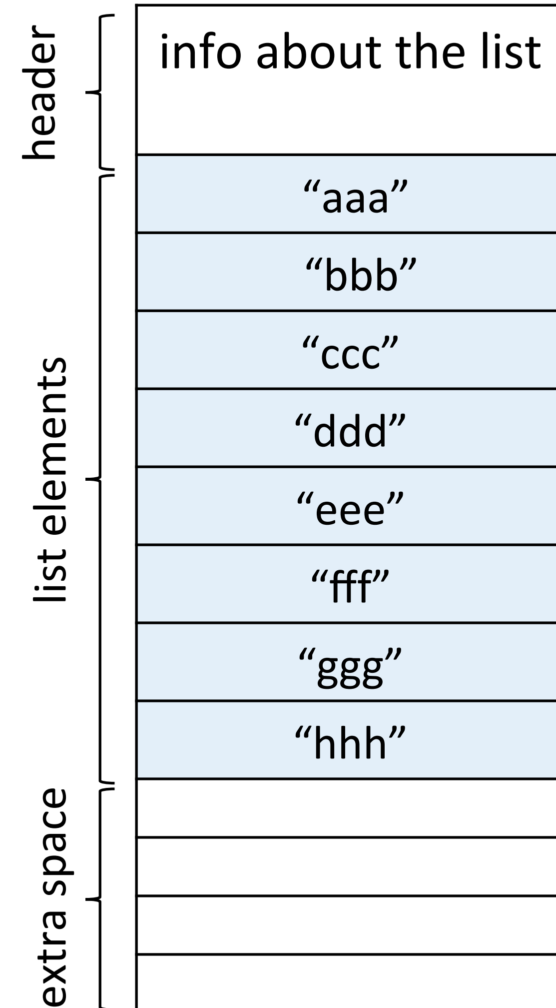


we typically write these data structures in a way that abstracts away actual address values

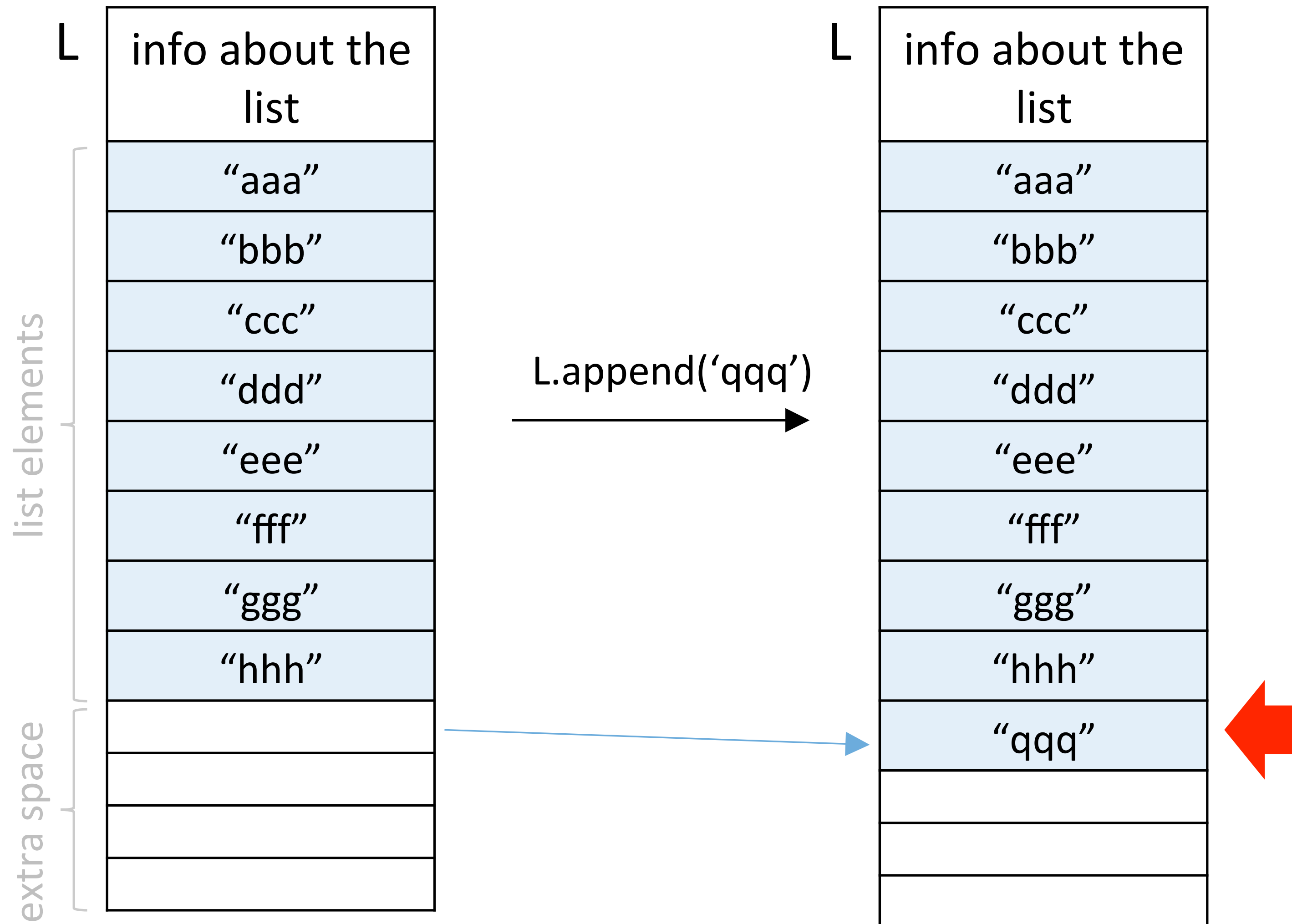
insert vs. append

List (array) organization in Python

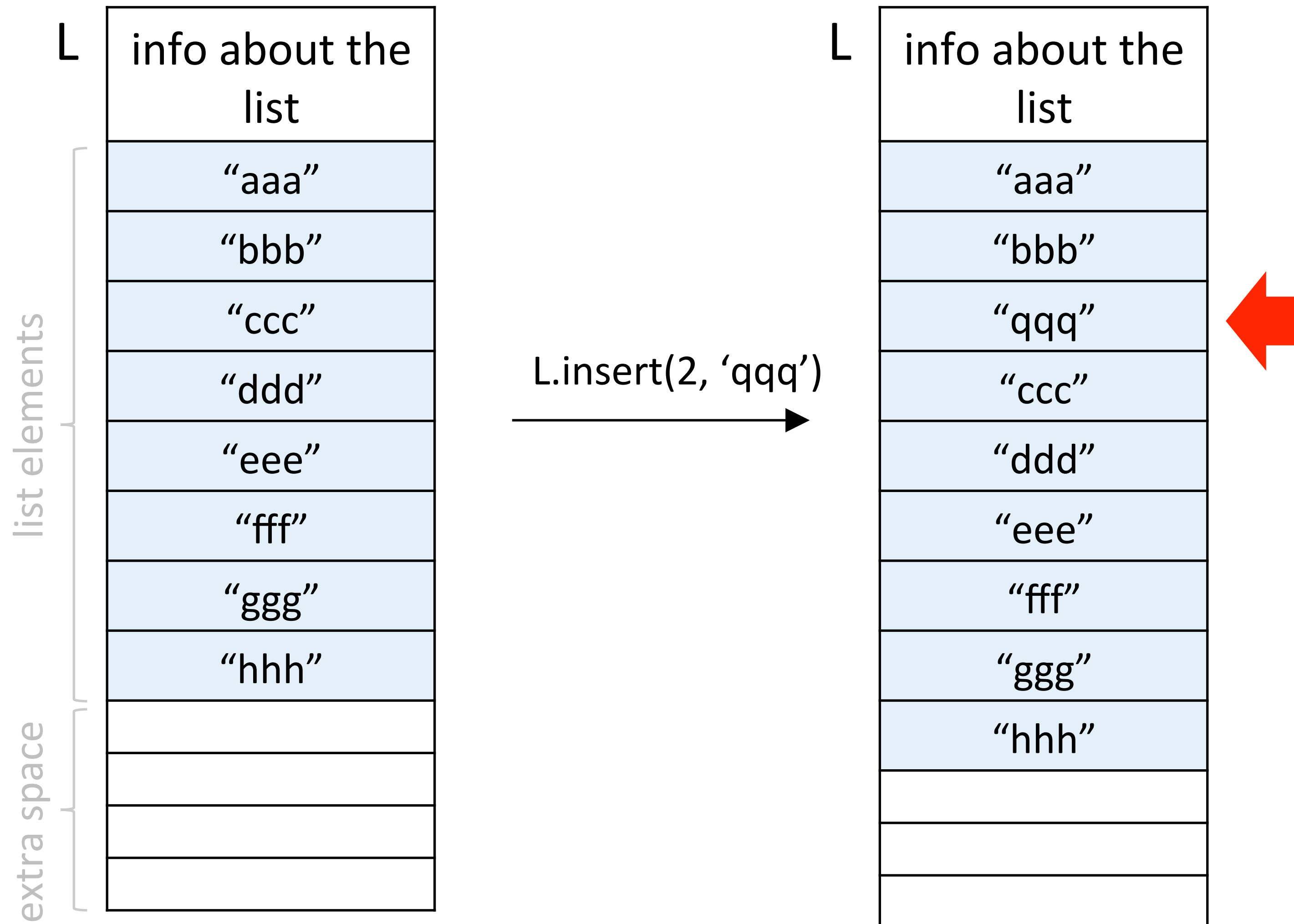
- (References to) the list elements are kept in a contiguous sequence of memory words
  - there is a little extra space at the end to give it some room to grow
- The following operations are O(1):
  - len()
    - read off length info from the header
  - accessing the ith element of the list
    - compute its address using the value of i
    - access memory location at that address



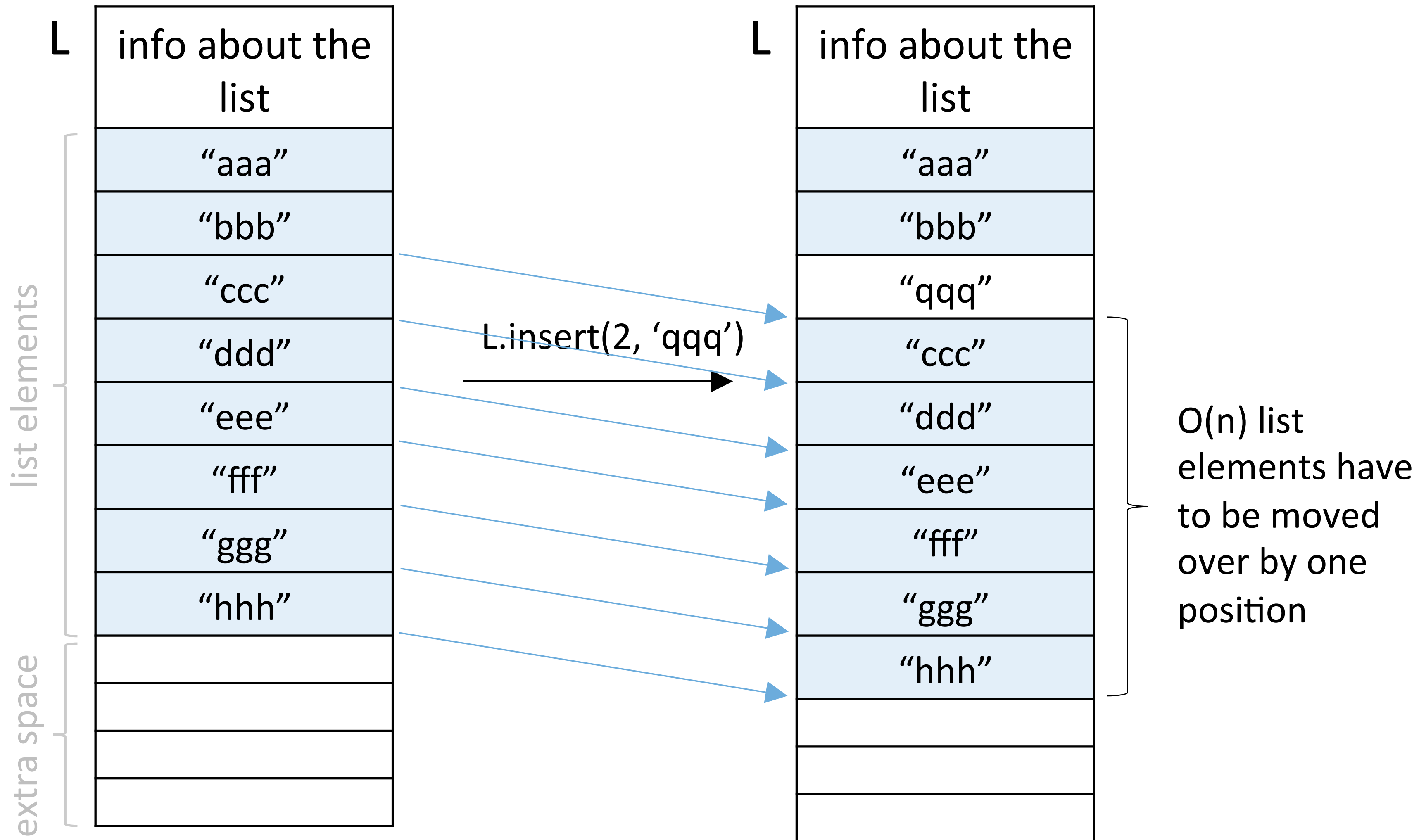
Appending to a list O(1)



Inserting into a list



Inserting into a list O(n)



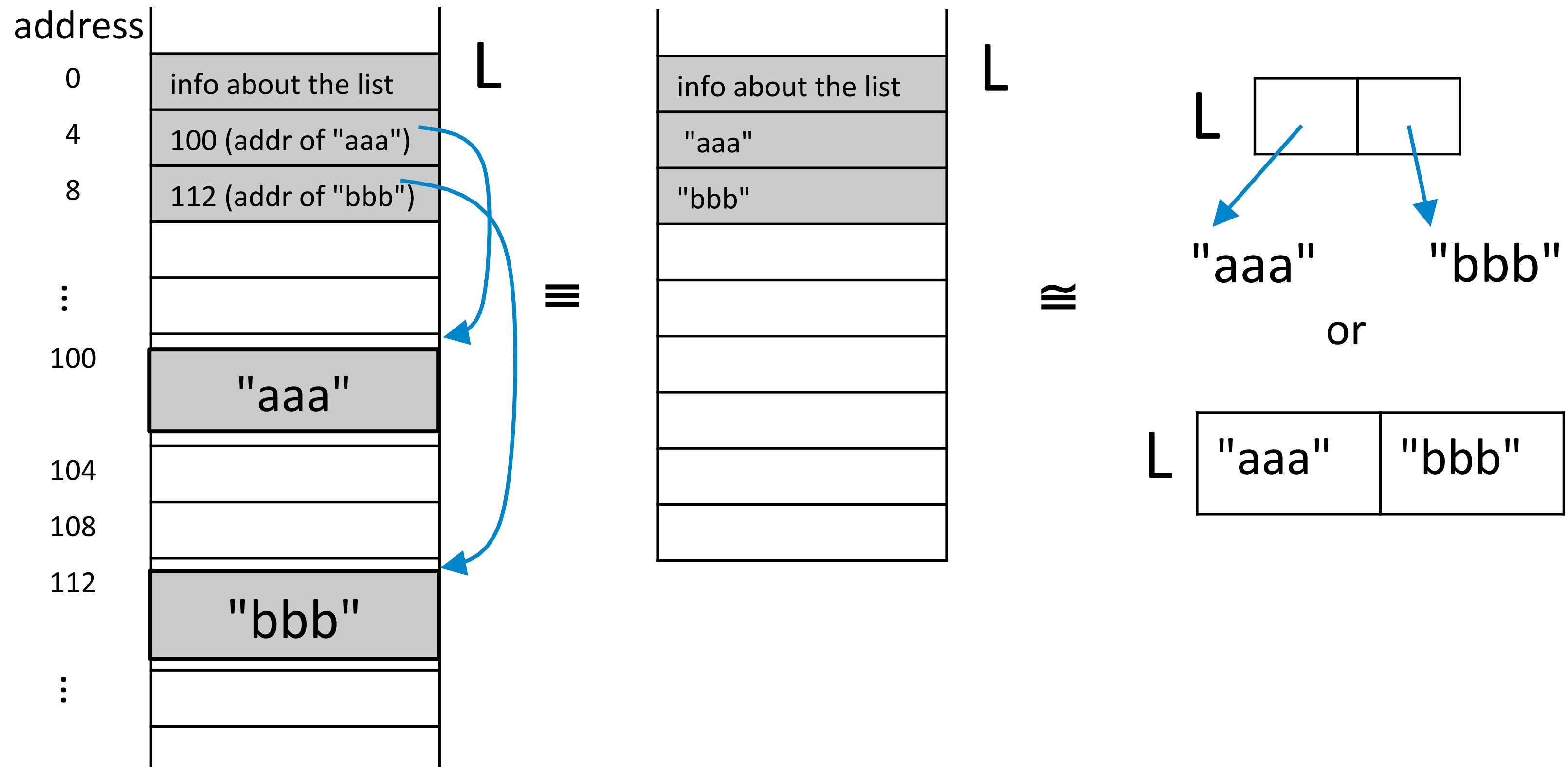
Python lists: complexity summary

Operation	Complexity
len	O(1)
access an element's value	O(1)
append	O(1)
insert, delete	O(n)

Q: Can we do insert in O(1) time?

(The complexity of other operations may change)

Data organization in memory



Given references, what happens when we copy a list?

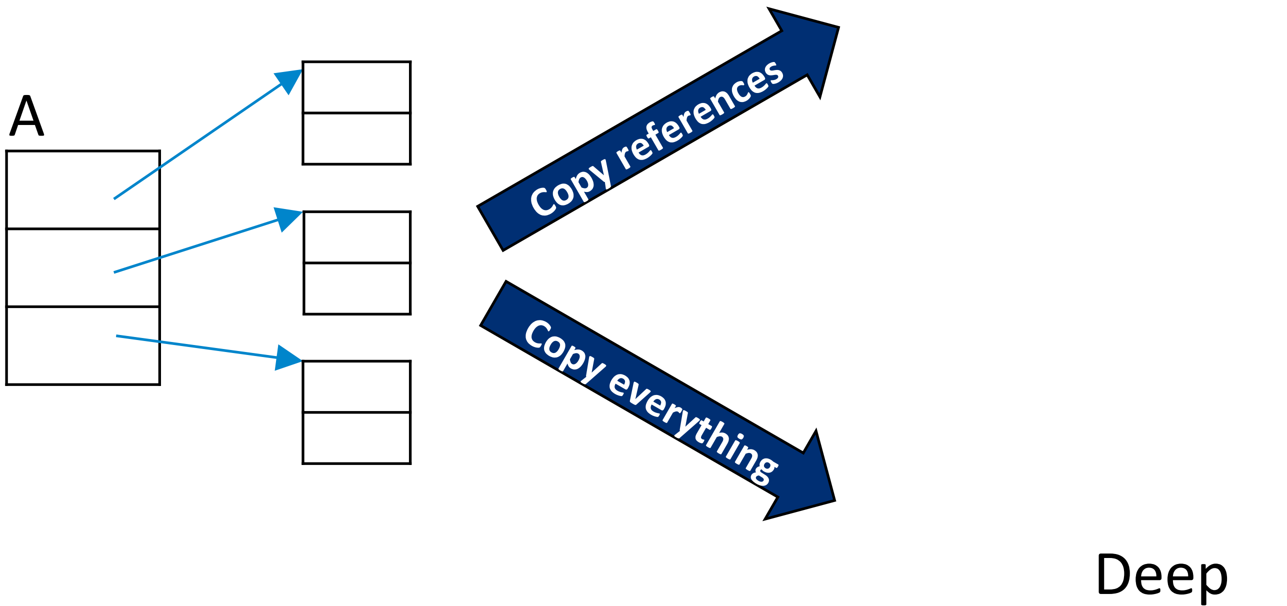
shallow vs. deep copying

Shallow vs. deep copying

For a *compound object A* (i.e., an object that contains references to other objects, e.g., lists, dictionaries):

- shallow copying:
  - creates a copy A' of *A*
  - inserts into A' references to the objects in A
- deep copying:
  - creates a copy A' of A
  - inserts into A' references to deep copies of objects in A

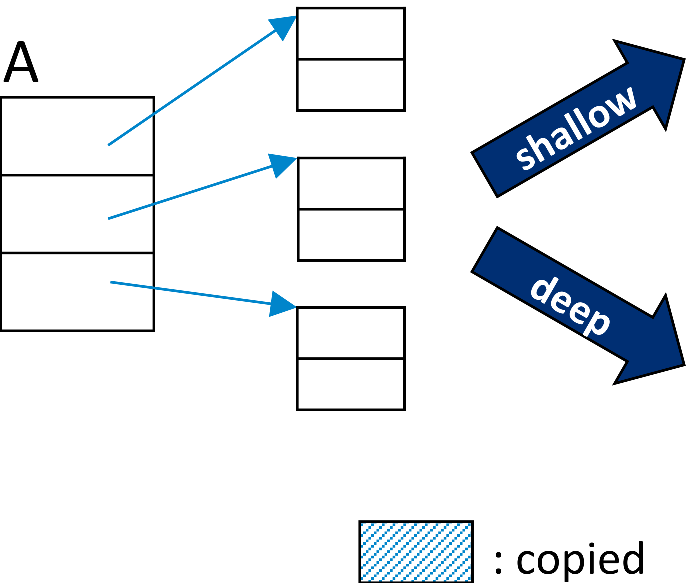
References and “copy”

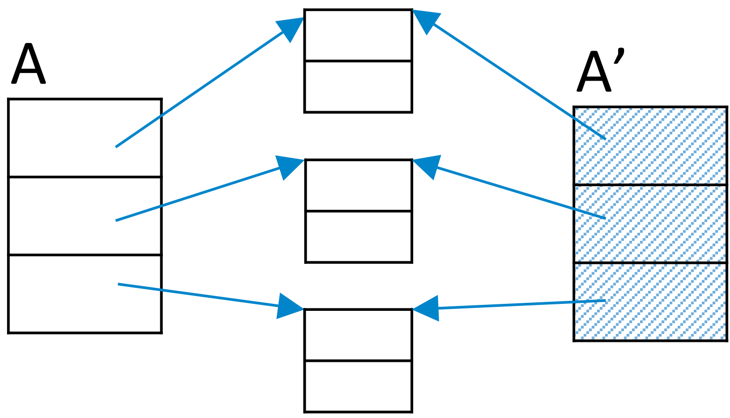


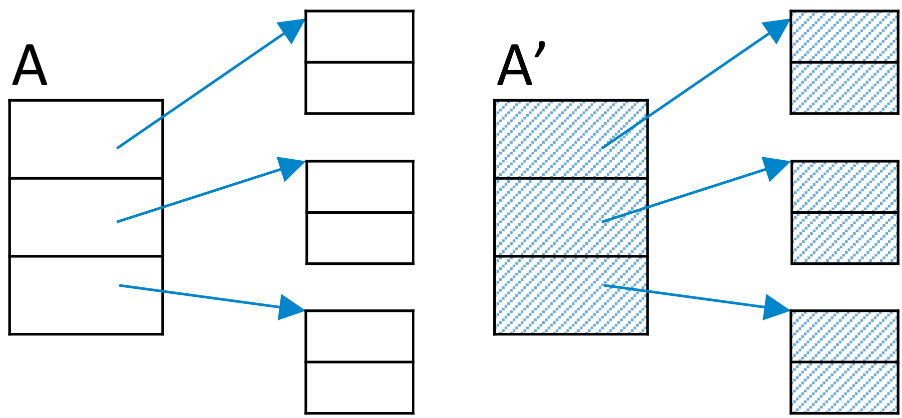
Shallow

Deep

Shallow vs. deep copying







Shallow vs. deep copying

```
def mk_nxn_list(n):
    return [[n]*n]*n
```

Shallow vs. deep copying

```
def mk_nxn_list(n):
    return [[n]*n]*n
```

n

time: O(1)

Shallow vs. deep copying

```
def mk_nxn_list(n):
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```
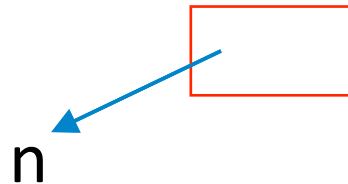
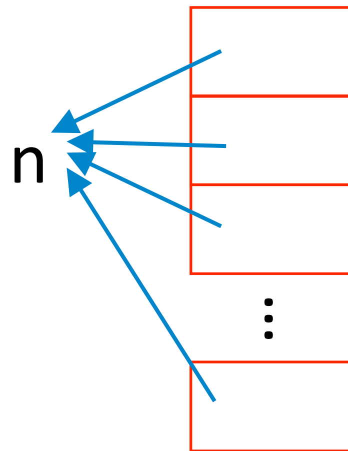



time: O(1)

Shallow vs. deep copying

```
def mk_nxn_list(n):
    return [[n]*n]*n
```

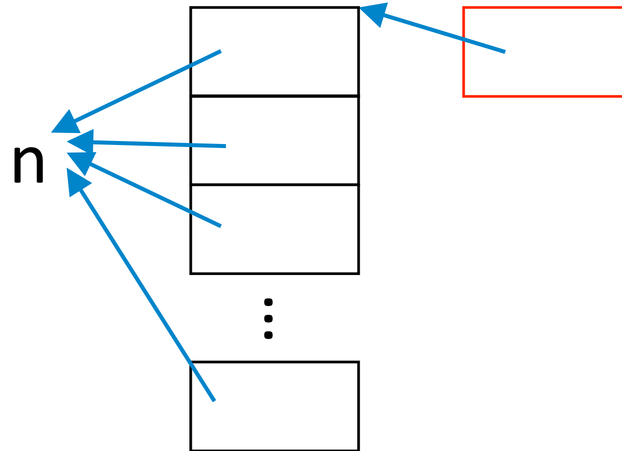
time: O(n)



Shallow vs. deep copying

```
def mk_nxn_list(n):
    return [[n]*n]*n
```

time: O(1)



Shallow vs. deep copying

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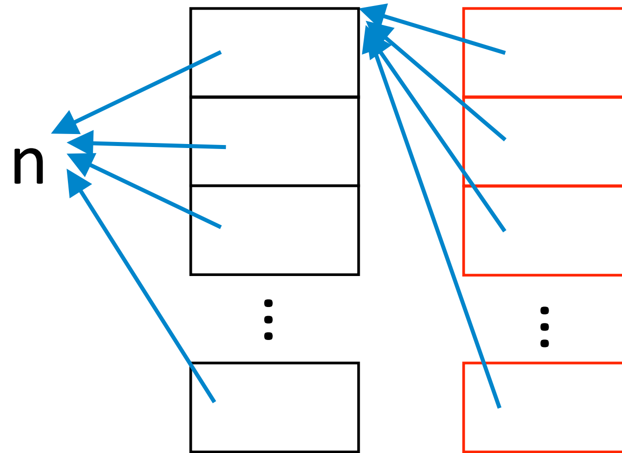
time: O(n)



Shallow vs. deep copying

```
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```
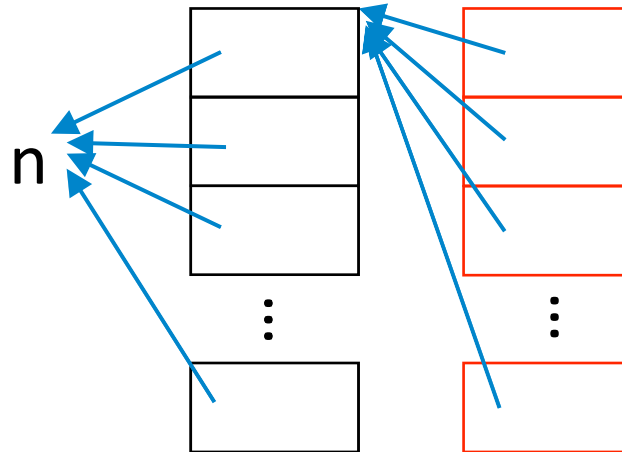
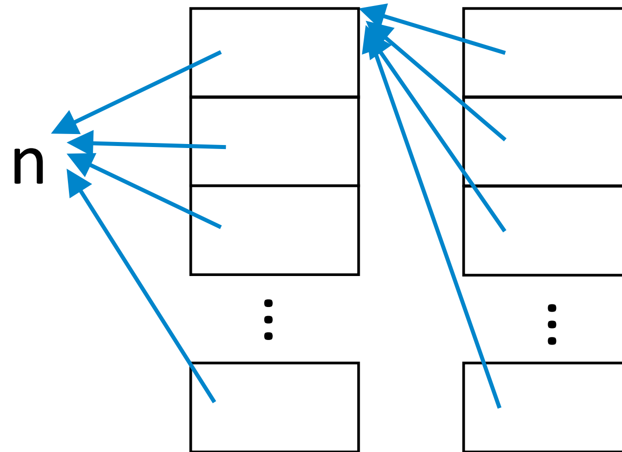

time: O(n)



Shallow vs. deep copying

```
def mk_nxn_list(n):
    return [[n]*n]*n
```

Overall: O(n)



Shallow vs. deep copying

```
def mk_nxn_list(n):
    outlist = []
    for i in range(n):
        row_i = []
        for j in range(n):
            row_i.append(n)
        outlist.append(row_i)
  return outlist
```

Shallow vs. deep copying

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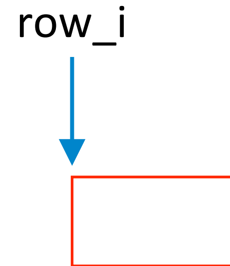

O(1)

Shallow vs. deep copying

```
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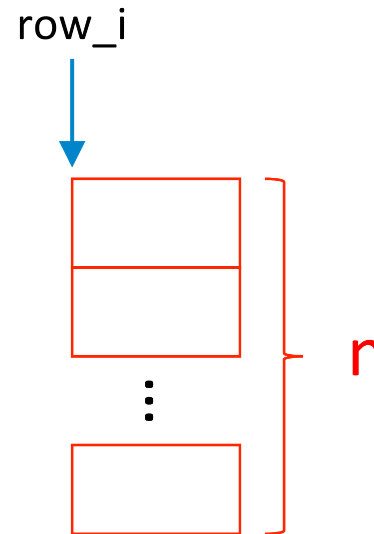

O(n)

Shallow vs. deep copying

```
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    return outlist
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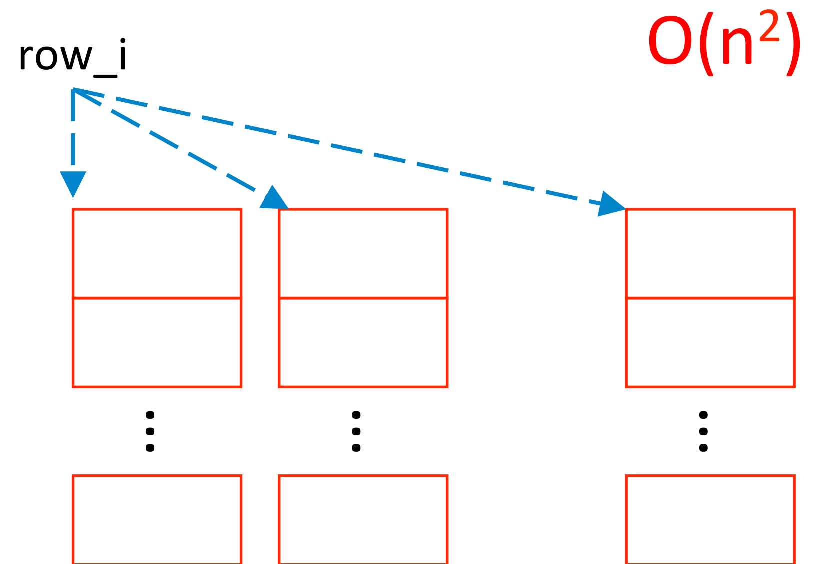

Shallow vs. deep copying

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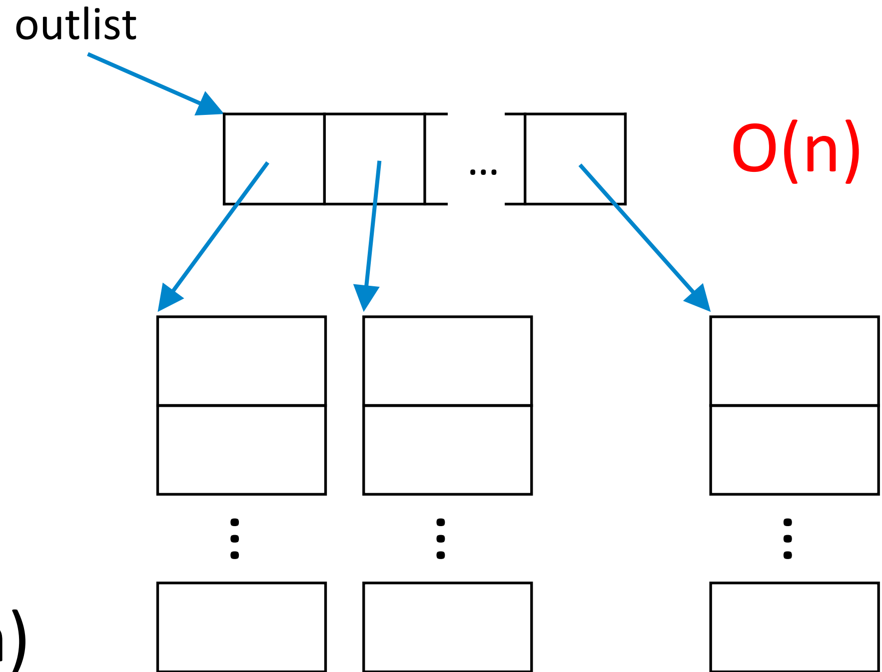
```



Shallow vs. deep copying

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```
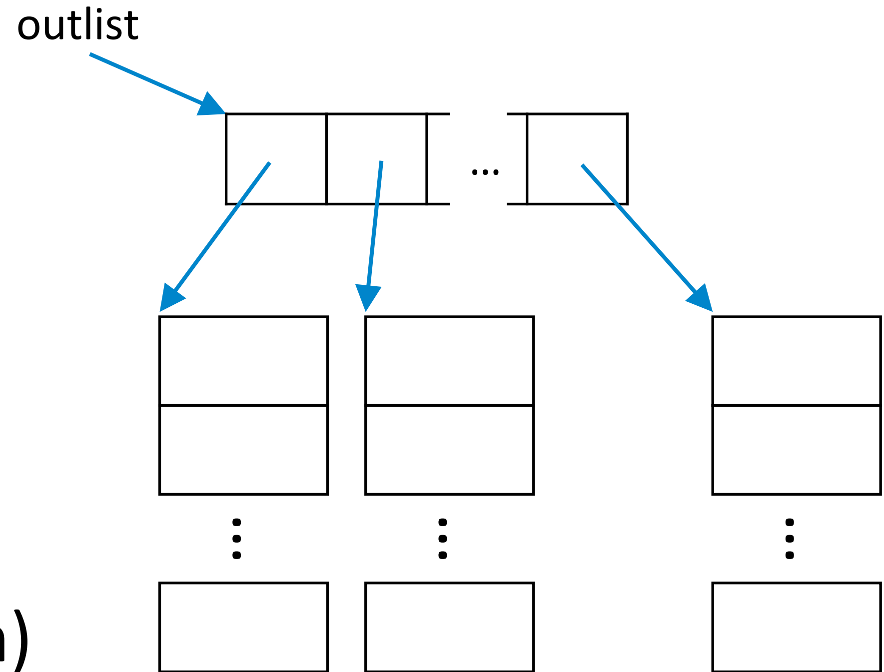



Overall: $O(n^2)$

Shallow vs. deep copying: howto

Shallow copy	Deep copy

```
>>> import copy
>>> x = [[1,2,3],[4,5,6]]
>>> y = copy.copy(x)
>>> y
[[1, 2, 3], [4, 5, 6]]
>>> x[0].append('abc')
>>> y
[[1, 2, 3, 'abc'], [4, 5, 6]]
>>> |
```

```
>>> import copy
>>> x = [[1,2,3],[4,5,6]]
>>> y = copy.deepcopy(x)
>>> y
[[1, 2, 3], [4, 5, 6]]
>>> x[0].append('pqr')
>>> x
[[1, 2, 3, 'pqr'], [4, 5, 6]]
>>> y
[[1, 2, 3], [4, 5, 6]]
>>> |
```

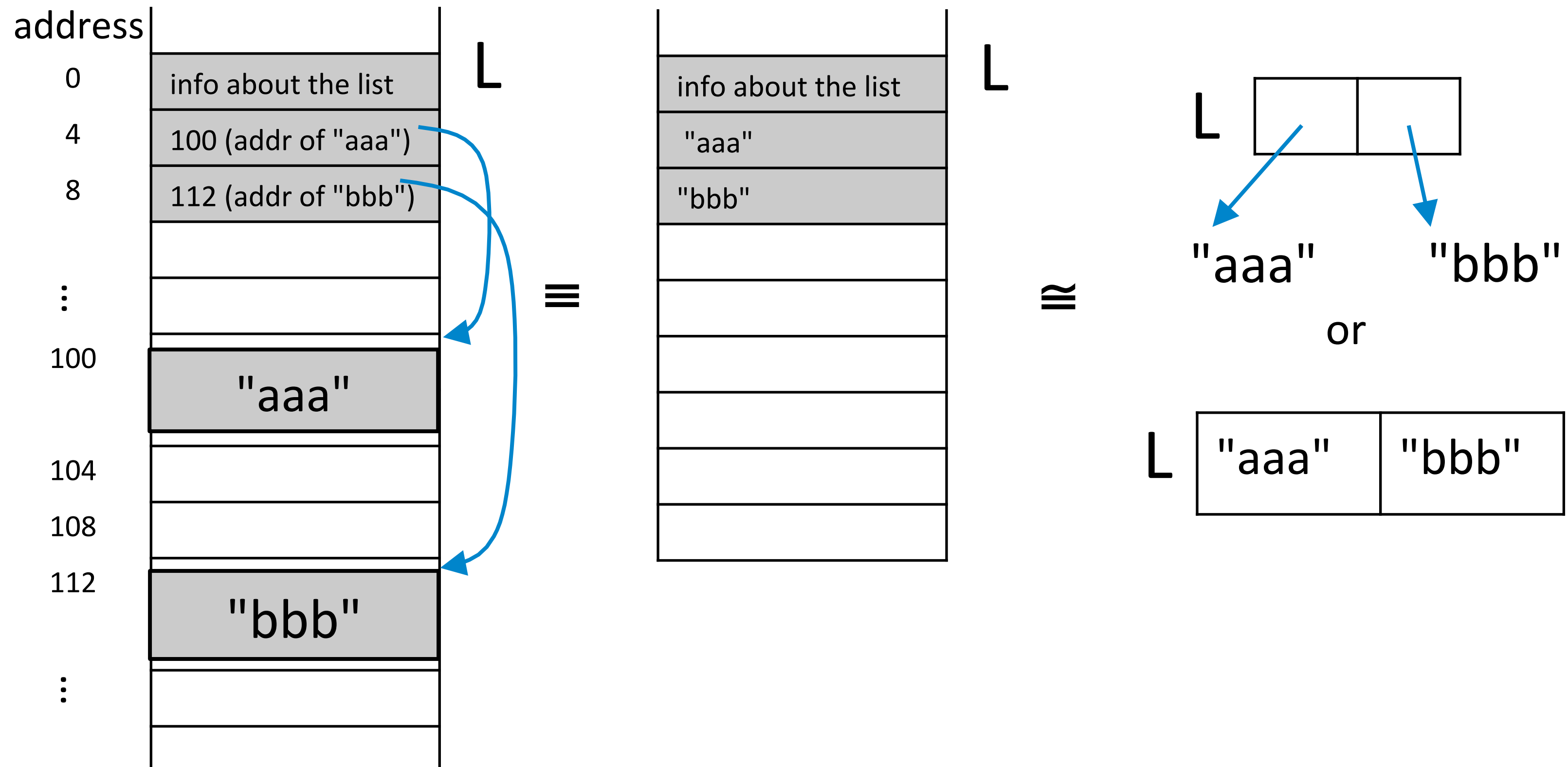
Summary

- Shallow vs. deep copying:
  - applies to any object, not just lists
  - how to:
    - import copy
    - copy.copy(obj), copy.deepcopy(obj)
  - shallow copying more efficient, but creates "aliases" that can cause weird behaviors

Aliases

- Aliasing occurs when more than one variable contains the same reference to the same object
- A *reference* is a location in memory
- Aliases are created when lists (and compound objects) are copied
- Aliases are also created through assignment

Data organization in memory



we will use the simplified diagram of a list for the next example

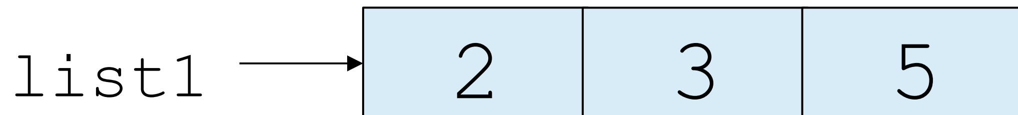
Example: aliasing

What is the content of each list after the following assignment statements?

```
list1 = [2,3,5]
list2 = [7,11,13]
list3 = list1
list4 = list1+list2

list1[2] = -3
list3.append("foo")
list4[0] = None
```

Example: aliasing

```
list1 = [2,3,5]
list2 = [7,11,13]
list3 = list1
list4 = list1+list2

list1[2] = -3
list3.append("foo")
list4[0] = None
```

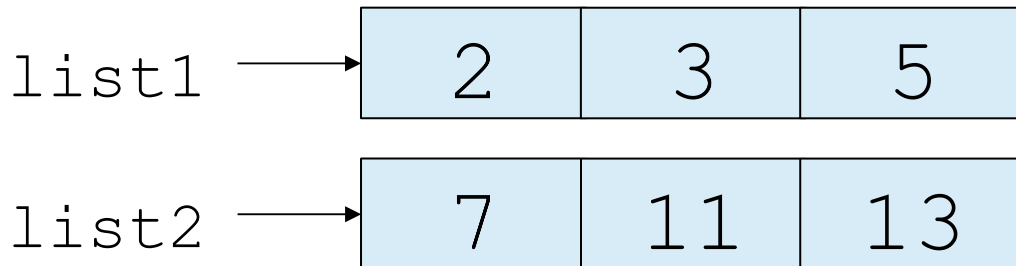


Remember, a list doesn't actually contain the values – it contains references to other objects.

But for simplicity, we often draw the object inside the list itself.

Example: aliasing

```
list1 = [2,3,5]
list2 = [7,11,13]
list3 = list1
list4 = list1+list2

list1[2] = -3
list3.append("foo")
list4[0] = None
```



Example: aliasing

```
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list3 = list1
list4 = list1+list2

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list4[0] = None
```
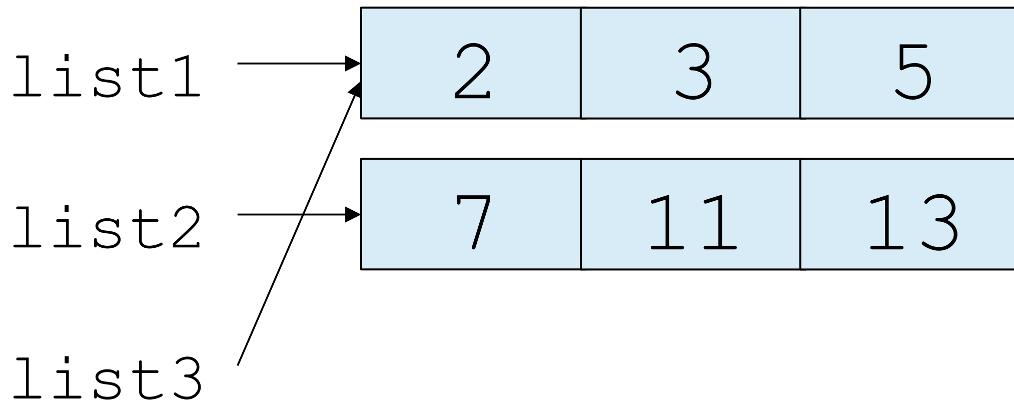
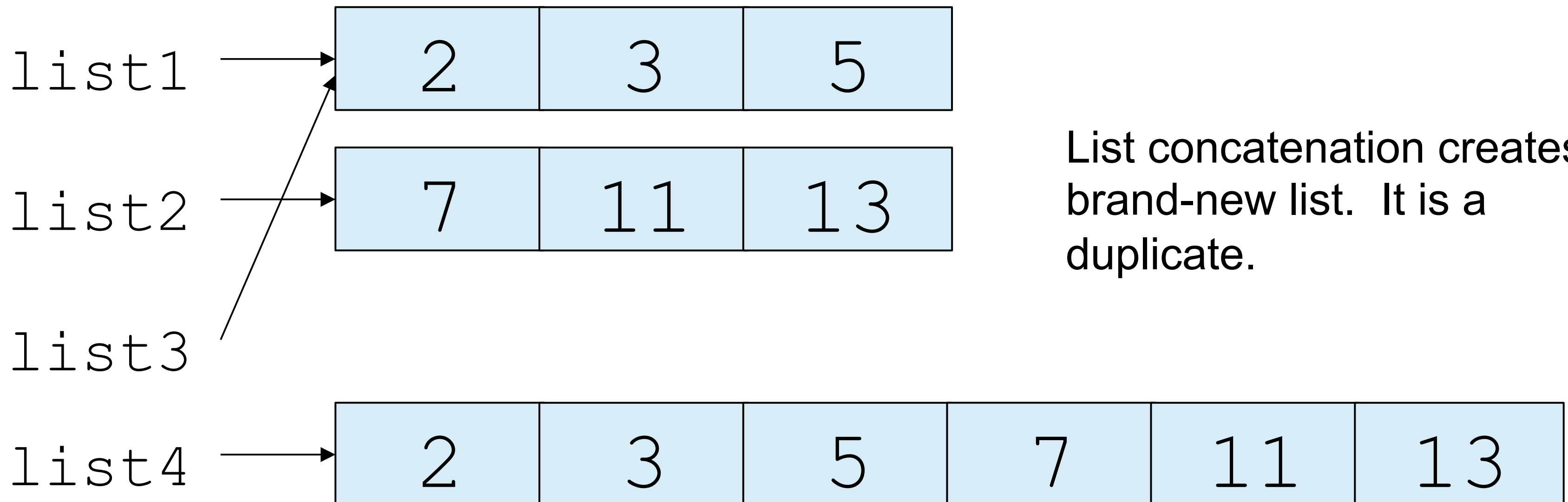



Assigning a list to a new variable creates an alias.

Example: aliasing

```
list1 = [2,3,5]
list2 = [7,11,13]
list3 = list1
list4 = list1+list2

list1[2] = -3
list3.append("foo")
list4[0] = None
```



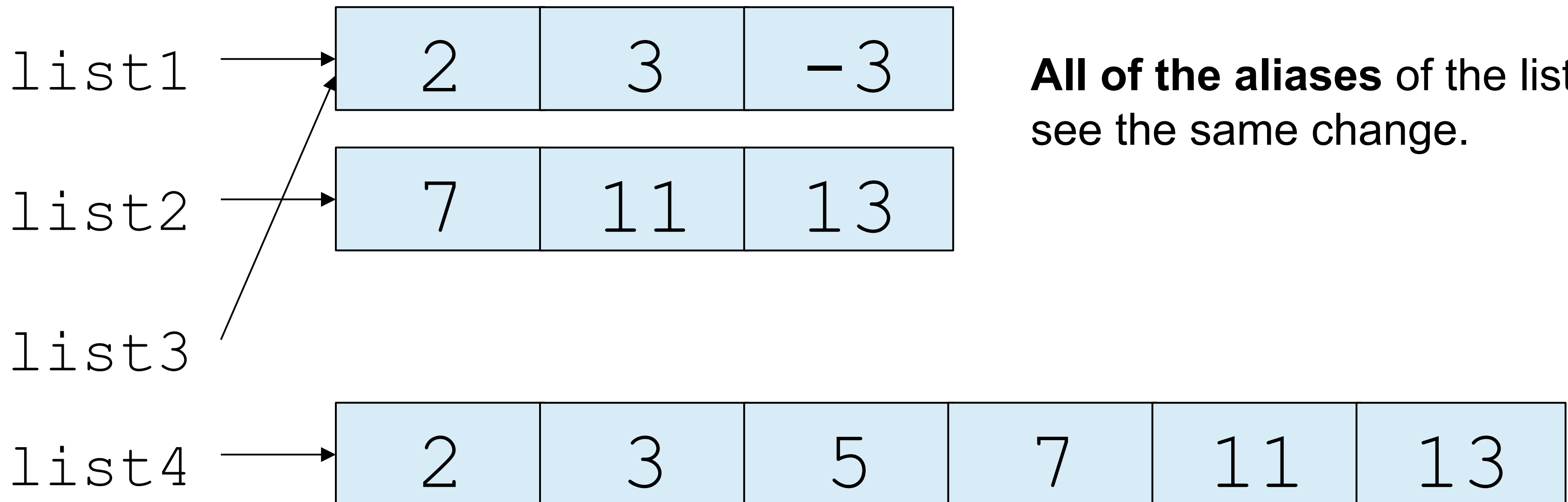
List concatenation creates a brand-new list. It is a duplicate.

```
list1 = [2,3,5]
list2 = [7,11,13]
list3 = list1
list4 = list1+list2

list1[2] = -3
list3.append("foo")
list4[0] = None
```

Example: aliasing

Changing a value inside a list changes one element.

All of the aliases of the list see the same change.

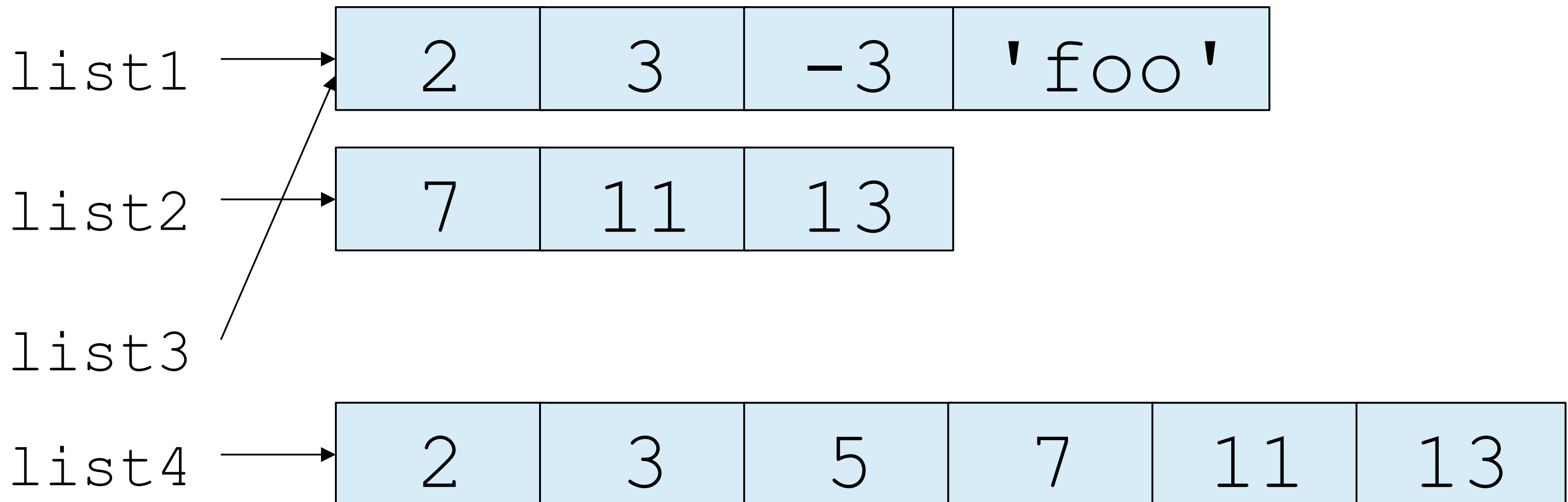


```
list1 = [2,3,5]
list2 = [7,11,13]
list3 = list1
list4 = list1+list2

list1[2] = -3
list3.append("foo")
list4[0] = None
```

Example: aliasing

In the same way,
.append()
modifies the list (and thus all aliases of it). It does **NOT** create a new list.

So .append() and + are different.

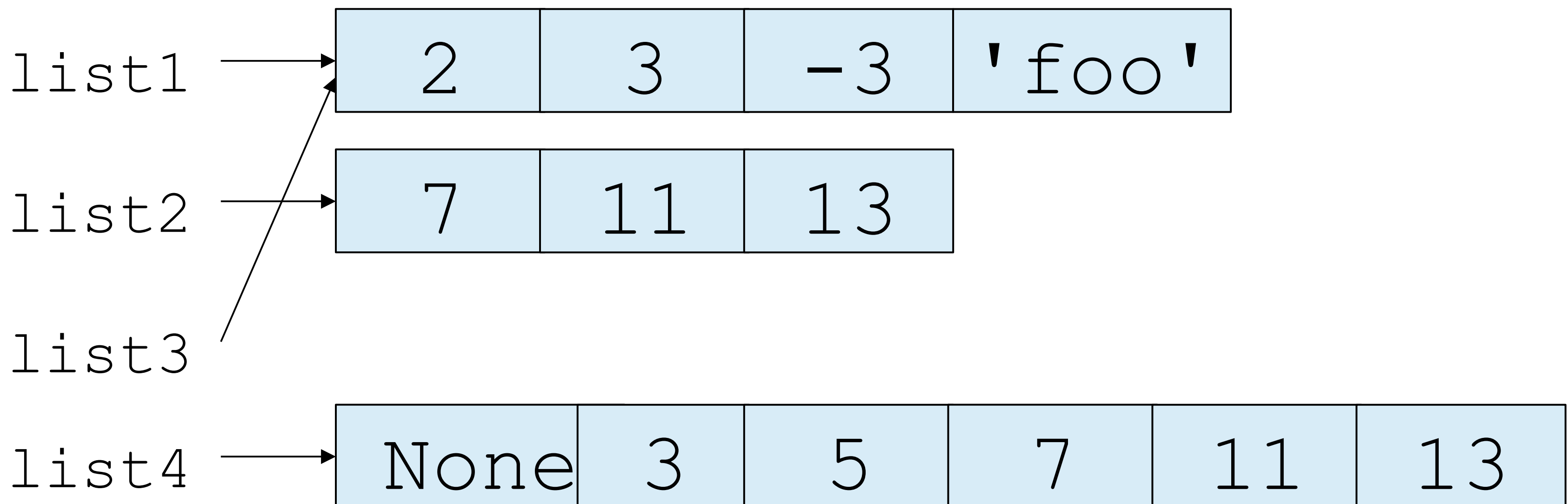


Example: aliasing

```
list1 = [2,3,5]

list2 = [7,11,13]
list3 = list1
list4 = list1+list2

list1[2] = -3
list3.append("foo")
list4[0] = None
```

There is not an alias to `list4`.

The assignment does not affect the other lists.



Summary

- Python lists ("arrays"): properties
  - len : O(1)
  - accessing an element by index: O(1)
  - append: O(1)
  - insert, delete: O(n)
- Shallow vs. deep copying:
  - applies to any object, not just lists
  - how to:
    - import copy
    - copy.copy(obj), copy.deepcopy(obj)
  - shallow copying more efficient, but creates "aliases" that can cause weird behaviors
  - assignment also create aliases

timing programs

```python
import time

def mklist(n):
    outlist = []
    for i in range(n):
        outlist.append(n)
    return outlist

# estimate overhead of timing loop
def get_overhead(niters):
    start_time = time.time()
    for i in range(niters):
        pass
    stop_time = time.time()
    overhead = stop_time - start_time
    return overhead

# do the timing
def do_time(listsz_start, listsz_stop, niters, overhead):
    listsz = listsz_start
    insertion_pt = listsz//2
    delta = 100
    while listsz <= listsz_stop:
        x = mklist(listsz)
        start_time = time.time()
        for i in range(niters):
            x.insert(insertion_pt, 0)
        stop_time = time.time()
        ave_time = (stop_time-start_time-overhead)/niters

        print("{:d}, {:f}".format(listsz, ave_time))

        if listsz >= 10*delta:
            delta *= 10
        listsz += delta    # next list size to try


def main():
    niters = 10000
    overhead = get_overhead(niters)
    do_time(100, 10000000, niters, overhead)

main()
```

```python
# do the timing
def do_time(listsz_start, listsz_stop, niters, overhead):
    listsz = listsz_start
    insertion_pt = listsz//2
    delta = 100
    while listsz <= listsz_stop:
        x = mklist(listsz)
        start_time = time.time()
        for i in range(niters):
            x.insert(insertion_pt, 0)
        stop_time = time.time()
        ave_time = (stop_time-start_time-overhead)/niters

        print("{:d}, {:f}".format(listsz, ave_time))

        if listsz >= 10*delta:
            delta *= 10
        listsz += delta    # next list size to try
```

```python
# estimate overhead of timing loop
def get_overhead(niters):
    start_time = time.time()
    for i in range(niters):
        pass
    stop_time = time.time()
    overhead = stop_time - start_time
    return overhead
```

```python
def main():
    niters = 10000
    overhead = get_overhead(niters)
    do_time(100, 10000000, niters, overhead)
```