Lists

- List syntax
- List operations
- copy.deepcopy
- range
- while-else
- for
- for-break-continue-else

List operations

- List syntax `[`*value*$_0$`,` *value*$_1$`, ...,` *value*$_{k\text{-}1}$`]`
- List indexing `L[`*index*`]`, `L[-`*index*`]`
- ★ List slices `L[`*from*`:`*to*`]`, `L[`*from*`:`*to*`:`*step*`]` or `L[slice(`*from*`,`*to*`,`*step*`)]`
- ★ Creating a copy of a list `L[:]` or `L.copy()`
- ★ List concatenation (creates new list) `X + Y`
- ★ List repetition (repeated concatenation with itself) `42 * L`
- Length of list `len(L)`
- Check if element is in list `e in L` (returns `True` or `False`)
- Check if element is not in list `e not in L` (same as `not e in L`)
- Index of first occurrence of element in list `L.index(e)`
- Number of occurrences of element in list `L.count(e)`
- `sum(L)` `min(L)` `max(L)`

★ = creates new list

docs.python.org/3/library/stdtypes.html#sequence-types-list-tuple-range

sum(...)

Python 3.12 change

Python shell

```
> 1 - 1/3 - 1 + 1/3  # mathematically should be zero
| 5.551115123125783e-17  # but floats are imprecise
> L = [1, -1/3, -1, 1/3]
> L
| [1, -0.3333333333333333, -1, 0.3333333333333333]  # mix of int and float
> sum(L)
| 5.551115123125783e-17
> sum([1.0, -1/3, -1.0, 1/3])  # all floats
| 5.551115123125783e-17  # Python 3.11
> sum([1.0, -1/3, -1.0, 1/3])
| 0.0  # Python 3.12 uses "Neumaier summation" to improve accuracy for floats
> sum([1, -1/3, -1, 1/3])
| 5.551115123125783e-17  # Python 3.12 looses accuracy when mixing int and float
> import math
> math.fsum([1, -1/3, -1, 1/3])  # math.fsum more accurate float sums
| 0.0
```

List modifiers (lists are mutable)

- Extend list with elements (`X` is modified) `X.extend(Y)`
- Append an element to a list (`L` is modified) `L.append(42)`
- Replace sublist by another list (length can differ) `X[i:j] = Y`
- Delete elements from list `del L[i:j:k]`
- Remove & return element at position `L.pop(i)`
- Remove first occurrence of element `L.remove(e)`
- Reverse list `L.reverse()`
- `L *= 42`
- `L.insert(i, x)` same as `L[i:i] = [x]`

Python shell

```
> x = [1, 2, 3, 4, 5]
> x[2:4] = [10, 11, 12]
> x
| [1, 2, 10, 11, 12, 5]
> x = [1, 2, 11, 5, 8]
> x[1:4:2] = ['a', 'b']
| [1, 'a', 11, 'b', 8]
```

docs.python.org/3/library/stdtypes.html#sequence-types-list-tuple-range

Questions – What is `x` ?

```
x = [1,2,3,4,5,6,7,8,9,10]
x[2:8:3] = ['a', 'b']
```

a) `[1,2,'a','b',5,6,7,8,9,10]`

b) `[1,'a',3,4,5,6,7,'b',9,10]`

c) `[1,2,3,4,5,6,7,'a','b']`

d) `[1,2,'a',4,5,'b',7,8,9,10]`

e) ValueError

f) Don’t know

Questions – What is `y` ?

```
y = [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19]
y = y[3:15:3][1:4:2]
```

a) `[3,6,9,12,15]`

 b) `[7,13]`

c) `[1,9]`

d) `[4,7,10,13,2,4]`

e) TypeError

f) Don’t know

Nested lists (multi-dimensional lists)

- Lists can contain lists as elements, that can contain lists as elements, that ...
- Can e.g. be used to store multi-dimensional data (list lengths can be non-uniform)

Note: For dealing with matrices the NumPy module is a better choice

multidimensional-lists.py

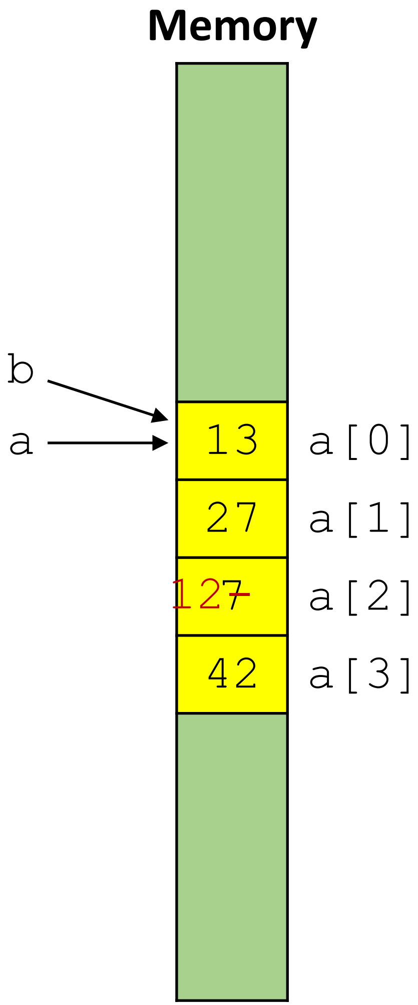
```
list1d = [1, 3, 5, 2]
list2d = [[1, 2, 3, 4],
          [5, 6, 7, 9],
          [0, 8, 2, 3]]
list3d = [[[5,6], [4,2], [1,7], [2,4]],
          [[1,2], [6,3], [2,5], [7,5]],
          [[3,8], [1,5], [4,3], [2,4]]]

print(list1d[2])
print(list2d[1][2])
print(list3d[2][0][1])
```

Python shell

```
| 5
| 7
| 8
```

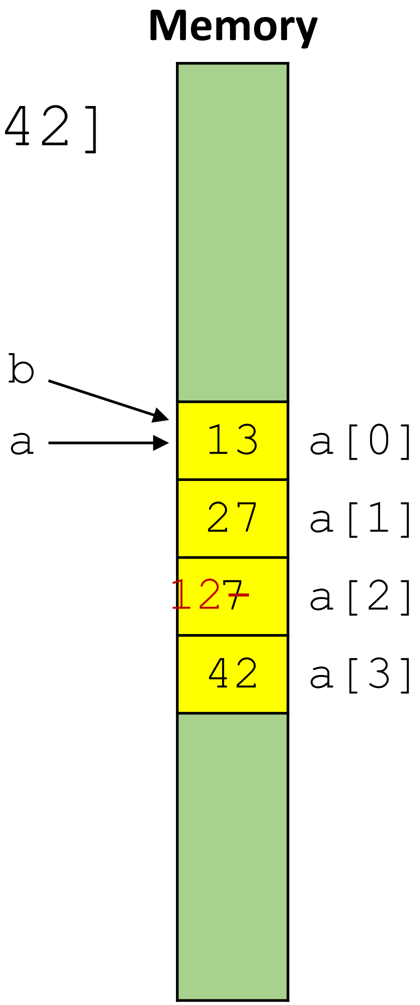
aliasing

```
a = [13, 27, 7, 42]
b = a
a[2] = 12
```

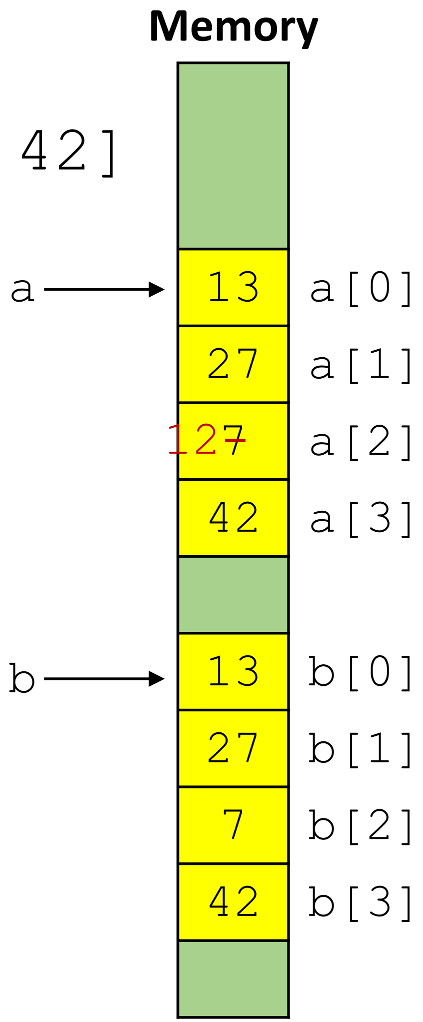


y = x vs y = x[:]

```
a = [13, 27, 7, 42]
b = a
a[2] = 12
```

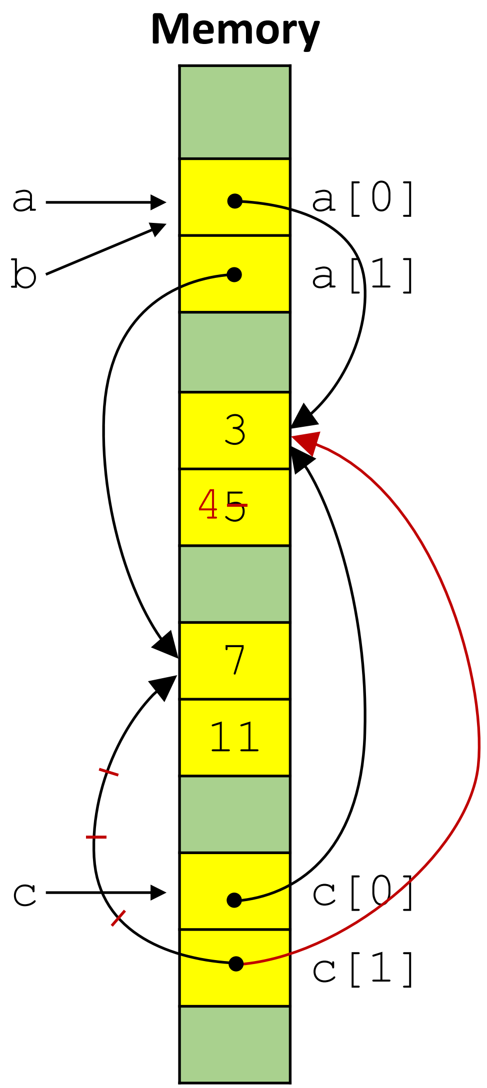



```
a = [13, 27, 7, 42]
b = a[:]
a[2] = 12
```



`x[:]` vs nested structures

```
a = [[3,5],[7,11]]
b = a
c = a[:]
a[0][1] = 4
c[1] = b[0]
```



Question – what is `c` ?

a) `[[3,5],[7,11]]`

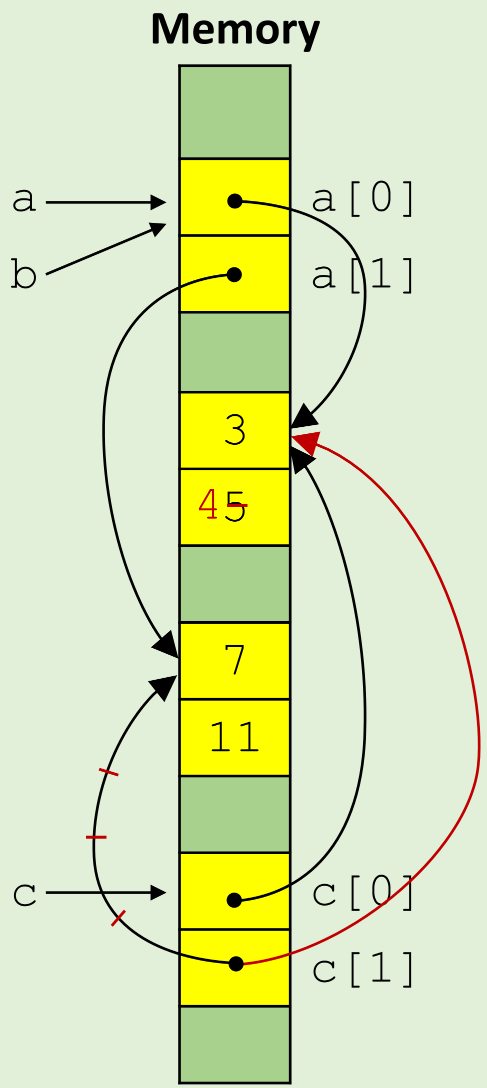
b) `[[3,5],[3,5]]`

c) `[[3,4],[3,5]]`

d) `[[3,4],[3,4]]`

e) Don't know

```
a = [[3,5],[7,11]]
b = a
c = a[:]
a[0][1] = 4
c[1] = b[0]
```



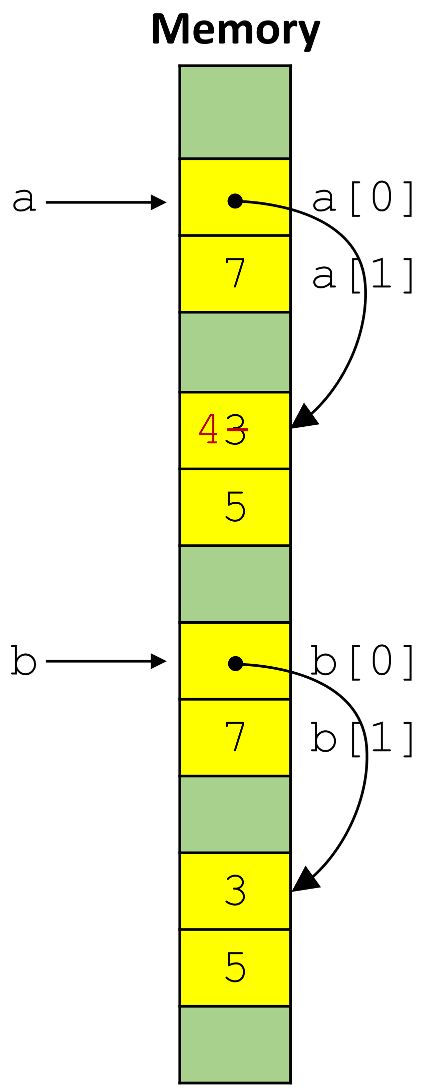
Try pythontutor.com

copy.deepcopy

- To make a copy of all parts of a composite value use the function deepcopy from module copy

Python shell

```
> from copy import deepcopy
> a = [[3, 5], 7]
> b = deepcopy(a)
> a[0][0] = 4
> a
| [[4,5],7]
> b
| [[3,5],7]
```



Initializing a 2-dimensional list

Python shell

```
> x = [1] * 3
> x
| [1, 1, 1]
> y = [[1] * 3] * 4
> y
| [[1, 1, 1], [1, 1, 1], [1, 1, 1], [1, 1, 1]]
> y[0][0] = 0
> y
| [[0, 1, 1], [0, 1, 1], [0, 1, 1], [0, 1, 1]]
```

Python shell

```
> y = []
> for _ in range(4): y.append([1] * 3)
> y[0][0] = 0
> y
| [[0, 1, 1], [1, 1, 1], [1, 1, 1], [1, 1, 1]]
```

range(*from*, *to*, *step*)

⚠ In Python 2, `range` generates the explicit list, i.e. always use memory proportional to the length; `xrange` in Python 2 corresponds to `range` in Python 3; Python 3 is more memory friendly

- `range(`*from*`,` *to*`,` *else*`)` represents the sequence of numbers starting with *from*, with increments of *step*, and smaller/greater than *to* if *step* positive/negative

`range(5)`	: `0, 1, 2, 3, 4`	(default *from* = 0, *step* = 1)
`range(3, 8)`	: `3, 4, 5, 6, 7`	(default *step* = 1)
`range(-2, 7, 3)`	: `-2, 1, 4`	(*from* and *to* can be any integer)
`range(2, -5, -2)`	: `2, 0, -2, -4`	(decreasing sequence if *step* negative)

- Ranges are immutable, can be indexed like a list, sliced, and compared (i.e. generate the same numbers)
- `list(range(...))` generates the explicit list of numbers

Python shell

```
> range(1, 10000000, 3)[2]
| 7
> range(1, 10000000, 3)[100:120:4]
| range(301, 361, 12)
> range(1, 10000000, 3)[100:120:4][2:3]
| range(325, 337, 12)
> list(range(5, 14, 3))
| [5, 8, 11]
```

Question – What is `range(3,20,4)[2:4][1]` ?

a) 3
b) 7
c) 11
d) 15
e) 19
f) Don’t know

for - loop

- For every element in a sequence execute a block of code:

  `for` *var* `in` *sequence*:
      block

- Sequences can e.g. be lists, strings, ranges
- `break` and `continue` can be used like in a while-loop to break out of the for-loop or continue with the next element in the sequence

Python shell

```
> for x in [1, 'abc', [2, 3], 5.0]:
>     print(x)
| 1
| abc
| [2, 3]
| 5.0
> for x in 'abc':
>     print(x)
| a
| b
| c
> for x in range(5, 15, 3):
>     print(x)
| 5
| 8
| 11
| 14
```

Question – What is printed ?

Python shell

```
> for i in range(1, 4):
>     for j in range(i, 4):
>         print(i, j, sep=':', end=' ')
```

a) 1:1 1:2 1:3 2:1 2:2 2:3 3:1 3:2 3:3


b) 1:1 1:2 1:3 2:2 2:3 3:3

c) 1:1 2:1 3:1 1:2 2:2 3:2 1:3 2:3 3:3

d) 1:1 2:1 3:1 2:2 3:2 3:3

e) Don’t know

Question – **`break`**, what is printed ?

Python shell

```
> for i in range(1, 4):
>     for j in range(1, 4):
>         print(i, j, sep=':', end=' ')
>         if j >= i:
>             break
```

a) *nothing*

b) `1:1`

c) `1:1 2:1 2:2 3:1 3:2 3:3`

d) `1:1 2:2 3:3`

e) Don't know

In nested `for`- and `while`-loops, `break` only breaks the innermost loop

```
    **** COMMODORE 64 BASIC V2 ****

 64K RAM SYSTEM  38911 BASIC BYTES FREE

READY.
10 FOR I=1 TO 10
20 PRINT I
30 NEXT
RUN
 1
 2
 3
 4
 5
 6
 7
 8
 9
 10

READY.
```

```
    **** COMMODORE 64 BASIC V2 ****

 64K RAM SYSTEM  38911 BASIC BYTES FREE

READY.
10 FOR I=1 TO 3
20   FOR J=I TO 3
30     PRINT I,J
40   NEXT
50 NEXT
RUN
 1         1
 1         2
 1         3
 2         2
 2         3
 3         3

READY.
```

Palindromic substrings

- Find all palindromic substrings of length ≥ 2, i.e. substrings spelled identically forward and backwards:

  abracadrabratrallalla

  ```
      i   j               i      j
  ```

- **Algorithm:** Test all possible substrings (brute force/exhaustive search)
- **Note**: the slice `t[::-1]` is `t` reversed

palindrom.py

```python
s = 'abracadrabratrallalla'

for i in range(len(s)):
    for j in range(i + 2, len(s) + 1):
        t = s[i:j]
        if t == t[::-1]:
            print(t)
```

Python shell

```
| aca
| alla
| allalla
| ll
| llall
| lal
| alla
| ll
```

Sieve of Eratosthenes

- Find all prime numbers ≤ n
- Algorithm:

2 3 4 5 6 7 8 9 10 11 12 13 14 ...
2 3 4 5 6 7 8 9 10 11 12 13 14 ...
2 3 4 5 6 7 8 9 10 11 12 13 14 ...
2 3 4 5 6 7 8 9 10 11 12 13 14 ...
2 3 4 5 6 7 8 9 10 11 12 13 14 ...
2 3 4 5 6 7 8 9 10 11 12 13 14 ...

eratosthenes.py

```python
n = 100
prime = [True] * (n + 1)

for i in range(2, n):
    for j in range(2 * i, n + 1, i):
        prime[j] = False

for i in range(2, n + 1):
    if prime[i]:
        print(i, end=' ')
```

Python shell

```
| 2 3 5 7 11 13 17 19 23 29 31 37 41
  43 47 53 59 61 67 71 73 79 83 89
  97
```

en.wikipedia.org/wiki/Sieve_of_Eratosthenes

while-else and for-else loops

- Both for- and while-loops can have an optional “else”:

```
for var in sequence:
        block
else:
        block

while condition:
        block
else:
        block
```

- The “else” block is only executed if no `break` is performed in the loop
- The “else” construction for loops is specific to Python, and does not exist in e.g. C, C++ and Java

Linear search

linear-search-while.py

```
L = [7, 3, 6, 4, 12, 'a', 8, 13]
x = 4

i = 0
while i < len(L):
    if L[i] == x:
        print(x, 'at position', i, 'in', L)
        break
    i = i + 1

if i >= len(L):
    print(x, 'not in', L)
```

linear-search-while-else.py

```
i = 0
while i < len(L):
    if L[i] == x:
        print(x, 'at position', i, 'in', L)
        break
    i = i + 1
else:
    print(x, 'not in', L)
```

linear-search-for.py

```
found = False
for i in range(len(L)):
    if L[i] == x:
        print(x, 'at position', i, 'in', L)
        found = True
        break

if not found:
    print(x, 'not in', L)
```

linear-search-for-else.py

```
for i in range(len(L)):
    if L[i] == x:
        print(x, 'at position', i, 'in', L)
        break
else:
    print(x, 'not in', L)
```

linear-search-builtin.py

```
if x in L:
    print(x, 'at position', L.index(x), 'in', L)
else:
    print(x, 'not in', L)
```

Some performance considerations

String concatenation

- To concatenate two (or few) strings use

  $str_1 \;+\; str_2$
  $var \;+=\; str$

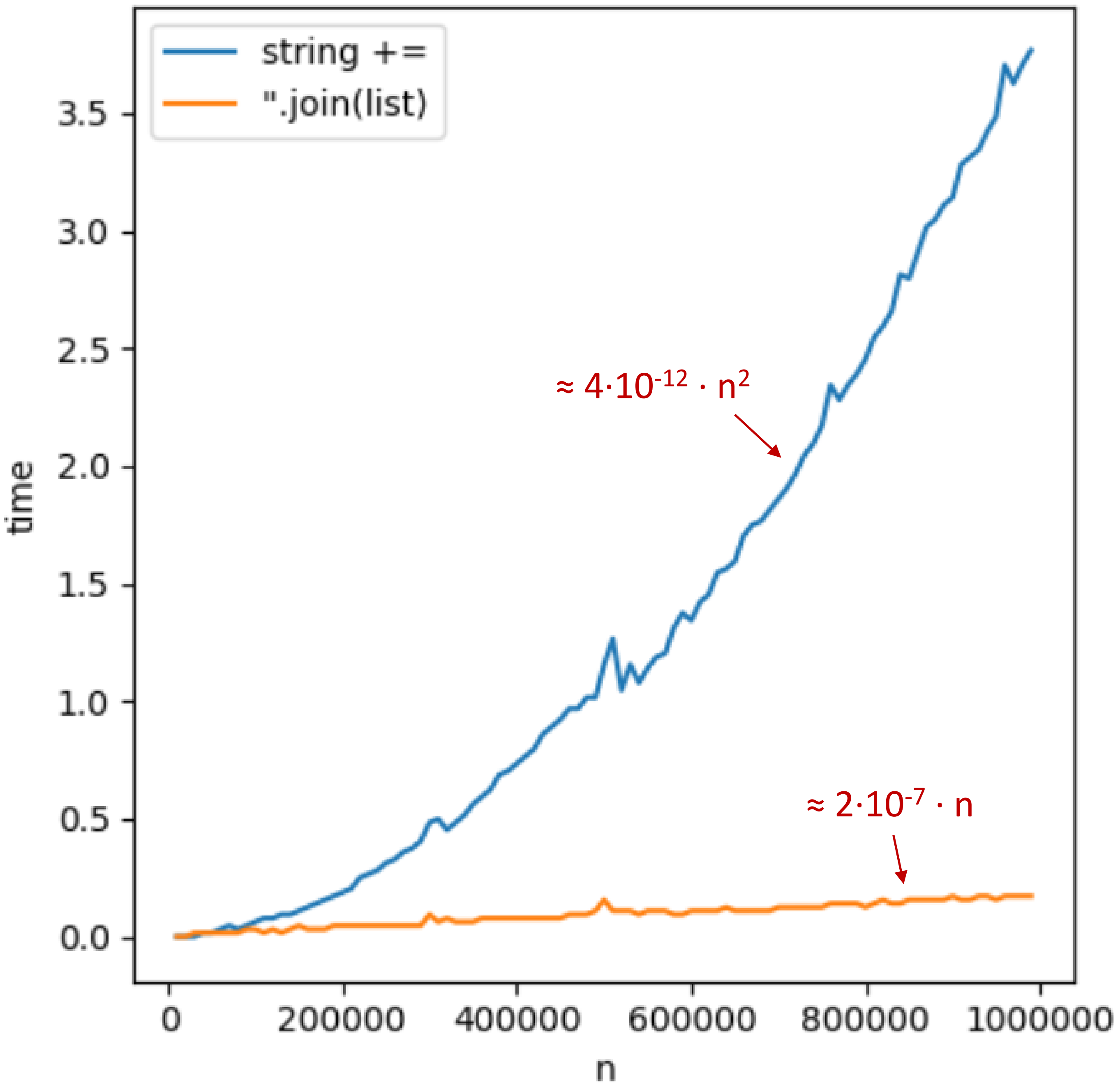
- To concatenate several/many strings use

  `''.join(`[str_1, str_2, str_3, ... , str_n]`)`

- Concatenating several strings by repeated use of + generates explicitly the longer-and-longer intermediate results; using `join` avoids this slowdown

Python shell

```
> s = 'A' + 'B' + 'C'
> s
| 'ABC'
> 'x'.join(['A', 'B', 'C'])
| 'AxBxC'
> s = ''
> s += 'A'
> s += 'B'
> s += 'C'
> s
| 'ABC'
> L = []
> L.append('A')
> L.append('B')
> L.append('C')
> L
| ['A', 'B', 'C']
> s = ''.join(L)
> s
| 'ABC'
```

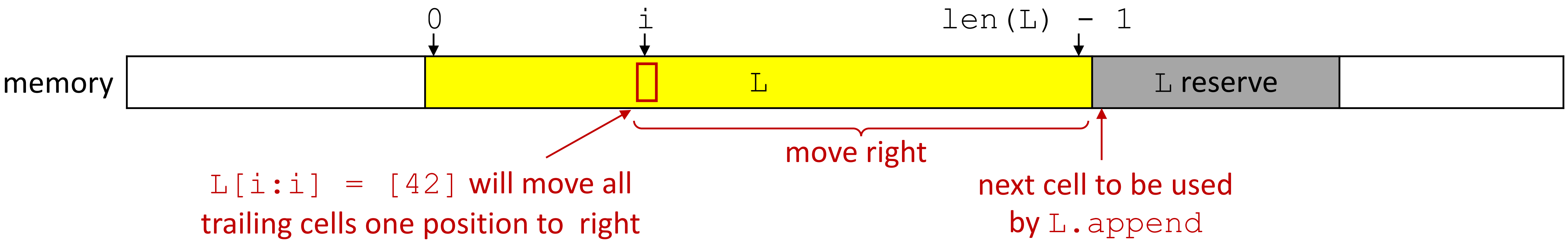


string-concatenation.py

```
from time import time
from matplotlib import pyplot as plt
ns = range(10_000, 1_000_000, 10_000)
time_string = []
time_list = []
for n in ns:
    start = time()
    s = ''
    for _ in range(n):
        s += 'abcdefgh'   # slow
    end = time()
    time_string.append(end - start)
    start = time()
    substrings = []
    for _ in range(n):
        substrings.append('abcdefgh');
    s = ''.join(substrings);
    end = time()
    time_list.append(end - start)
plt.plot(ns, time_string, label='string +=')
plt.plot(ns, time_list, label="''.join(list)")
plt.xlabel('n')
plt.ylabel('time')
plt.legend()
plt.show()
```

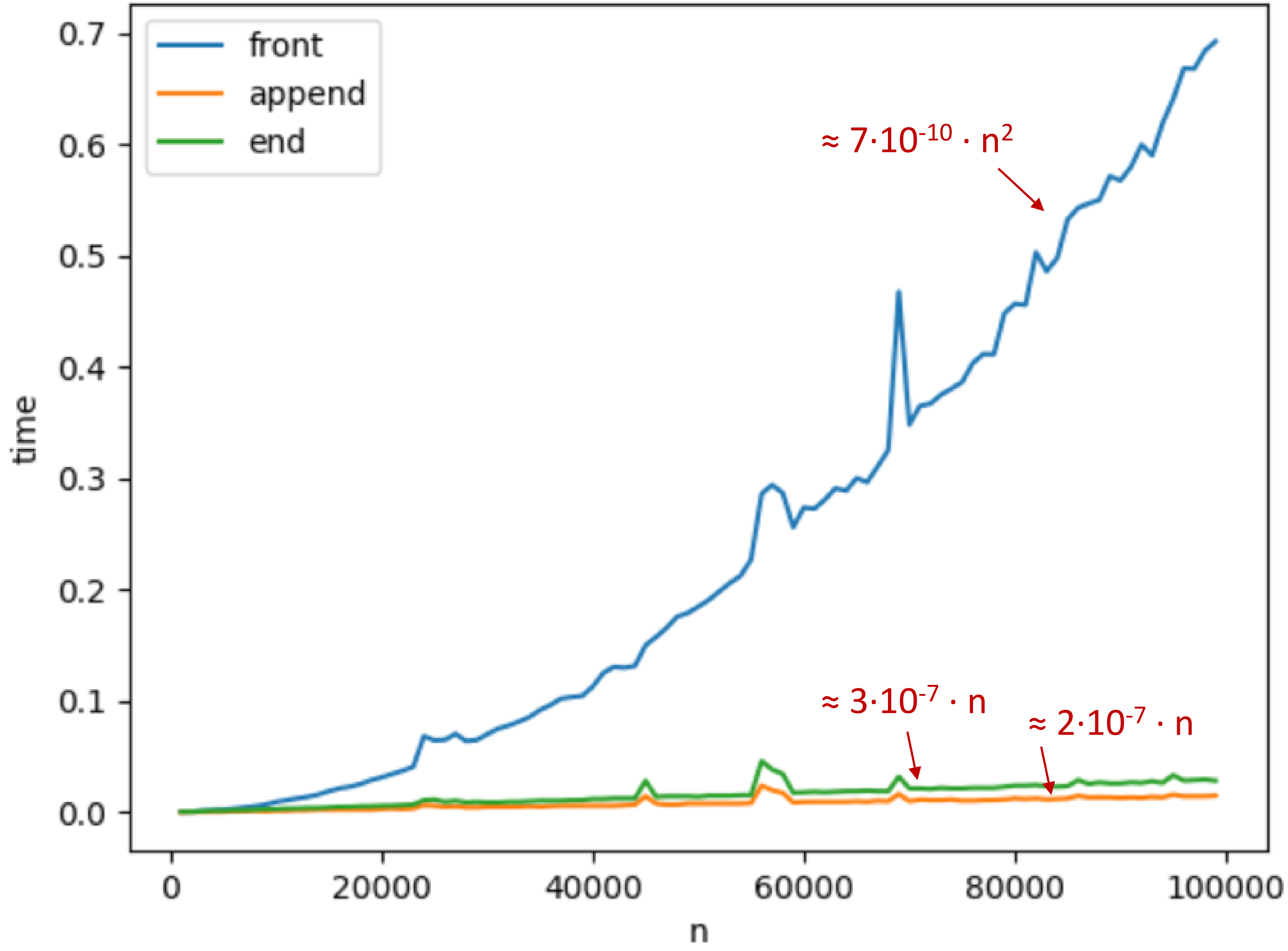
The internal implementation of Python lists

- Accessing and updating list positions take the same time independently of position
- Creating new / deleting entries in a list depends on position,
  Python optimizes towards updates at the end
- Try to organize your usage of lists to insert / delete elements at the end
  `L.append(`*element*`)` and `L.pop()`
- Python lists internally have space for adding ≈ 12.5 % additional entries at the end; when the reserved extra space is exhausted the list is moved to a new chunk of memory with ≈ 12.5 % extra space



github.com/python/cpython/blob/master/Objects/listobject.c

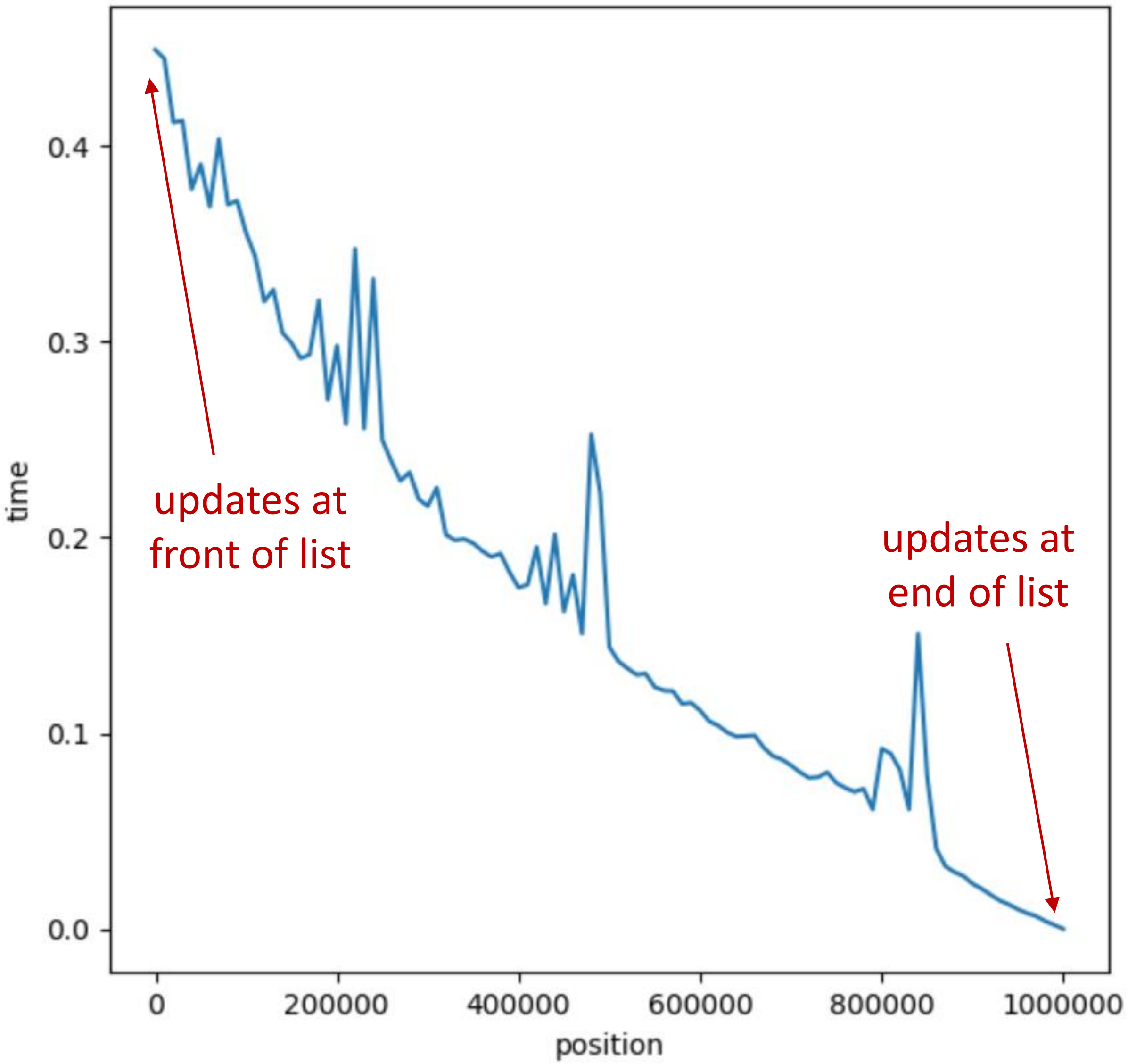
List insertions at front vs end



list-insertions.py

```python
from time import time
from matplotlib import pyplot as plt

ns = range(1000, 100_000, 1000)
time_end = []
time_append = []
time_front = []
for n in ns:
    start = time()
    L = []
    for i in range(n):
        L[i:i] = [i]  # insert after list
    end = time()
    time_end.append(end - start)

    start = time()
    L = []
    for i in range(n):
        L.append(i)  # append to list
    end = time()
    time_append.append(end - start)

    start = time()
    L = []
    for i in range(n):
        L[0:0] = [i]  # insert at front
    end = time()
    time_front.append(end - start)

plt.plot(ns, time_front, label='front')
plt.plot(ns, time_append, label='append')
plt.plot(ns, time_end, label='end')
plt.xlabel('n')
plt.ylabel('time')
plt.legend()
plt.show()
```

Updates (insertions + deletions) in the middle of a list



list-updates.py

```
from time import time
from matplotlib import pyplot as plt

ns = range(0, 1_000_001, 10_000)
time_pos = []
L = list(range(1_000_000))   # L = [0, ..., 999_999]
for i in ns:
    start = time()
    for _ in range(1000):
        L[i:i] = [42]   # insert element before L[i]
        del L[i]        # remove L[i] from L
    end = time()
    time_pos.append(end - start)

plt.plot(ns, time_pos)
plt.xlabel('position')
plt.ylabel('time')
plt.show()
```