15-110 Principles of Computing – S19

Lecture 7:

Lists and Tuples Data Structures 2

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Tuple and Lists: so far

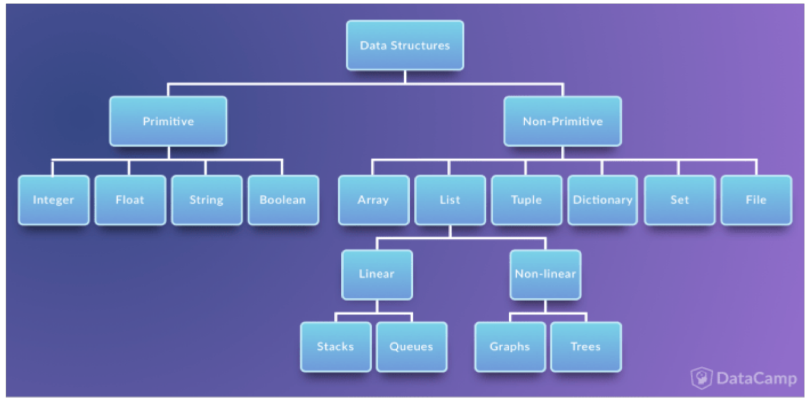
- **Tuple:** (non-scalar type) ordered sequence of *objects* (any type, not need same type), immutable

```
person_info = ('Donald', 'Trump', 14, 'June', 1946, 'President')
```

- **List:** (non-scalar type) ordered sequence of *objects* (any type, not need same type), mutable

```
person_info = ['Donald', 'Trump', 14, 'June', 1946, 'President']
```

Data structures



- **Access (read) operations**, at any position:
  - ➢ get data by index   x[], x[:], x[::]   x[][][]
  - ➢ find data by content

a = x[1], a = x[0:3], a = x[1:6:2], a = x[1][0][2]

- **Update operations**, *at any position*, only for lists: x[], x[:], x[::]   x[][][]
  - ➢ **change** the value of an item
  - ➢ **remove** one item
  - ➢ **add** one or more new items anywhere

x[1] = 2, x[0:3] = [1,3,5], x[1:6:2] = [2,3]
x[1][0][2]=3

y = [1,2,3], x = y

Mutable vs. Immutable types: int

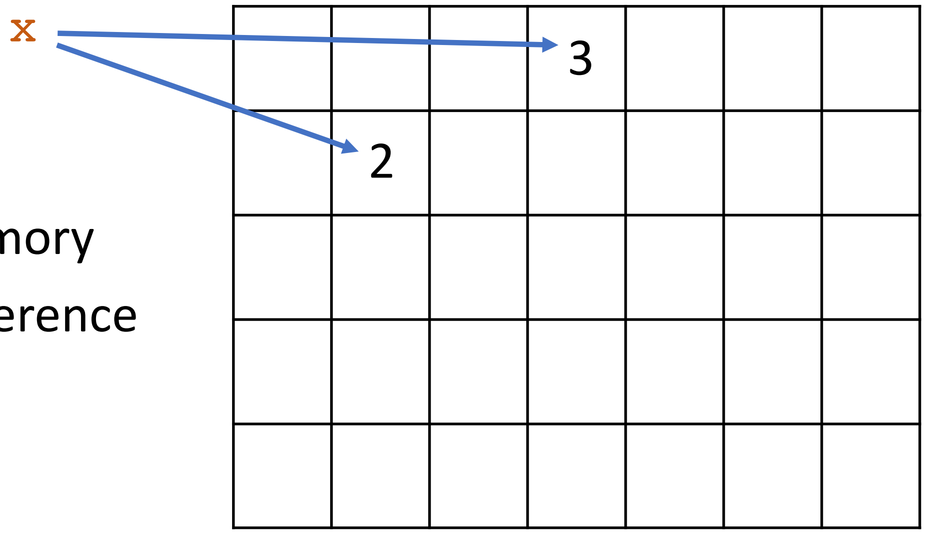
1. <u>In the high-level program:</u>

   `x = 2` meaning that variable `x` has (`int`) value 2

   - <u>Internal to pyhton / computer:</u>

     variable `x` holds the **reference** (the <u>address</u>) to the memory location to where its value 2 is currently *stored* (the reference is associated to the identity `id()` of the variable)

     ```
     print( id(x) )
     ```



2. <u>Next instruction in the high-level program:</u>

   `x = 3` meaning that variable `x` has changed its (`int`) value to 3

   - <u>Internal to pyhton / computer:</u>

     variable `x` is of <u>immutable</u> type `int`, meaning that *its value in memory cannot be changed* → A <u>new memory location</u> is allocated to hold the integer literal 3. `x` now holds the reference to the new memory location (check `id(x)`!)

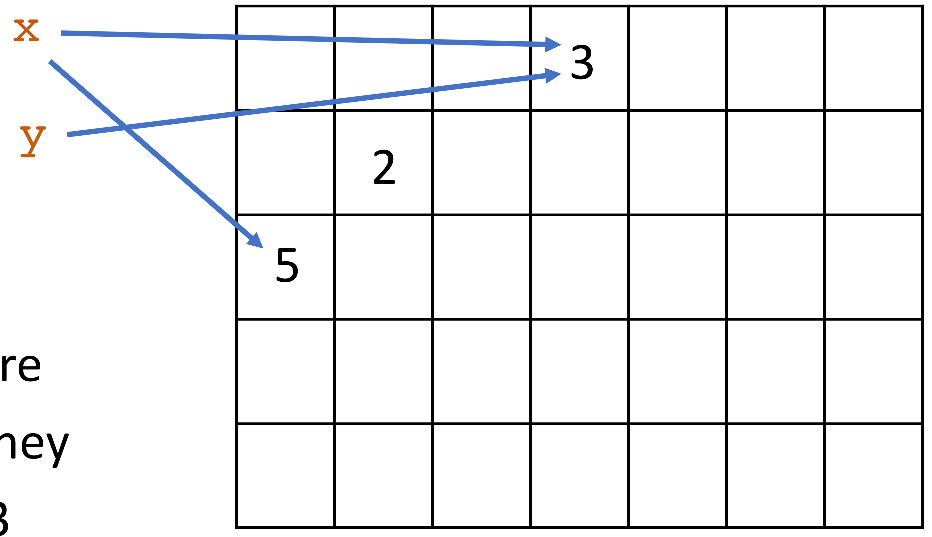
Mutable vs. Immutable types: int

3. Next instruction in the high-level program:

   `y = x` meaning that variable `y` gets the same value of `x`, and vice versa!

   - Internal to pyhton / computer

     variable `y` gets the reference held by `x`, `y` and `x` are bound to the **same memory location** for their value, they are *temporary* **aliases** for referring to the same value 3



- `int` is an *immutable type*, such that any further change in the values of either `x` or `y` brakes their bound, creating a *new variable*

4. Next instruction in the high-level program:

   `x = 5` meaning that variable `x` now gets a new value, which is allocated to a new, different memory location

- Internal to pyhton / computer:

  variable `x` gets the new reference associate to 5's memory location, `y` still references to value 3

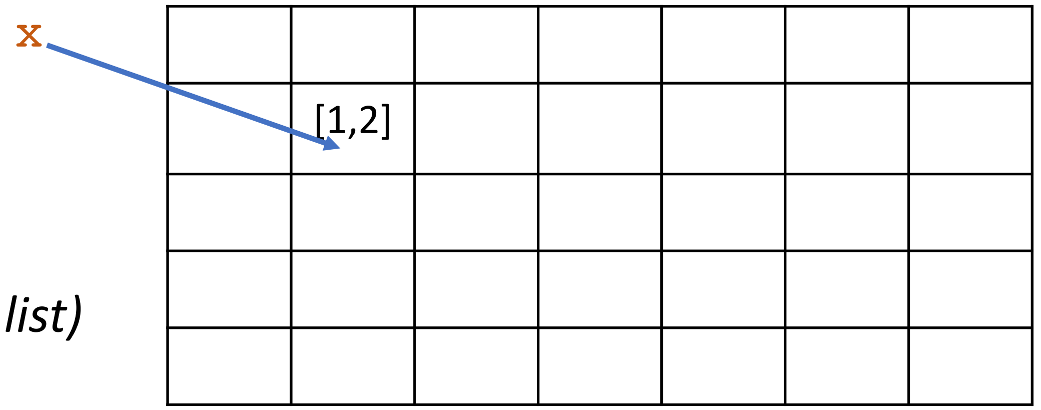
Mutable vs. Immutable types: list

1. In the high-level program:

   `x = [1,2]` meaning that list `x` has value [1,2]

   - Internal to pyhton / computer:

     variable `x` holds the **reference** (address) to the memory location to where the list values are stored *(head of the list)*



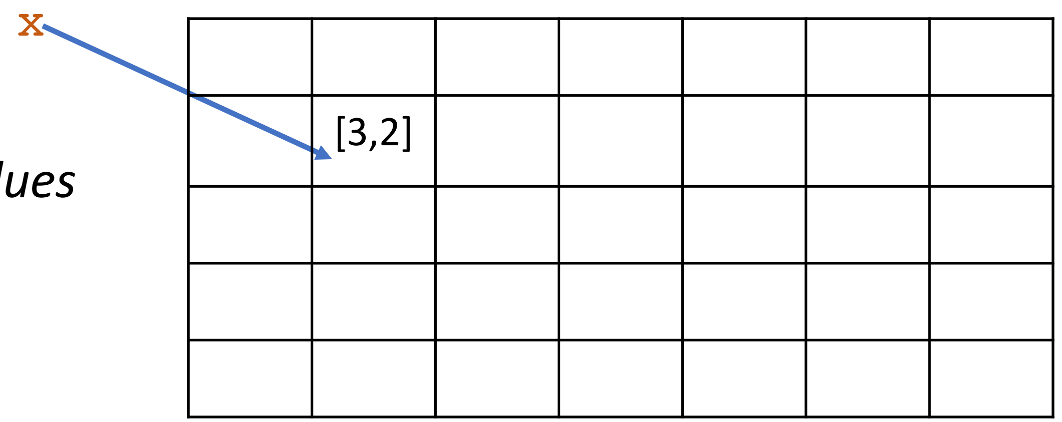
2. Next instruction in the high-level program:

   `x[0] = 3` meaning that the value at index 0 has changed to 3

   - Internal to pyhton / computer:

     variable `x` is of mutable type `list`, meaning that *its values in memory can be changed* → The value at the memory location holding `x[0]` is updated with the value 3.

     `x` holds the same reference as prior this instruction



Mutable vs. Immutable types

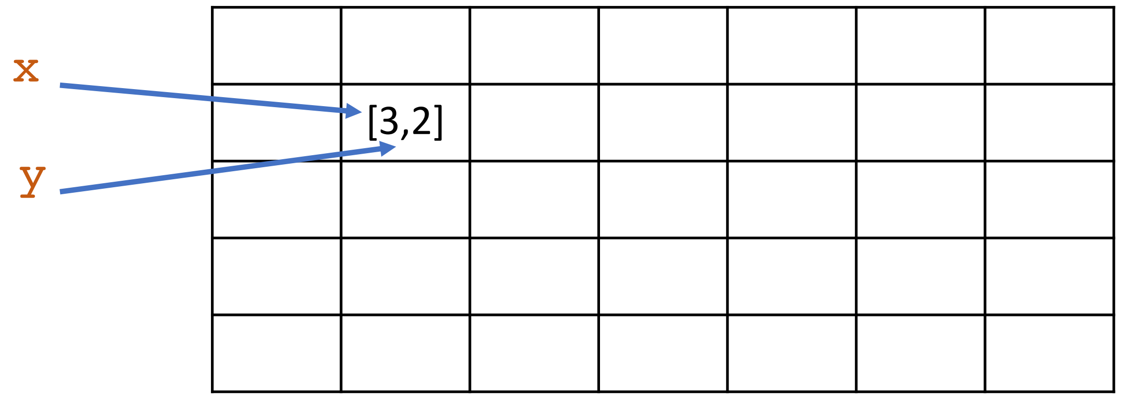
3. Next instruction in the high-level program:

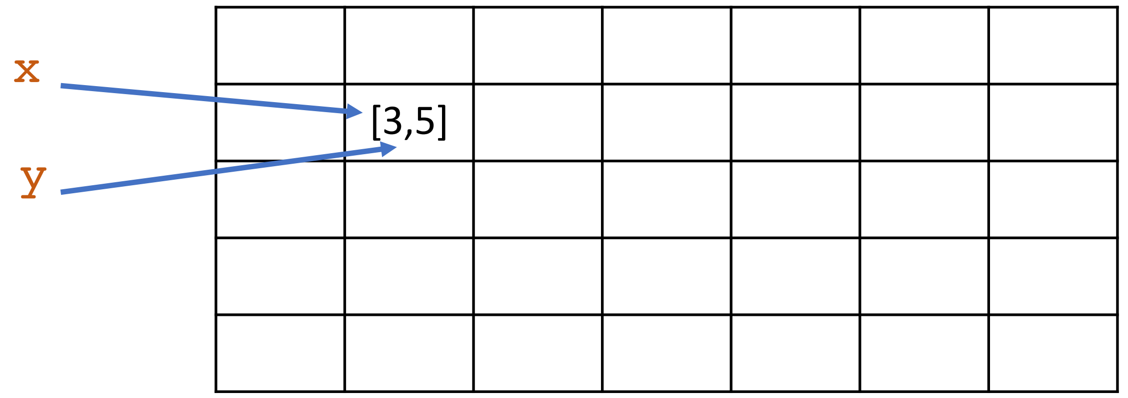
   `y = x` meaning that list variable `y` gets the same value of `x`, and vice versa!

- Internal to pyhton / computer:

  variable `y` gets the reference held by `x`, `y` and `x` are bound to the **same memory location** for their value, they are **permanent aliases**

  - `list` is a *mutable type*, such that any further change in the values of either `x` or `y` will be reflected in the other list because of their bound





4. Next instruction in the high-level program:

   `x[1] = 5` meaning that variable `x` updates to 5 its value at index 1

- Internal to pyhton / computer:

  the memory location referenced by both `x` and `y` gets updated in value → both `x` and `y` now have value [3,5]

Cloning vs. Aliasing: Issues and opportunities of mutability

- Initializing a list with another list?

```
primes = [1, 3, 5, 7]
numbers = primes

primes[1] = 29
```

what is the value of `numbers?`

- Initializing a list with the contents of another list using a range?

```
primes = [1, 3, 5, 7]
numbers = primes[0:3]

primes[1] = 29
```

what is the value of `numbers?`

```
print(“Do the lists have the same contents?”, numbers == primes)
print(“Primes:”, primes)
print(“Numbers:”, numbers)
print(“Are the two lists the ‘same’ list?”, id(primes) == id(numbers))
```

Cloning vs. Aliasing: Issues and opportunities of mutability

From one variable to another: we can transfer data only or data & identity

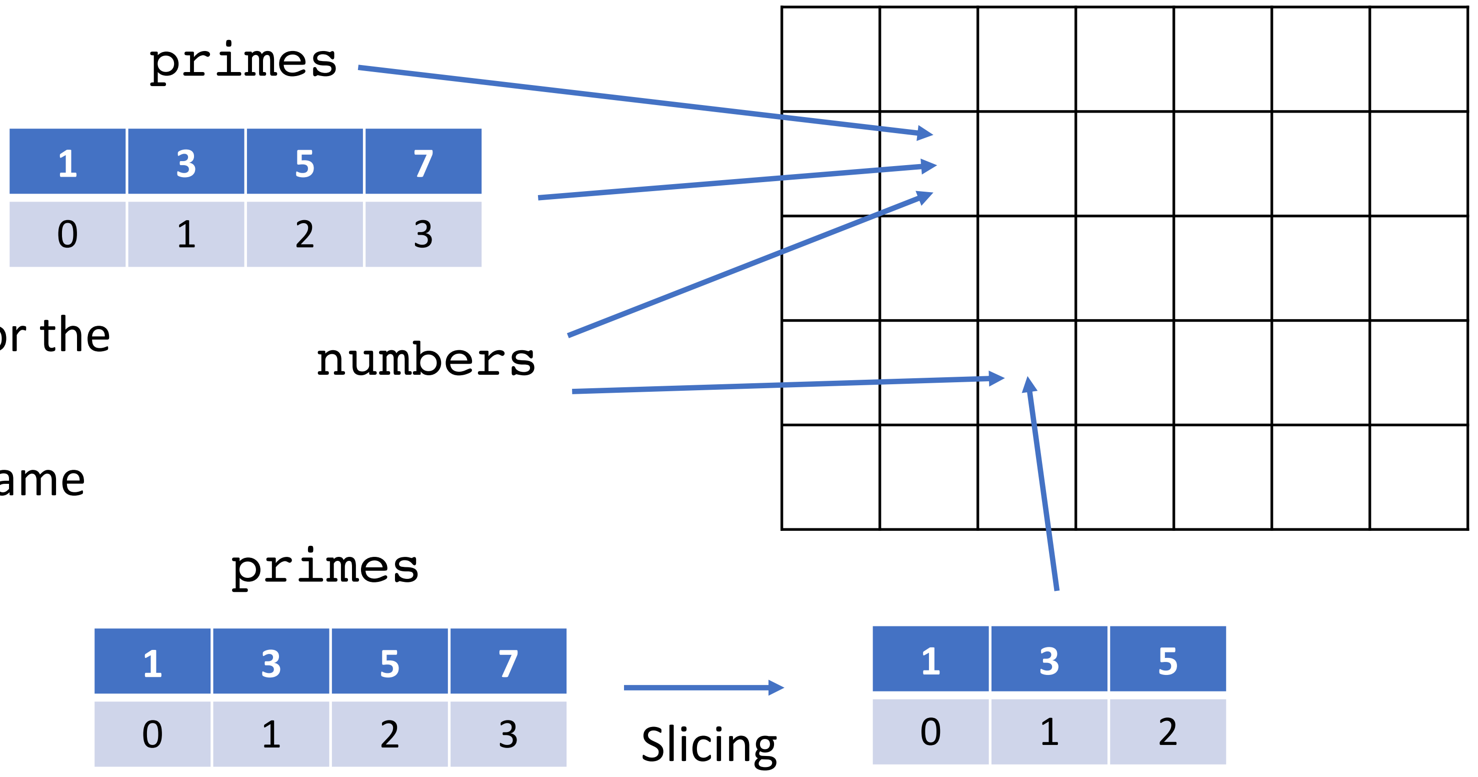
```
primes = [1, 3, 5, 7]
numbers = primes
```

Variables are passed by identity, by *reference* address → **Aliasing**

- numbers and primes are *aliases* for the same mutable list in memory!
  - ✓ `numbers[1] = 29` has the same effects than `primes[1]=29`

```
primes = [1, 3, 5, 7]
numbers = primes[0:3]
```

Slicing extracts content from one list, makes a *copy* of it, and pass it to the receiving list → **Cloning, shallow copy**



Pay attention to statements resulting in cloning vs. aliasing!

Cloning vs. Aliasing: Issues and opportunities of mutability

- Previous reasoning apply also when we create list of lists:

```
p = [1, 3, 5, 7]
pp = [11, 13, 17]
n = [p, pp]
```

Any (*in-place*) change to either `p` or `pp` is reflected on `n`, and vice versa

Cloning vs. Aliasing: Issues and opportunities of mutability

What about the following piece of code with `int` variables?

```
p = 1
n = p
print(n, p, id(n), id(p))
p = 29
print(p, n)
n = -1
print(p, n)
```

`int`, `float`, `bool`, `str` variables are <u>immutable</u>: we don’t update the content at the same memory location, every time a change is made, a new memory variable (memory location) is potentially generated, that potentially has a new identity

Cloning vs. Aliasing: Issues and opportunities of mutability

When to use aliasing vs. cloning with lists?

- **Aliasing**: For instance, when we need to create aliases in the program such that it is convenient (or more clear) to refer to the same object using different names, maybe in different parts of the program

```
# sport, sedan and family lists have been defined already
cars = [sport, sedan, family]
```

E.g., based on different input data (web requests, email data, files, keyboard inputs, …), the program manipulates and updates data about sport, sedan, and family cars in separate parts / modules of the program, updating the specific list (`sport, sedan, family`) only

Using the alias, any updates to any sub-set of cars gets automatically reflected in updates in the general `cars` list, that can be accessed being always up-to-date with current data

Cloning vs. Aliasing: Issues and opportunities of mutability

When to use aliasing vs. cloning with lists?

- **Cloning:** If we are only interested in the *values* held by a certain list, such that we want to *use/transfer* its data without creating any binding between the variables

```
basic_primes = [1,3,5,7,11]
primes = basic_primes[:]
# later on additional primes can be added to primes, unaffecting basic_primes
```

- Given an existing list b, a few equivalent alternatives (with the same macroscopic effects) are possible to create a new list a that inherits data from b but doesn't establish any binding aliases

Slicing

```
a = b[:]

a = []
a = b[:]
```

Concatenating

```
a = []
a = a + b

a = []
a += b
```

List methods

```
a = []
a.extend(b)

a = b.copy()
```

Basic list/tuple operators: +, *

- Operator + : **Concatenation of lists/ tuples**

Cloning

```
prime_numbers = [1, 3, 5, 7, 11]
other_primes = [13, 17, 19]
new_primes = prime_numbers + other_primes
```
→ new list/tuple with [1,3,5,7,11,13,17,19]

```
my_list = [1,2,3] + (1,3,5)
```
→ error! operator + needs same type operands

- Operator * : **Duplication of lists/tuples**

```
prime_numbers = [1, 3, 5]
repeat_primes = prime_numbers * 2
```
→ new list/tuple with [1,3,5,1,3,5]

```
x = [1,1,1,1,1,1,1,1,1,1]
```
→ create a list/tuple with 10 elements all initialized to integer value 1

```
x = [1]*10
```
→ create a list/tuple with 10 elements all initialized to the integer value 1

Basic list/tuple operators: in, not in

- Operator `in`: **Membership**, returns `True` if item belongs to the list/tuple, `False` otherwise

```
prime_numbers = [1, 3, 5, 7, 11]
is_prime = 5 in prime_numbers
```

→ new `bool` variable with value `True`

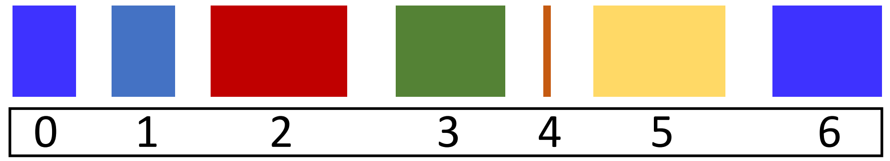
- Operator `not in`: **Membership**, returns `False` if item belongs to the list/tuple, `True` otherwise

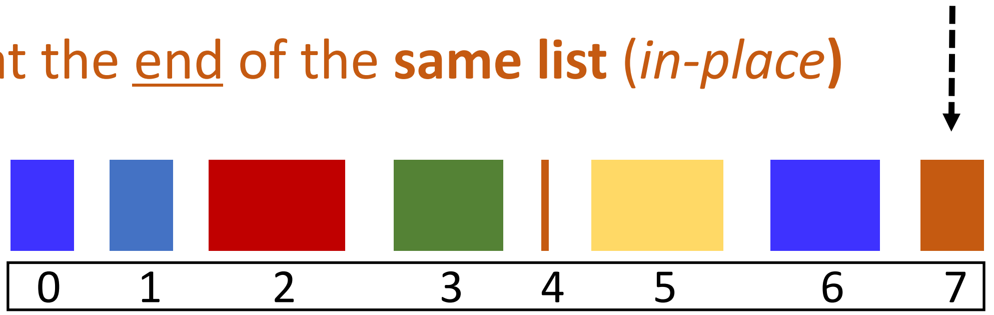
```
prime_numbers = [1, 3, 5, 7, 11]
is_prime = 5 not in prime_numbers
```

→ new `bool` variable with value `False`

Adding single list elements: append(), insert() methods

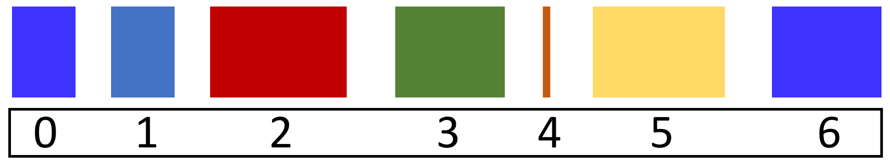
- Method `l.append(item)`: add an item at the end of the same list (*in-place*)

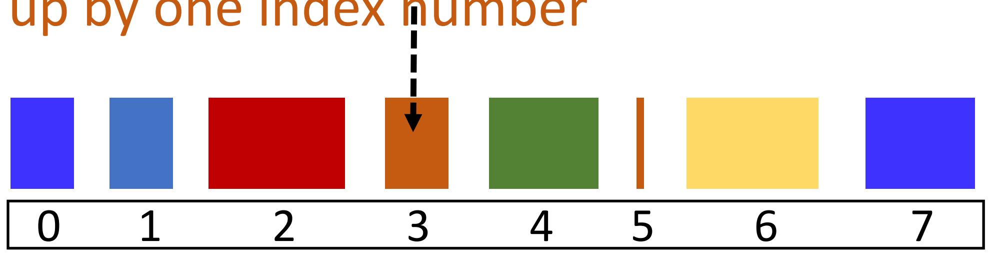




```
primes = [1, 3, 5, 7, 11, 13, 17]
```
`primes.append(19)` → same list, extended to the end by adding one `int` literal of value 19

- Method `l.insert(index, item)`: add an item at the `index` position of the **same list** (*in place*), moving all the other items in the list up by one index number



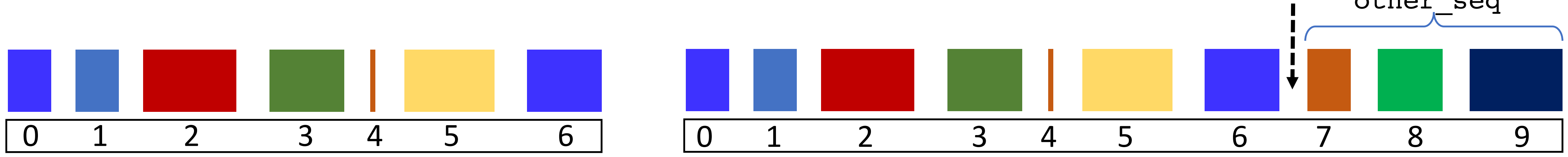


```
primes = [1, 3, 5, 7, 11, 13, 17]
```
`primes.insert(3,19)` → same list with new item: [1, 3, 5, 19, 7, 11, 13, 17]

`primes.insert(0,23)` → same list, with new item, all index shifted: [23, 1, 3, 5, 19, 7, 11, 13, 17]

Adding multiple list elements: extend() method

- Method `l.extend(other_seq)`: add items from another list/tuple onto the end of the **same list** `l` (*in-place*)



```
primes = [1, 3, 5, 7, 11, 13, 17]
other_primes = (19, 23, 29)
primes.extend(other_primes)
```
→ same list, extended to the end by adding the items of other_primes

```
primes.extend(other_primes[0:2])
```
→ extended to the end by adding two items of other_primes

Adding multiple list elements: +, +=

- Concatenation operator `+` : add items from another list/tuple onto the end of the list

```
primes = [1, 3, 5, 7, 11, 13, 17]
primes = primes + [19, 23, 29]
```
→ list with the same resulting content as with extend() but different identity

+ operator : `primes` changes *identity, not in-place*

(check it with `print(id(primes))` before and after concatenation!)

➢ <u>Compact notation</u> for the above type of expressions using **operator addition**: +=

`primes += [19, 23, 29]` same *high-level* result as `primes = primes + [19, 23, 29]`

+= operator: `primes` doesn't change identity, *in-place*

(check it with `print(id(primes))` before and after +=)

➢ Also true for **operator multiplication**: `*=`

`a = a * b` *is the same in value as* `a *= b`

Removing single list elements: remove(), pop() methods

- Method `l.remove(item)`: remove the (first) element with value `item` in the list, moving all the other items in the list up by one index number (*in-place*) → Removal **by content**

`numbers = [1, 3, 5, 4, 5, 5, 17]`

`numbers.remove(5)` → same list, with the first element of value 5 being removed [1,3,4,5,5,17]

`numbers.remove(15)` → error! an item with value 5 is not found in the list: use `in` prior to `remove()`

- Method `l.pop(index)`: takes the argument `index` and removes the item present at that index, moving all the other items in the list up by one index number (*in-place*), the removed item is also returned by the function → Removal **by index**

`numbers = [1, 3, 5, 4, 5, 5, 17]`

`numbers.pop(2)` → same list, with the item at index 2, of value 5, being removed [1,3,4,5,5,17]

`n = numbers.pop(0)` → n gets value 1

`numbers.pop(8)` → error! an index 8 is out of range for the list: use `len()` prior to pop()

Getting information about elements: count(), index() methods

- `t.count(item)` : Returns the number of occurrences of `item` in the list/tuple `t`

```
scores = [1, 11, 5, 11, 4, 11, 7, 9, 0, 4]
n = scores.count(11)      → n is an integer of  value 3, the # of occurrences of 11 in scores
l = (True, False, True).count(True)  → l is an integer of value 2  (two occurrences of True)
```

- `t.index(item)` : Returns the index of the first occurrence of `item` in the list/tuple `t`

```
scores = [1, 11, 5, 11, 4, 11, 7, 9, 0, 4]
n = scores.index(11)  →  n is an integer of  value 1, the index of first occurrence of 11 in scores
n = scores.index(19)  →  generates an error since 19 is not in scores: to avoid the error use the
                          operator in to check membership first
```

Useful operations: len(), getsizeof(), del functions

- `len(l)` : Returns the **length** of a list/tuple `l` (the integer number of elements in the tuple/list)

```
prime_numbers = [1, 3, 5, 7, 11]
n = len(prime_numbers)
```
→ n is an integer of value 5, the number of elements in the list/tuple

- How many **bytes** are used in memory for a list `l` (or any other object)? `sys.getsizeof(l)`

```
import sys
total_bytes_empty = sys.getsizeof([])

prime_numbers = [1, 3, 5, 7, 11]
total_bytes_five_int = sys.getsizeof(prime_numbers))
```

- Can we explicitly ***delete*** **an unused list** `l`, or, in general an **unused object**? (e.g., it occupies a lot of memory, and we can't / don't want to wait for the *garbage collector*): `del l`

```
my_unused_list = [1, 3, 5, 7, 11]
del my_unused_list
```

Useful operations: sort (), reverse() methods

- `sort(key, reverse)` : Changes (*in-place*) the list `l` (not applicable to tuples!) with the elements sorted according to the (optional) criterion `key` for comparing the items ; the (optional) parameter `reverse`, if set to `True`, provides the result in *descending* order

`numbers = [1, 4, 2, -7, 0, 6]`

`numbers.sort()` → items are all integer, no criterion is required, `numbers` is sorted ascending:
[-7, 0, 1, 2, 4, 6]

`cars = [‘toyota’, ‘BMW’, ‘nissan’]`

`cars.sort(reverse=True)` → items are str, no criterion is required, `cars` is sorted descending:
['toyota', 'nissan', 'BMW']

`mix = [‘toyota’, ‘BMW’, ‘nissan’, 3]`

`cars.sort()` → error! items have mixed types, a comparison criterion is required

Useful operations: sort (), reverse() methods

- A *list of lists/tuples of primitive types* is sorted according to the first element(s) of each list/tuple

```
my_tuples = [(1,2), (5,7,8), (-1,), (0,9,1,3)]
my_tuples.sort()
```
→ `[(-1,), (0, 9, 1, 3), (1, 2), (5, 7, 8)]`

```
my_tuples = [(-1,2), (5,7,8), (-1,3), (0,9,1,3)]
my_tuples.sort()
```
→ `[(-1,2), (-1,3), (0, 9, 1, 3), (5, 7, 8)]`

- *Ties* do not matter since the items become indistinguishable

```
my_tuples = [(-1,2), (5,7,8), (-1,2), (0,9,1,3)]
my_tuples.sort()
```
→ `[(-1,2), (-1,2), (0, 9, 1, 3), (5, 7, 8)]`

Useful operations: sort (), reverse() methods

- `reverse()` : Changes (*in-place*) the list `l` (not applicable to tuples!) putting the elements in the reverse order compared to the original list

```
numbers = [1, 4, 2, -7, 0, 6]
numbers.reverse()
```

→ `numbers` list is now: [6, 0, -7, 2, 4, 1]

- Other way to obtain the same macroscopic result using [] operator:

```
numbers = [1, 4, 2, -7, 0, 6]
numbers = numbers[::-1]
```

→ `numbers` list is now: [6, 0, -7, 2, 4, 1]

- Watch out: a list with a *new* identity is being created (but the *macroscopic* effect is the same)

```
numbers = [1, 4, 2, -7, 0, 6]
print(id(numbers))                → 4729970376
numbers = numbers[::-1]
print(id(numbers))                → 4729921992
```

→ identity values (*memory addresses of list's content*) will be different on different executions / computers

copy() method: in-place methods vs. methods returning a value

```
a = [2,4,1]
b = a.sort()
print(a,b)    → [1, 2, 4] None
```

```
a = [1,2]
b = a.extend([4,5])
print(a,b)          → [1, 2, 4, 5] None
```

All the methods so far operate *in-place*, they change the object but **do *not* return it**

```
a = [2,4,1]
a.sort()
b = a
print(a,b)  → [1, 2, 4] [1, 2, 4]
```

```
a = [1,2]
a.extend([4,5])
b = a
print(a,b)          → [1,2,4,5] [1,2,4,5]
```

a and b are **aliases**, have the same identity!

- Method `copy()` returns a copy (**cloning**) of the list/tuple (and does *not* modify it)

```
a = [2,4,1]
b = a.copy()
print(a,b)              → [2,4,1] [2,4,1]
print(id(a), id(b))     →  4730312200  4695822984
```

a and b are now different objects

Useful operations: max(), min() functions

- `max(t, key)` : Returns the **item** of the list/tuple `t` with **maximum value**
  - Without a key (optional criterion for comparison), it can be applied only to homogeneous lists/tuples (all elements of the same type)
  - Return type depends on the type of the items

```
prime_numbers = [1, 3, 5, 7, 11]
n = max(prime_numbers)      → n is an integer of value 11, the item of highest value
c = max('red', 'green', 'blue') → c is a string of value 'red', corresponding the item of
                                   highest code value (starting from 'r') in UTF-8
l = max('a', 'c', 'C') → l is a string of value 'c', that has highest code value in UTF-8
logical = max(True, False, True) → logical is a boolean of value True (1)
x = max(1, 3, True, 'red') → generates an error (how to compare different items?)
```

Useful operations: max(), min() functions

- `min(t, key)` : Returns the **item** of the list/tuple `t` with **minimum value**
  - Without a key (optional criterion for comparison), it can be applied only to homogeneous lists/tuples (all elements of the same type)
  - Return type depends on the type of the items

`l = min[‘a’, ‘c’, ‘C’]` → `l` is a string of value ‘C’, that has lowest code value in UTF-8

`logical = min(True, False, True)` → `logical` is a boolean of value `False` (0)

Use of a *key* for item comparison in sort(), max()/min(),…

- `sort(key, reverse)` : Changes (in-place) the list `l` (not applicable to tuples!) with the elements sorted according to the (optional) criterion `key` for comparing the items ; the (optional) parameter `reverse`, if set to `True`, provides the result in *descending* order

- **key** parameter:
  - specifies a **function** to be called **on each list element** prior to making comparisons

    → a function that takes a single input parameter, `F(x)`
  - the **return value** of the function is the key used for *comparison purposes*
  - return value must be a **primitive type**, such that python knows how to make comparisons among keys

```
my_tuples = [(1,2), (5,7,8), (1,), (2,2,0,0)]
my_tuples.sort(key = len)
```

→ [(1,), (1, 2), (5, 7, 8), (2, 2, 0, 0)]

```
my_strings = [‘hello’, ’Good morning’, ‘I am’, ‘list example’, ‘zzTop’]
my_strings.sort(key = str.lower)
```

→ ['Good morning', 'hello', 'I am', 'list example', 'zzTop']

Use of a key for item comparison in sort(), max()/min(),...

```
def cmp_on_second_element(item):
    return item[1]
```

Write your own **custom function** for performing comparisons

```
my_tuples = [(1,2), (5,7,8), (1,0), (2,2,0,0)]
my_tuples.sort(key = cmp_on_second_element)
```

```
def cmp_on_second_element(item):
    if len(item) >= 2
        return item[1]
    else
        return -1
```

Watch out: We must ensure that `item` is a list/tuple, otherwise `len(item)` would return an error in this example

```
my_tuples = [(1,2), (5,7,8), (1,), (2,2,0,0)]
my_tuples.sort(key = cmp_on_second_element)
```

Iterating over (all) the elements of a list

- We might want to perform actions **on the entire list**, potentially on all items, or subsets of items

- **Initialize** a large list according to a given pattern that might depend on *index* values
  - Set up a list of n (e.g., 1000) elements such that the element at position i has value i
    ```
    sequential_numbers = [0, 1, 2, 3, 4, 5, 6, 7, 8, ..., 999]
    ```
  - Set up a list of n (e.g., 1000) elements such that the element at position i has value $\sum_{k=0}^{i} k$
    ```
    incremental_sum = [0, 1, 3, 6, 10, 15, 21, ..., 4999500]
    ```
  - Set up a list of n (e.g., 256) elements such that each element is a unique string of 0 and 1
    ```
    binary = [‘00000000’, ‘00000001’, ‘00000010’, ..., ‘11111111’]
    ```

Iterating over (all) the elements of a list

- **Modify** or **use/extract** all values (or all values that satisfy a given condition) of a large list according to a given pattern that depends on *item* values
    - Scale all values by a factor 0.5 (e.g., price discount rate)

```
articles = [[‘book’, 15], [‘toy’, 25], [‘cookies’, 8], ...]
articles ← [[‘book’, 7.5], [‘toy’, 12.5], [‘cookies’, 4], ...]
```

    - Extract all items that are older than one week (e.g., food articles)

```
articles = [[‘cheese’, 10], [‘milk’, 2], [‘butter’, 8], ...
expiring ← [[‘cheese’, 10], [‘butter’, 8], ...]
```

    - Find items satisfy a condition and perform an incremental operation (e.g., sum money invested in edge funds)

```
investments = [[‘EF1’, 100000], [‘B1’, 50000], [‘EF4’, 2000], ...
capital_in_EF ← 100000 + 2000 + ...
```

Iterating over (all) the elements of a list

- How do we perform these list-level operations? → **Iterators**
- Constructs to repeat actions without explicitly enumerating all the elements to act upon

Operators for iterations:

✓ `for i in` *`sequence`*

✓ `while` *`condition_is_true`*

Next time!