ILP 2023 – W5S1 Numpy library (part 1) and imports

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Outline (Week5, Session1 – W5S1)

- Memory management and lists: aliasing, shallow and deep copies
- The Numpy library (part 1): arrays, math functions, etc.
- About the import procedure
- Project organizing
- Mini-project

Memory of a computer

- The memory of a computer consists of several “boxes”, which can contain values for variables. Each “box” is identified by an **integer**, which corresponds to the **address/ID** of the “box”.

Identifier	**Memory**	
	Address	**Value**
x1	140725454247872	10
	…	…

Memory of a computer

- The memory of a computer consists of several "boxes", which can contain values for variables. Each "box" is identified by an **integer**, which corresponds to the **address/ID** of the "box".
- When a variable is created:
  - A "box" is assigned for the variable and its value is stored in the "box".
  - The variable name simply refers to the address/ID of the "box".

Identifier	**Memory**	
	Address	**Value**
x1	140725454247872	10
	…	…

Memory of a computer

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- When a variable is created:
  - A “box” is assigned for the variable and its value is stored in the “box”.
  - The variable name simply refers to the address/ID of the “box”.

Identifier | **Memory**

x1

Address	Value
140725454247872	10
…	…

```
x1 = 10
print(x1)
print(id(x1))
```

```
10
140725454247872
```

Recall: the id() function

- The **id()** function returns an integer, which corresponds to the **address/ID**, where the variable is stored in memory.

```python
x1 = 10
print(x1)
print(id(x1))
```

```
10
140725454247872
```

```python
x2 = 17
print(x2)
print(id(x2))
```

```
17
140725454248096
```

Recall: the id() function

- The **id()** function returns an integer, which corresponds to the **address/ID**, where the variable is stored in memory.
- Two variables names with identical values will have the same **id().**

```python
x1 = 10
print(x1)
print(id(x1))
```

```
10
140725454247872
```

```python
x2 = 17
print(x2)
print(id(x2))
```

```
17
140725454248096
```

```python
x3 = x1
print(x3)
print(id(x3))
print(id(x1))
```

```
10
140725454247872
140725454247872
```

Recall: the id() function

- The **id()** function returns an integer, which corresponds to the **address/ID**, where the variable is stored in memory.
- Two variables names with identical values will have the same **id()**.
- **Aliasing:** Python saves memory space by having two variables names **point to the same memory ID**.

Identifier	Memory: Address	Memory: Value
x1, x3 →	140725454247872	10
	…	…

```python
x3 = x1
print(x3)
print(id(x3))
print(id(x1))
```

```
10
140725454247872
140725454247872
```

Recall: the id() function

- The **id()** function returns an integer, which corresponds to the **address/ID**, where the variable is stored in memory.
- Two variables names with identical values will have the same **id().**
- **Aliasing:** Python saves memory space by having two variables names **point to the same memory ID**.

Identifier	Memory: Address	Memory: Value
x3 →	140725454247872	10
x1 →	140725454247936	12

```python
x1 = 12
print(x1)
print(x3)
print(id(x1))
print(id(x3))
```

```
12
10
140725454247936
140725454247872
```

Memory management in lists

- A **list** is a collection of variables.

```python
list1 = [x1, x2, x3]
print(list1)
print(id(list1))
```

```
[12, 17, 10]
1769354632448
```

```python
print(id(list1))
print("-")
print(id(list1[0]))
print(id(x1))
print("-")
print(id(list1[1]))
print(id(x2))
print("-")
print(id(list1[2]))
print(id(x3))
```

```
1769354632448
-
140725454247936
140725454247936
-
140725454248096
140725454248096
-
140725454247872
140725454247872
```

Memory management in lists

- A **list** is a collection of variables. The variables in a list are **chained** together.

Identifier

Memory

Identifier	Address	Value
list1	1769354632448	List value
	…	…

list1[0]

Address	140725454247936
Value	12
Next Address	140725454247872

list1[1]

Address	140725454247872
Value	17
Next Address	140725454248096

list1[2]

Address	140725454248096
Value	10
Next Address	End of list

Memory management in lists

- A **list** is a collection of variables. The variables in a list are **chained** together.
- If x1 is changed, Python will adjust so that the list remains unaffected.
- It simply reallocates x1 to another location in memory.

```python
print(x1)
print(id(x1))
x1 = "Hello"
print(id(x1))
print(list1)
```

```
12
140726382041088
2120755150000
[12, 17, 10]
```

Aliasing in lists: problem

- A **list** is a collection of variables. The variables in a list are **chained** together.
- **Aliasing:** We can assign a list to another variable name.

```
list2 = list1
print(list2)
print(id(list1))
print(id(list2))
```

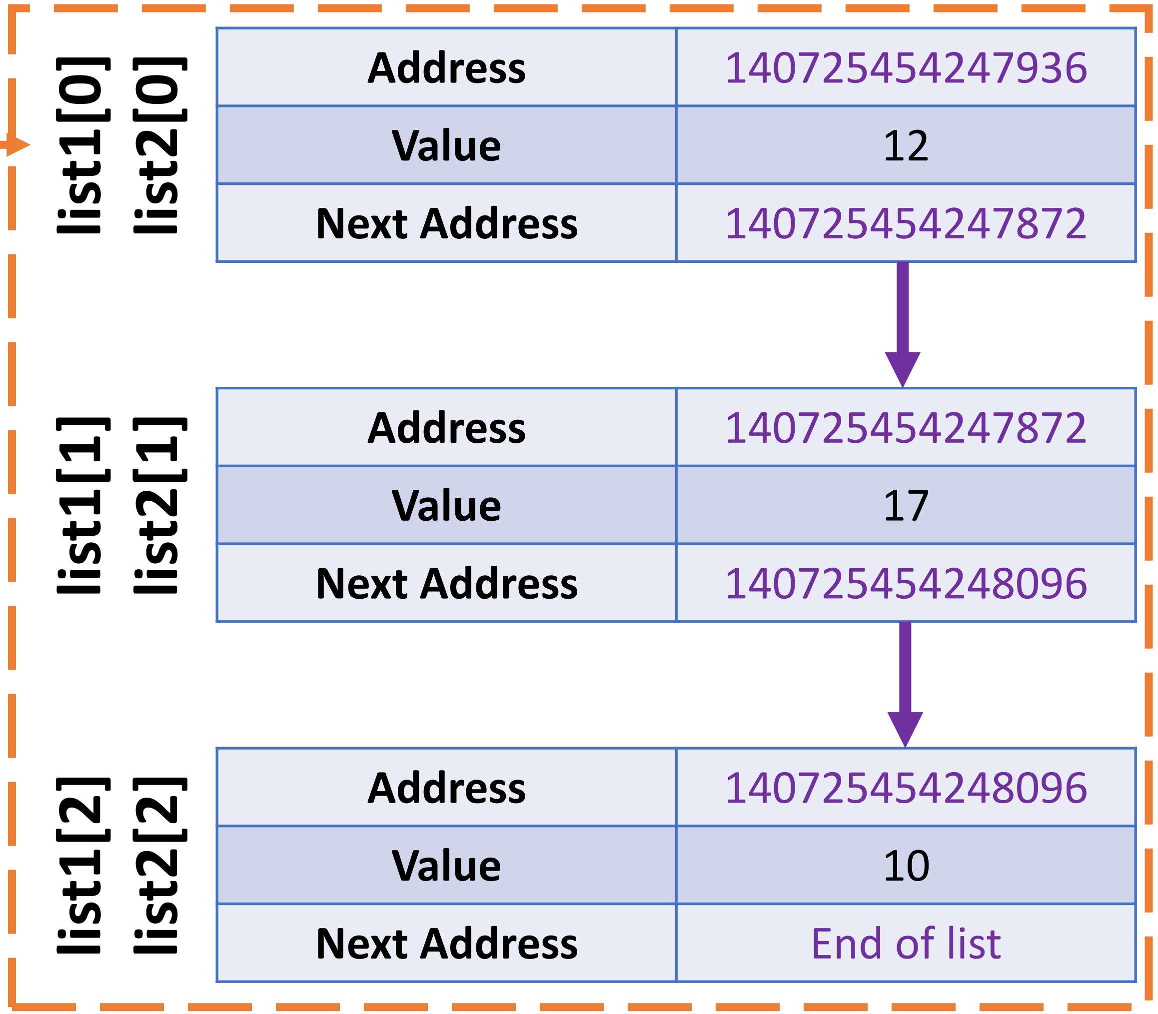
```
[12, 17, 10]
1983742564288
1983742564288
```

Aliasing in lists: problem

- A **list** is a collection of variables. The variables in a list are **chained** together.
- **Aliasing:** We can assign a list to another variable name.

Identifier **Memory**

Identifier	Address	Value
list1, list2	1769354632448	List value
	…	…



Aliasing in lists: problem

- A **list** is a collection of variables. The variables in a list are **chained** together.
- **Aliasing:** We can assign a list to another variable name.
- **Problem:** changing list1[0] changes list1 values, but also changes list2.

```python
print(id(list1[0]))
list1[0] = "SUTD"
print(list1)
print(id(list1[0]))
```

```
140726382041088
['SUTD', 17, 10]
2120755353584
```

```python
print(list2)
print(id(list2[0]))
```

```
['SUTD', 17, 10]
2120755353584
```

Aliasing in lists: problem

- A **list** is a collection of variables. The variables in a list are **chained** together.
- **Aliasing:** We can assign a list to another variable name.
- **Problem:** changing list1[0] changes list1 values, but also changes list2.

Identifier **Memory**

Identifier	Address	Value
list1, list2	1769354632448	List value
	…	…

list1[0] list2[0]

Address	140725454247936
Value	**12 → "SUTD"**
Next Address	140725454247872

list1[1] list2[1]

Address	140725454247872
Value	17
Next Address	140725454248096

list1[2] list2[2]

Address	140725454248096
Value	10
Next Address	End of list

Shallow copy of a list

- **Problem:** changing list1[0] changes list1 values, but also changes list2.
- **Shallow copy:** list1[:] makes list2 a shallow copy of list1. By doing so, list2 will be saved to its own location of memory.

```python
list1 = [12, 17, 10]
list2 = list1[:]
print(list1)
print(list2)
print(id(list1))
print(id(list2))
```

```
[12, 17, 10]
[12, 17, 10]
2120755431296
2120755345920
```

Shallow copy of a list

- **Problem:** changing list1[0] changes list1 values, but also changes list2.
- **Shallow copy:** list1[:] makes list2 a shallow copy of list1. By doing so, list2 will be saved to its own location of memory.
- Changing a value in list1, with list1[index] = …, no longer affects list2.
- **Note:** you can also use the copy() method.

```python
list1 = [12, 17, 10]
list2 = list1[:]
print(list1)
print(list2)
print(id(list1))
print(id(list2))
```

```
[12, 17, 10]
[12, 17, 10]
2120755431296
2120755345920
```

```python
list1[0] = "SUTD"
print(list1)
print(list2)
```

```
['SUTD', 17, 10]
[12, 17, 10]
```

Shallow copy: problem

- **Note:** if an element of a list is a list (case of lists of lists), then the shallow copy will not copy the sublists to different locations of memory.
- **Problem:** changing a sublist element then affects both lists, even though these lists are shallow copies of each other.

```python
list1 = [[8, 9, 11], 7, 4]
list2 = list1[:]
print(list1)
print(list2)
print(id(list1))
print(id(list2))
print(id(list1[0][1]))
print(id(list2[0][1]))
```

```
[[8, 9, 11], 7, 4]
[[8, 9, 11], 7, 4]
2120755333248
2120755332928
140726382040992
140726382040992
```

```python
list1[0][1] = "Damn it!"
print(list1)
print(list2)
```

```
[[8, 'Damn it!', 11], 7, 4]
[[8, 'Damn it!', 11], 7, 4]
```

Deep copy

- **Solution:** make a **deep copy**, using the Python built-in **copy** library.

- A deep copy forces Python to make sure **all elements and sub-elements** are assigned to different locations in memory.

```
from copy import deepcopy
```

```
list1 = [[8, 9, 11], 7, 4]
list2 = deepcopy(list1)
print(list1)
print(list2)
print(id(list1[0]))
print(id(list2[0]))
```

```
[[8, 9, 11], 7, 4]
[[8, 9, 11], 7, 4]
2120754851072
2120754850304
```

```
list1[0][1] = "Deep copy works?"
print(list1)
print(list2)
print(id(list1[0][1]))
print(id(list2[0][1]))
```

```
[[8, 'Deep copy works?', 11], 7, 4]
[[8, 9, 11], 7, 4]
2120755409424
140726382040992
```

Matt's Great advice #10

Matt's Great Advice #10: Keep the aliasing, shallow and deep copies concepts in mind for now.

If you find that modifying a list object ends up unexpectedly changing another, then you might have an aliasing or shallow copy problem.

When in doubt, make a deep copy.

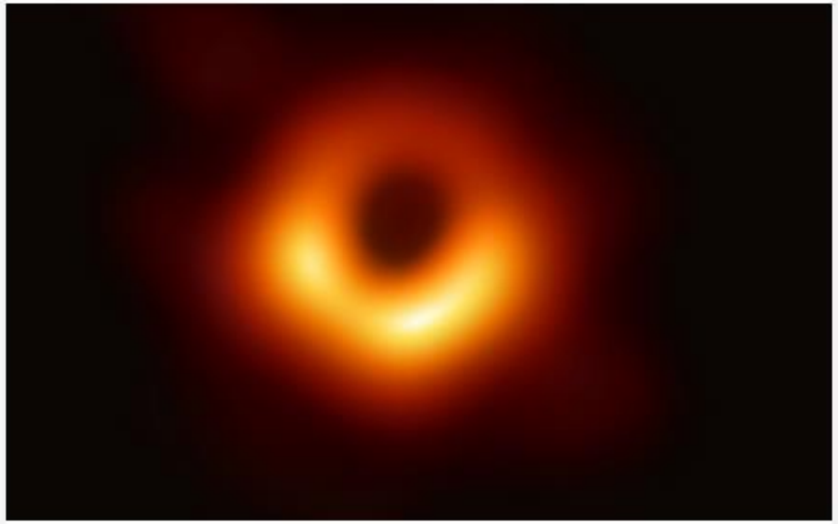
For now, do not worry about understanding all these memory concepts, these will be covered in another advanced course!

About the numpy library

- **Numpy** is one of the most common (if not the most popular) **libraries** in Python.

- Used for many applications: computing, modelling, data science, astrophysics, etc.
- **Linear algebra** (one of the main concepts of math with many applications in computing)

FIRST IMAGE OF A BLACK HOLE



How NumPy, together with libraries like SciPy and Matplotlib that depend on NumPy, enabled the Event Horizon Telescope to produce the first ever image of a black hole

A new type of objects: Numpy Arrays

- **Numpy arrays** are objects from the **Numpy** library.
  - Typically used to describe **matrices** and **vectors,**
  - Or **tables** of data.
- The look very similar to (**nested lists of) lists**, which we have used earlier for many applications.
- The Numpy library, however, comes with many additional functions and methods.

```python
import numpy as np
```

```python
array1 = np.array([0, 2, 1, 4])
print(array1)
```

```
[0 2 1 4]
```

```python
print(array1)
print(type(array1))
array1_as_list = list(array1)
print(array1_as_list)
print(type(array1_as_list))
```

```
[0 2 1 4]
<class 'numpy.ndarray'>
[0, 2, 1, 4]
<class 'list'>
```

Length, size, shape

- Just like lists, the Numpy arrays have a length, which can be checked with **len()**.
- The also have a **shape** and a **size attribute**, which give additional information, in the case of arrays with more than 1D.
- **Attribute: "sub-variable"** of an object; applies to an object using the **.** operator. (Object-oriented concept, not covered yet)

```
array1 = np.array([0, 2, 1, 4])
print(len(array1))
print(array1.shape)
print(array1.size)
```

```
4
(4,)
4
```

```
two_d_array = np.array([[1,2],[3,4]])
print(two_d_array)
print(len(two_d_array))
print(two_d_array.shape)
print(two_d_array.size)
```

```
[[1 2]
 [3 4]]
2
(2, 2)
4
```

Indexing an array

- Just like lists, the Numpy arrays are indexed and their element can be accessed with **[]**.
- You can equivalently use the **[i,j]** and **[i][j]** notations on arrays.
- Replacing an index with a colon symbol **:**, means “take all”.
- For instance, **[:, j]** means **all elements in column j**, whereas **[i, :]** means **all elements in row i**.

```python
array1 = np.array([0, 2, 1, 4])
print(array1)
print(array1[0])
print(array1[1])
```

```
[0 2 1 4]
0
2
```

```python
two_d_array = np.array([[1,2],[3,4]])
print(two_d_array)
print(two_d_array[0])
print(two_d_array[0][1])
```

```
[[1 2]
 [3 4]]
[1 2]
2
```

```python
print(two_d_array[0,1])
print(two_d_array[:,1])
print(two_d_array[0,:])
```

```
2
[2 4]
[1 2]
```

Traversing an array with for

- As with **lists**, we can traverse a Numpy array, in an element-wise manner, using a **for** loop.

```
array1 = np.array([0, 2, 1, 4])
print(array1)
for element in array1:
    print(element)
```

```
[0 2 1 4]
0
2
1
4
```

```
my_list = [1, 4, 9, 14, 15]
print(my_list)
```

```
[1, 4, 9, 14, 15]
```

```
# Element-wise
for element in my_list:
    print("--")
    print(element)
```

```
--
1
--
4
--
9
--
14
--
15
```

The + operator on arrays

- **The + operator on lists**: On lists, the + operator will **concatenate** both lists into a new one.
- **The + operator on Numpy arrays – (vector sum):** On Numpy arrays, however, the + operator will **sum** the elements of both Numpy arrays.
- **Broadcasting:** If summed with a number instead, the elements in the Numpy array will each be incremented by the given value.

```
a_list = [0, 1, 2]
another_list = [1, 4, 7]
list_sum = a_list + another_list
print(list_sum)
```

```
[0, 1, 2, 1, 4, 7]
```

```
array1 = np.array([0, 2, 1, 4])
array2 = np.array([1, 2, 3, 5])
print(array1)
print(array2)
sum_array = array1 + array2
print(sum_array)
```

```
[0 2 1 4]
[1 2 3 5]
[1 4 4 9]
```

```
array1 = np.array([0, 2, 1, 4])
number = 7
print(array1)
sum_array = array1 + number
print(sum_array)
```

```
[0 2 1 4]
[ 7  9  8 11]
```

Concatenation on arrays

- Since the **+** operator cannot be used for **concatenation**, Numpy comes with a **concatenate()** function.

```
print(array1)
print(array2)
conc_array = np.concatenate([array1, array2])
print(conc_array)
```

```
[0 2 1 4]
[1 2 3 5]
[0 2 1 4 1 2 3 5]
```

The * operator on arrays

- The * operator behaves as the + operator on Numpy arrays.
- It consists of an **element-wise multiplication** of the elements in arrays.
- **Broadcasting:** if a Numpy array is multiplied by a number, the number will multiply each element in the array.

```
array1 = np.array([0, 2, 1, 4])
array2 = np.array([1, 2, 3, 5])
print(array1)
print(array2)
mult_arrays = array1*array2
print(mult_arrays)
```

```
[0 2 1 4]
[1 2 3 5]
[ 0  4  3 20]
```

```
n = 4
mult_array_int = array1*n
print(mult_array_int)
```

```
[ 0  8  4 16]
```

Additional functions

Additional Numpy functions

- **Min, max:** returns the minimal, resp. maximal, values in array.
- **Argmin, argmax:** returns the index where the minimal, resp. maximal, values are.
- **Mean, median:** returns the mean, resp. median, value for a given array.
- **Sum:** sums all the elements in the array together

```python
array1 = np.array([0, 2, 1, 4, 7])
print(array1)
min_val = np.min(array1)
print(min_val)
argmin_val = np.argmin(array1)
print(argmin_val)
max_val = np.max(array1)
print(max_val)
argmax_val = np.argmax(array1)
print(argmax_val)
mean_val = np.mean(array1)
print(mean_val)
median_val = np.median(array1)
print(median_val)
summed_val = np.sum(array1)
print(summed_val)
```

```
[0 2 1 4 7]
0
0
7
4
2.8
2.0
14
```

Mathematical functions and constants

Numpy also contains

- Many **mathematical functions** (cosine, sine, logarithm, exponential, etc.)
- And many **mathematical constants** (pi, etc.)

```python
print(np.cos(0))
print(np.sin(0))
print(np.pi)
print(np.log(1))
print(np.exp(0))
```

```
1.0
0.0
3.141592653589793
0.0
1.0
```

Aliasing, Shallow and Deep copies in arrays

- As with lists, Numpy arrays are subject to the same issues about **aliasing, shallow and deep copies**.

- If needed, use deep copies of the arrays.

```
two_d_array1 = np.array([[1,2],[3,4]])
two_d_array2 = two_d_array1
print(two_d_array1)
print(two_d_array2)
print(id(two_d_array1))
print(id(two_d_array2))
```

```
[[1 2]
 [3 4]]
[[1 2]
 [3 4]]
1750029422960
1750029422960
```

```
two_d_array1[0][0] = 17
print(two_d_array1)
print(two_d_array2)
```

```
[[17  2]
 [ 3  4]]
[[17  2]
 [ 3  4]]
```

And so much more! RTFM!

- Numpy has **many more functions and tools** to offer!
- E.g., **Random functions** (to be covered in an upcoming session, if time allows?)

- Learn more about Numpy (RTFM!) here:

https://numpy.org/doc/stable/

```
# Numpy.random.choice() mimics a dice roll
dice_roll = np.random.choice([1, 2, 3, 4, 5, 6])
print(dice_roll)
dice_roll = np.random.choice([1, 2, 3, 4, 5, 6])
print(dice_roll)
dice_roll = np.random.choice([1, 2, 3, 4, 5, 6])
print(dice_roll)
dice_roll = np.random.choice([1, 2, 3, 4, 5, 6])
print(dice_roll)
dice_roll = np.random.choice([1, 2, 3, 4, 5, 6])
print(dice_roll)
dice_roll = np.random.choice([1, 2, 3, 4, 5, 6])
print(dice_roll)
```

```
4
6
1
4
3
2
```

Activity 1 - Exam adjustments

- Let us assume, that I have **grades** from my students listed in some **np.array** variables, as shown below.

```
columns_labels_list = ["MidTerm Score", "FinalExam Score", "Average Score"]
students_list = ["Chris", "Oka", "Norman", "Natalie", "Tony"]
grades_table = np.array([[60, 80, 70], \ # Chris scored 60% on MidTerm, 80% on Finals, Average is 70%
                         [50, 80, 65], \
                         [40, 70, 55], \
                         [60, 70, 65], \
                         [60, 90, 75]])
print(grades_table)
```

```
[[60 80 70]
 [50 80 65]
 [40 70 55]
 [60 70 65]
 [60 90 75]]
```

Activity 1 - Exam adjustments

- Let us assume, that I have **grades** from my students listed in a **np.array**.
- The first line contains the column labels (student name, some scores) and the other lines will consist of entries regarding some of the students.

- Let us assume that, as a professor, I have decided to be lenient towards my students.
- I realized that the midterm was a bit too difficult compared to last year.
- To compensate for that, I would like to increase the scores of all students on the midterm by 50%.

Activity 1 - Exam adjustments

Write a function **grade_adjustment()**,

- which **receives** a grades table, **grades_table**,
- **increases** the **scores** of all students on the **midterm** by **50%**,
- **re-calculates** the **average score**, with the **new adjusted midterm score**,
- and then returns the **updated grades table** as its sole output.

- **Important note:** The **maximal score** for the midterm exam is **capped** to **100**. This means that a student which scores 80 points on the midterm, will not obtain 120 points after the adjustment, but only 100.

The import procedure

- The import procedure is used to **import functions defined in external .py files.**

my_code.py file

jupyter my_code.py Last Tuesday at 1:22 PM

File Edit View Language

```python
def my_function(x):
    return 2*x + 1

def my_function2(x):
    return 3*x + 4

def my_function3(x):
    return 4*x + 7
```

The import procedure

- The import procedure is used to **import functions defined in external .py files.**
- To demonstrate, we have defined a **my_code.py** file with three functions.

my_code.py file

jupyter my_code.py Last Tuesday at 1:22 PM

File Edit View Language

```
def my_function(x):
    return 2*x + 1

def my_function2(x):
    return 3*x + 4

def my_function3(x):
    return 4*x + 7
```

The import procedure

- The import procedure is used to **import functions defined in external .py files.**
- To demonstrate, we have defined a **my_code.py** file with three functions.
- We can then import one of these functions in our Notebook, by using the **from … import …** command.

my_code.py file

jupyter my_code.py Last Tuesday at 1:22 PM

File Edit View Language

```
def my_function(x):
    return 2*x + 1

def my_function2(x):
    return 3*x + 4

def my_function3(x):
    return 4*x + 7
```

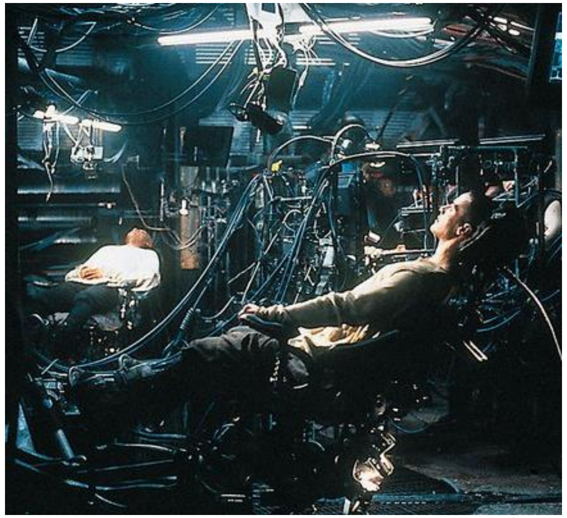
In our notebook

```
from my_code import my_function
```

```
print(my_function(2))
```

```
5
```

The import procedure



Operator:
Cosine function coming right up!


```
print(cos(0))
```

Importing as

- If needed, we can **import** and **rename** a function by using the as keyword.
- The whole command then reads **from … import … as …**
- **Note:** if you rename the function, its calling name changes to the alias you specified.

my_code.py file

jupyter my_code.py Last Tuesday at 1:22 PM

File Edit View Language

```python
def my_function(x):
    return 2*x + 1

def my_function2(x):
    return 3*x + 4

def my_function3(x):
    return 4*x + 7
```

In our notebook

```python
from my_code import my_function2 as custom_name
```

```python
print(my_function2(2))
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
<ipython-input-4-20b74e0a7273> in <module>
----> 1 print(my_function2(2))

NameError: name 'my_function2' is not defined
```

```python
print(custom_name(2))
```

```
10
```

Importing several functions

- If needed, you can import **multiple functions** in a single import call.
- Simply use **commas (,) symbols** to separate the different functions names.
- Or, you can also **import all functions** at once, by simply entering *.

my_code.py file

jupyter my_code.py Last Tuesday at 1:22 PM

File Edit View Language

```python
def my_function(x):
    return 2*x + 1

def my_function2(x):
    return 3*x + 4

def my_function3(x):
    return 4*x + 7
```

In our notebook

```python
from my_code import my_function, my_function2
```

```python
from my_code import *
```

```python
print(my_function3(2))
```

```
15
```

Importing an entire module

- You can also import a whole file, as a **module.**
- To do so, simply start with **import** instead of **from**.
- By doing so, you import all the functions, but **they have to be called using the module name and the dot operator** (.).
- This can make the code more readable, but is also a bit more inconvenient.

more_code.py file

jupyter more_code.py ✓ Last Tuesday at 1:26 PM

File Edit View Language

```python
def my_function4(x):
    return x + 1

def my_function5(x):
    return "Hello {}!".format(x)
```

In our notebook

```python
import more_code
```

```python
print(my_function4(2))
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
<ipython-input-9-0bc0cdce5e54> in <module>
----> 1 print(my_function4(2))

NameError: name 'my_function4' is not defined
```

```python
print(more_code.my_function4(2))
```

```
3
```

Importing an entire module

- You can also use an alias for the module using the **as** keyword, as before.
- Typically, we often do it with Numpy!

import numpy as np

more_code.py file

jupyter more_code.py ✓ Last Tuesday at 1:26 PM

File Edit View Language

```python
def my_function4(x):
    return x + 1

def my_function5(x):
    return "Hello {}!".format(x)
```

In our notebook

```python
import more_code as mc
```

```python
print(mc.my_function4(2))
```

```
3
```

```python
import numpy as np
```

```python
print(np.cos(0))
```

```
1.0
```

Folders to import from

- **Observation:** Python imported functions from my_code.py, which was located in the same folder as my Notebook.
- **But there was no <u>numpy.py file</u> in this location.**
- **What happened?**

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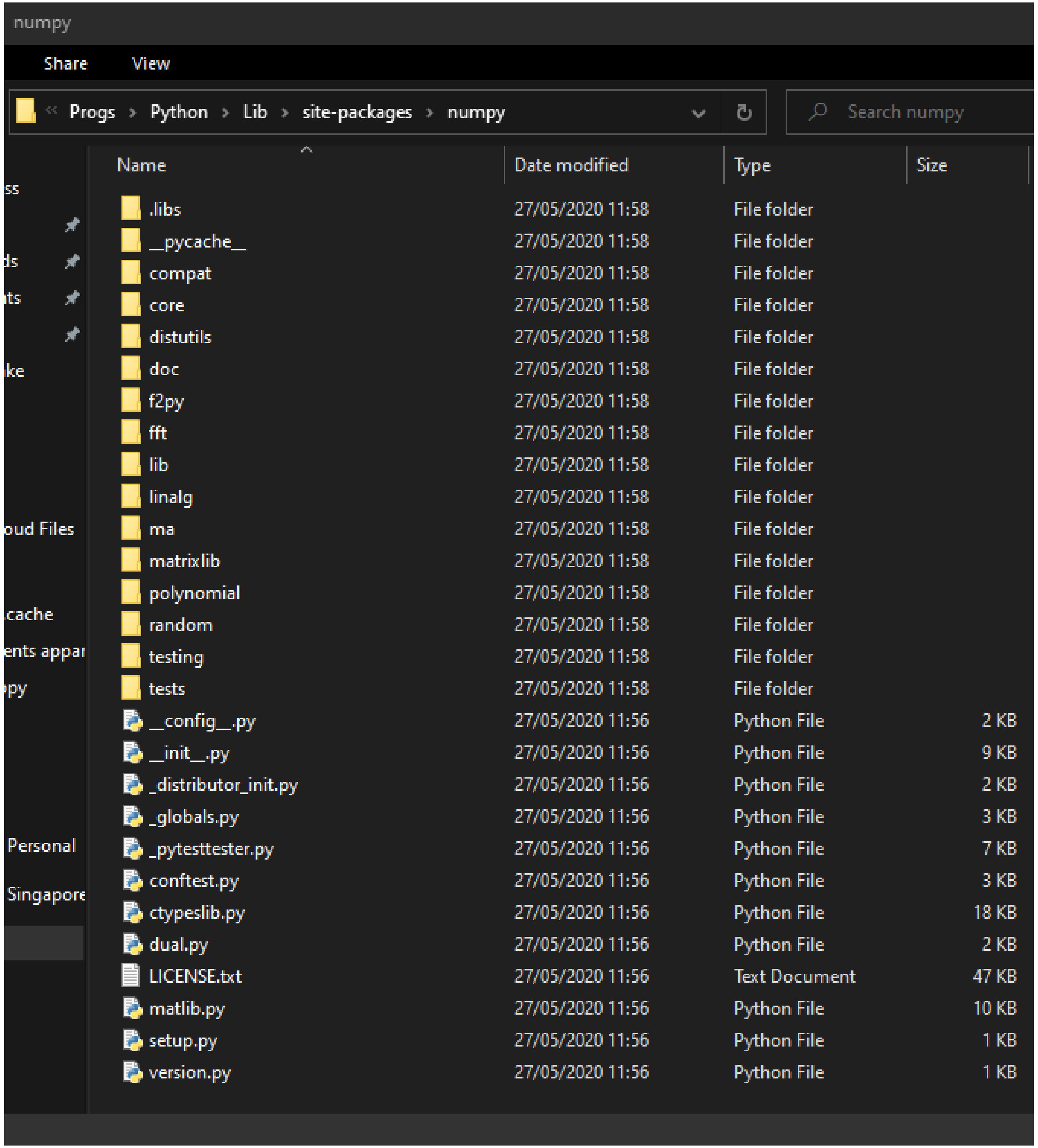

Project organizing

- In many projects, several developers will often collaborate on a single project.
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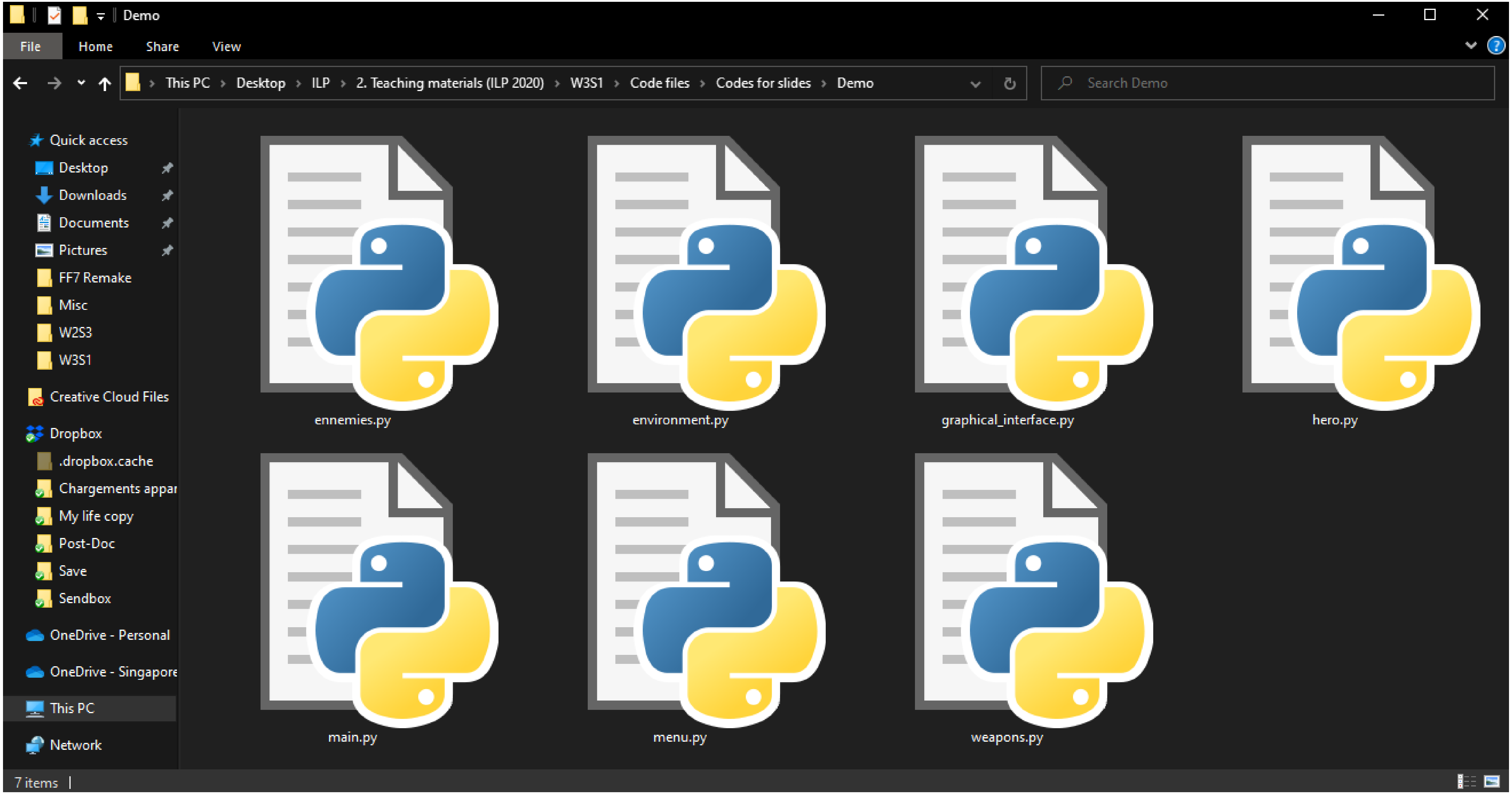
E.g. in a video game:

- One developer can design the main character,
- Another one will develop enemies,
- Another one will develop items and weapons,
- Another one will design the map/environment in which heroes and enemies evolve,
- Etc.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Chargements appar
My life copy
Post-Doc
Save
Sendbox
OneDrive - Personal
OneDrive - Singapore
This PC
Network
ennemies.py
environment.py
graphical_interface.py
hero.py
main.py
menu.py
weapons.py
7 items

Project organizing

- Each developer will then work on his/her own .py file, taking care of his/her specific subtask.
- Later on, other developers might **import** functions from files created by other people.
- Eventually assemble all pieces in a **main.py** file!

Project organizing

- Each developer will then work on his/her own .py file, taking care of his/her specific subtask.
- Later on, other developers might **import** functions from files created by other people.
- Eventually assemble all pieces in a **main.py** file!
- This is something very common in programming projects.
- **Important:** you need to build the habit of documenting your functions!

Matt's Great advice #11

Matt's Great Advice #11: Good import practices

Some good practices in projects

1. As with the variables and functions names, it is a good idea to **make your file names explicit**.
2. Have **a file for each sub-concept**, and **a single main file that assembles them all** at the end.
3. It is often better to **import only what is needed** (**from** … **import** …) rather than importing everything (**from** … **import** *, **import** …).

Conclusion

- Memory management and lists: aliasing, shallow and deep copies
- The Numpy library (part 1): arrays, math functions, etc.
- About the import procedure
- Project organizing
- Mini-project