Software Engineering – Architectures, Designs, and Code

L01 on Coding

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Location of the material:
https://github.com/GiancarloSucci/UniBo.SE.A2023

Structure of the Part on Coding

- Part 0:
  - Revision of the strategy pattern in Java (and, a very little bit, on C++)
- Part 1:
  - Introduction on Python as a self-proclaimed multiparadigm language
- Part 2:
  - Patterns in Python with an eye on ChatGPT and around

Caveat on Python (1/2)

- Here we will reflect on the concepts we saw on architecture and design looking at the code
- We will focus on a concrete example, which could be used also in the overall course
- We will see many examples of code
- Also very detailed, step-by-step examples
- Our focus will be on the software engineering side, though
- That is in understanding why and how people achieved what they achieved
    - not on hacking solutions

Caveat on Python (2/2)

- The most liked programming languages by the instructor
  - 1. C++
  - 2. C
  - 3. Java
  - 4. Haskell
  - 5. SmallTalk
  - 6. ...
  - ...
  - n-1. ...
  - n. Python
- We use Python because it is becoming a standard
- But we start with a mention of the ancestor

Python for our purposes

- About the language
- Structure of the execution of Python
- Virtual Environment

About the language

- Origin and principles of the language
- Fundamental syntax
- Structure of execution
- String formatting
- Object orientation
- Polymorphism and late binding
- Functions as objects
- Decorators
- Static members
- Structure of the virtual machine

Origin of the language

- The language was conceived by Guido van Rossum at CWI in the '80s, got its first implementation in the early '90, and then was modified and upgraded multiple times
- The latest stable version of Python (at the time of writing these slides) is 3.11.5, released on 5th October 2022
- The language is releases in a "kind of" open source license, the Python Software Foundation License but there are debates about it
- Apparently, Python comes from ABC and SETL (see `https://en.wikipedia.org/wiki/History_of_Python`)
- The instructor sees a strong resemblance of SmallTalk (see the references below)

- **References**:
  - Python vs. Smalltalk: from StackOverflow and from Medium.
  - About Python in wikipedia: `https://en.wikipedia.org/wiki/Python_(programming_language)`, `https://en.wikipedia.org/wiki/History_of_Python` and related pages

Principles of the language

- Multiparadigm (scripting, imperative, object oriented, and functional)
- Dynamically typed
- Garbage collected
- “Batteries included”
- Based on a virtual machine (“kind of” interpreted)
- **References**:
  - About Python in wikipedia: `https://en.wikipedia.org/wiki/Python_(programming_language)`

The Zen of Python (1/2)

- By Tim Peters
    - Beautiful is better than ugly.
    - Explicit is better than implicit.
    - Simple is better than complex.
    - Complex is better than complicated.
    - Flat is better than nested.
    - Sparse is better than dense.
    - Readability counts.
    - Special cases aren't special enough to break the rules.
    - Although practicality beats purity.
    - Errors should never pass silently.
    - Unless explicitly silenced.
- **References**:
    - About the Zen of Python in wikipedia: `https://en.wikipedia.org/wiki/Zen_of_Python`

The Zen of Python (2/2)

- By Tim Peters
  - In the face of ambiguity, refuse the temptation to guess.
  - There should be one-- and preferably only one --obvious way to do it.
  - Although that way may not be obvious at first unless you're Dutch.
  - Now is better than never.
  - Although never is often better than *right* now.
  - If the implementation is hard to explain, it's a bad idea.
  - If the implementation is easy to explain, it may be a good idea.
  - Namespaces are one honking great idea – let's do more of those!
- **References**:
  - About the Zen of Python in wikipedia: `https://en.wikipedia.org/wiki/Zen_of_Python`

Multiparadigm

- We will now explore Python in its 4 paradigms
  - Scripting
  - Imperative
  - Functional
  - Object Oriented
- With such an approach we will cycle over the syntax and the semantics of the language to get a comprehensive view of it and revising the fundamental principles of software engineering

Python as a scripting language

Scripting (1/3)

- Install the Python interpreter: multiple options including
  - Mac: see the guidelines in **Pip Upgrade – And How to Update Pip and Python**
  - Windows: like here: **pyenv for Windows**
- Open the Python interpreter . . .
- . . . and try :)
- Analysing the scripting perspective of Python exposes us to the fundamental control structures
  - variables, if, blocks via indentation, while, for, collections, iterations

Scripting (2/3)

```
% python3.11
Python 3.11.2 (v3.11.2:878ead1ac1, Feb  7 2023, 10:02:41) [Clang 13.0.0 (clang
     -1300.0.29.30)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> print("Hello World!")
Hello World!
>>> 4+3
7
>>> x = 7+1
>>> x**2
64
>>>
```

Scripting (3/3)

```
% python3.11
Python 3.11.2 (v3.11.2:878ead1ac1, Feb  7 2023, 10:02:41) [Clang 13.0.0 (clang
     -1300.0.29.30)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> the_world_is_flat = True
>>> if the_world_is_flat:
...     print("Be careful not to fall off!")
...
Be careful not to fall off!
>>> ^D
```

Source: `https://docs.python.org/3/tutorial/interpreter.html`

Indentation

- If I forget the indentation ...

```
% python3.11
Python 3.11.2 (v3.11.2:878ead1ac1, Feb  7 2023, 10:02:41) [Clang 13.0.0 (clang
     -1300.0.29.30)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> the_world_is_flat = True
>>> if the_world_is_flat:
... print("Be careful not to fall off!")
  File "<stdin>", line 2
    print("Be careful not to fall off!")
    ^
IndentationError: expected an indented block after 'if' statement on line 1
>>> ^D
```

Source: `https://docs.python.org/3/tutorial/interpreter.html`

Dynamic Typing

- Typing is dynamic and enforced ...

```
% python3.11
Python 3.11.2 (v3.11.2:878ead1ac1, Feb  7 2023, 10:02:41) [Clang 13.0.0 (clang
    -1300.0.29.30)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> x = "a string"
>>> x = 1
>>> print(x)
1
>>> y = 1 + "a string"
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unsupported operand type(s) for +: 'int' and 'str'
>>>
```

Source: `https://docs.python.org/3/tutorial/introduction.html`

Math

- Mathematics follows mostly the usual approaches ...

```
% python3.11
>>> 3+4
7
>>> 6-3.4
2.6
>>> 4*7.0
28.0
>>> 7/3
2.3333333333333335
>>> 7//3
2
>>> 7%3
1
>>> 7**3
343
>>> 3 + _
346
>>>
```

Source: https://docs.python.org/3/tutorial/introduction.html

Strings (1/2)

- Strings are a bit more peculiar ...

```
>>> x='strings can be single quoted '
>>> y="or double quoted "
>>> x + y + "and  joined with  +  "
'strings can be single quoted or double quoted and joined with +  '
>>>
>>> z=''' strings can span
... multiple lines using triple
...
... quotes'''
>>> z
' strings can span\nmultiple lines using triple\n\nquotes'
>>> print(z)
 strings can span
multiple lines using triple

quotes
>>>
```

Source: https://docs.python.org/3/tutorial/introduction.html

Strings (2/2)

- Strings are a bit more peculiar ...

```
>>> w='And I can add \n special chars like in C, which are printed using print'
>>> w
'And I can add \n special chars like in C, which are printed using print'
>>> print(w)
And I can add
 special chars like in C, which are printed using print
>>> c='concatenation ' 'is done just sequencing strings '
>>> c
'concatenation is done just sequencing strings '
>>> c ' but not using variables'
  File "<stdin>", line 1
    c ' but not using variables'
      ^^^^^^^^^^^^^^^^^^^^^^^^^^
SyntaxError: invalid syntax
>>> 2*' and the n* operator repeats the string n times'
' and the n* operator repeats the string n times and the n* operator repeats the
      string n times'
```

Source: `https://docs.python.org/3/tutorial/introduction.html`

Indexing Strings (1/2)

- Strings can be indexed ...

```
>>> e='My Example of Python'
>>> e[0]
'M'
>>> e[19]
'n'
>>> e[20]
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
IndexError: string index out of range
>>> e[-1]
'n'
>>> e[-19]
'y'
>>> e[-20]
'M'
>>> e[3:5]
'Ex'
>>> e[-4:-1]
'tho'
```

Indexing Strings (2/2)

- Ranges are start-included, end-excluded ...
- Slicing can include the step as third parameter

```
>>> e[0:3]
'My '
>>> e[11:]
'of Python'
>>> e[:11]+e[11:]
'My Example of Python'
>>> e[2:10:2]
' xml'
>>> e[::2]
'M xml fPto'
>>> e[::-1]
'nohtyP fo elpmaxE yM'
```

Source: `https://docs.python.org/3/tutorial/introduction.html`

More on Strings

- Strings are immutable

```
>>> e[0]='T'
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: 'str' object does not support item assignment
>>> w = 'T' + e[1:]
>>> w
'Ty Example of Python'
>>>
```

- Length of a string

```
>>> len(w)
20
>>> len("123")
3
```

Source: `https://docs.python.org/3/tutorial/introduction.html`

Collections

- Python does not have arrays
- Python has 4 basic collection types, partly with syntax similar to that of strings:
  - Lists: ordered, mutable collections with duplicates
  - Tuples: ordered, immutable collection with duplicates
  - Sets: unordered collection, without duplications, whose members are immutable
  - Dictionaries: ordered, mutable collections without duplicates

Source: `https://www.w3schools.com/python/python_tuples.asp`

Lists (1/8)

- List are ordered collections of elements, with a syntax resembling that of strings

```
>>> odd = [1, 3, 5, 7, 9]
>>> odd
[1, 3, 5, 7, 9]
>>> odd[0]
1
>>> odd[4]
9
>>> odd[-1]
9
>>> odd[-5]
1
>>> odd[1:3]
[3, 5]
>>> odd[:2]+odd[2:]
[1, 3, 5, 7, 9]
>>> len(odd)
5
```

Source: https://docs.python.org/3/tutorial/introduction.html

Lists (2/8)

- List are mutable, append-able, slice-able

```
>>> odd[2]=20
>>> odd
[1, 3, 20, 7, 9]
>>> odd.append(11)
>>> odd
[1, 3, 20, 7, 9, 11]
>>> odd[3:5]=[100,200,300]
>>> odd
[1, 3, 20, 100, 200, 300, 11]
>>> odd[1:3] = []
>>> odd
[1, 100, 200, 300, 11]
>>> odd[:] = []
>>> odd
[]
```

Source: `https://docs.python.org/3/tutorial/introduction.html`

Lists (3/8)

- List are nestable and heterogeneous

```
>>> a = [1,2,3]
>>> b = [10,20]
>>> c = [90, 800, -34]
>>> n = [a, b, c]
>>> n
[[1, 2, 3], [10, 20], [90, 800, -34]]
>>> n[2][1]
800
>>> z = [1, "xxx", 3]
>>> z
[1, 'xxx', 3]
>>> z[1]
'xxx'
```

Source: `https://docs.python.org/3/tutorial/introduction.html`

Lists (4/8)

- Copy of references

```
>>> x = [1, 2, 3, 4]
>>> y = x
>>> y[2]=200
>>> x
[1, 2, 200, 4]
```

Source: https://www.geeksforgeeks.org/copy-python-deep-copy-shallow-copy/

Lists (5/8)

- Shallow copies

```
>>> w = x.copy()
>>> w[1]=350
>>> w
[1, 350, 200, 4]
>>> x
[1, 2, 200, 4]
```

Source: https://www.geeksforgeeks.org/copy-python-deep-copy-shallow-copy/

Lists (6/8)

- Shallow copies (more)

```
>>> z = [11,22,33]
>>> k = [121, 132, 143, 154]
>>> j = [z,k]
>>> j
[[11, 22, 33], [121, 132, 143, 154]]
>>> i = j.copy()
>>> k[1] = 222
>>> i
[[11, 22, 33], [121, 222, 143, 154]]
>>> i[0] = [5, 8, 13]
>>> k[1] = 222
>>> i
[[5, 8, 13], [121, 222, 143, 154]]
>>> j
[[11, 22, 33], [121, 222, 143, 154]]
```

Source: https://www.geeksforgeeks.org/copy-python-deep-copy-shallow-copy/

Lists (7/8)

- Deep copies

```
>>> j
[[11, 22, 33], [121, 222, 143, 154]]
>>> import copy
>>> dc = copy.deepcopy(j)
>>> k[1] = 423
>>> j
[[11, 22, 33], [121, 423, 143, 154]]
>>> dc
[[11, 22, 33], [121, 222, 143, 154]]
```

- Membership

```
>>> aList = [1, 2, 3, 5, 0, 9, 0, 7, 1, 5]
>>> 3 in aList
True
>>> 12 in aList
False
```

Source: https://www.geeksforgeeks.org/copy-python-deep-copy-shallow-copy/

Lists (8/8)

- Deletion

```
>>> aList = [1, 2, 3, 5, 0, 9, 0, 7, 1, 5]
>>> aList.pop(2)
3
>>> aList
[1, 2, 5, 0, 9, 0, 7, 1, 5]
>>> aList.pop(-3)
7
>>> aList
[1, 2, 5, 0, 9, 0, 1, 5]
>>> aList.remove(5)
>>> aList
[1, 2, 0, 9, 0, 1, 5]
>>> del aList[1]
>>> aList
[1, 0, 9, 0, 1, 5]
>>> aList.clear()
>>> aList
[]
```

Source: https://note.nkmk.me/en/python-list-clear-pop-remove-del//

Tuples (1/5)

- Tuples are ordered, immutable collections of elements, with syntax resembling arrays

```
>>> aTuple=("touple", 2, 9, [10, 2, 3], "start")
>>> aTuple
('touple', 2, 9, [10, 2, 3], 'start')
>>> aTuple[0]
'touple'
>>> aTuple[-1]
'start'
>>> aTuple[2:]
(9, [10, 2, 3], 'start')
>>> aTuple[1] = "tryToChange"
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: 'tuple' object does not support item assignment
>>> aTuple.append(3)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: 'tuple' object has no attribute 'append'
```

Source: https://www.w3schools.com/python/python_tuples.asp/

Tuples (2/5)

- Tuples are immutable!

```
>>> anAlias=aTuple
>>> aTuple = aTuple + (1, 2, 3)
>>> aTuple
('touple', 2, 9, [10, 2, 3], 'start', 1, 2, 3)
>>> anAlias
('touple', 2, 9, [10, 2, 3], 'start')
>>> aTuple = aTuple + (3)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: can only concatenate tuple (not "int") to tuple
>>> aTuple = aTuple + (3,)
>>> aTuple
('touple', 2, 9, [10, 2, 3], 'start', 1, 2, 3, 3)
>>> len(aTuple)
9
>>> 2 in aTuple
True
>>> 12 not in aTuple
True
```

Tuples (3/5)

- Tuples are immutable ... but be careful of references!

```
>>> a = [3,4,5]
>>> b=(a,6)
>>> b
([3, 4, 5], 6)
>>> a[0]=1
>>> b
([1, 4, 5], 6)
>>> c = b
>>> a[1]=10
>>> b
([1, 10, 5], 6)
>>> c
([1, 10, 5], 6)
>>> c = b.copy()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: 'tuple' object has no attribute 'copy'
```

Source: https://www.w3schools.com/python/python_tuples.asp/

Tuples (4/5)

- Tuples are immutable ... but be careful of references!

```
>>> import copy
>>> d = copy.deepcopy(b)
>>> d
([1, 10, 5], 6)
>>> a[2]=8
>>> b
([1, 10, 8], 6)
>>> c
([1, 10, 8], 6)
>>> d
([1, 10, 5], 6)
>>>
```

Source: https://www.w3schools.com/python/python_tuples.asp/

Tuples (5/5)

- Shortcuts and conversions

```
>>> anAlias=aTuple
>>> aTuple += (55,)
>>> aTuple
('touple', 2, 9, [10, 2, 3], 'start', 1, 2, 3, 3, 55)
>>> anAlias
('touple', 2, 9, [10, 2, 3], 'start', 1, 2, 3, 3)
>>> aList = [1, 2, 3]
>>> aConvertedTuple = tuple(aList)
>>> aList
[1, 2, 3]
>>> aConvertedTuple
(1, 2, 3)
>>> aList[2]=5
>>> aList
[1, 2, 5]
>>> aConvertedTuple
(1, 2, 3)
```

Source: https://www.w3schools.com/python/python_tuples_update.asp/

Sets (1/3)

- Sets are unordered collections without duplicates whose elements cannot change

```
>>> aSet = {1, 2, "red"}
>>> aSet
{1, 2, 'red'}
>>> anotherSet = {3, 4, "green", 4, "green"}
>>> anotherSet
{3, 4, 'green'}
>>> 1 in aSet
True
>>> "green" in aSet
False
>>> "green" in anotherSet
True
>>> oneIsLikeTrue = { 1, True, "green"}
>>> oneIsLikeTrue
{1, 'green'}
>>> len(oneIsLikeTrue)
2
```

Source: `https://www.w3schools.com/python/python_sets.asp/`

Sets (2/3)

```
>>> aThirdSet = aSet | anotherSet
>>> aThirdSet
{1, 2, 3, 4, 'green', 'red'}
>>> aFourthSet = aThirdSet & {2, 3, 200, 'green'}
>>> aFourthSet
{2, 3, 'green'}
>>>
>>> aSetFromAList = set([9, 8, 7])
>>> aSetFromAList
{8, 9, 7}
>>> aSetFromATuple = set((6, 5, 4))
>>> aSetFromATuple
{4, 5, 6}
>>> aSetFromATuple + aSetFromAList
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unsupported operand type(s) for +: 'set' and 'set'
```

Source: https://www.w3schools.com/python/python_sets.asp/

Sets (3/3)

- Mutable elements like lists, the same sets, and dictionaries cannot be part of sets

```
>>> a = {3, 1, 5, 4}
>>> b = [10, 11, 12]
>>> a.add(b)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unhashable type: 'list'
>>> c = (10, 11, 12)
>>> a.add(c)
>>> a
{1, 3, 4, 5, (10, 11, 12)}
>>> d = {3, 4, 1}
>>> a.add(d)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unhashable type: 'set'
```

Source: https://www.w3schools.com/python/python_sets.asp/

Dictionaries (1/2)

- Dictionaries are ordered collections of pair (key:value), indexed by key, where each key can appear only once

```
>>> aDictionary = { "breed":"Dog", "weight":8, "name":"Deimon", "age":3}
>>> aDictionary
{'breed': 'Dog', 'weight': 8, 'name': 'Deimon', 'age': 3}
>>> aDictionary["breed"]
'Dog'
>>> len(aDictionary)
4
>>> aDictionary.keys()
dict_keys(['breed', 'weight', 'name', 'age'])
>>> aDictionary.values()
dict_values(['Dog', 8, 'Deimon', 3])
>>> aDictionary.update({"weight":7.5,"color":"blenheim"})
>>> aDictionary
{'breed': 'Dog', 'weight': 7.5, 'name': 'Deimon', 'age': 3, 'color': 'blenheim'}
```

Source: https://www.w3schools.com/python/python_dictionaries.asp/

Dictionaries (2/2)

- Dictionaries can be largely manipulated

```
>>> aDictionary.popitem()
('color', 'blenheim')
>>> aDictionary
{'breed': 'Dog', 'weight': 7.5, 'name': 'Deimon', 'age': 3}
>>> aDictionary.pop('weight')
7.5
>>> aDictionary
{'breed': 'Dog', 'name': 'Deimon', 'age': 3}
>>> del aDictionary["age"]
>>> aDictionary
{'breed': 'Dog', 'name': 'Deimon'}
```

Source: `https://www.w3schools.com/python/python_dictionaries_remove.asp/`

The `range` function

- The **range** function is used to generate lists of numbers for iterations
- It returns a range object, which could then be converted in a list for printing

```
>>> list(range(3))
[0, 1, 2]
>>> list(range(-4, 5))
[-4, -3, -2, -1, 0, 1, 2, 3, 4]
>>> list(range(2, 20, 3))
[2, 5, 8, 11, 14, 17]
>>> list(range(2, 20, 7))
[2, 9, 16]
>>> list(range(0))
[]
>>> range(4.3)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: 'float' object cannot be interpreted as an integer
```

Source: https://thepythonguru.com/python-builtin-functions/range/

Control flow – `if`

- The `if` statement is all based on indentation

```
>>> import math
>>> a = 4
>>> b = 5
>>> c = -1
>>> delta = b**2 - 4*a*c
>>> if delta > 0:
...      x1 = (-b - math.sqrt(delta))/(2*a)
...      x2 = (-b + math.sqrt(delta))/(2*a)
... elif delta == 0:
...      x1 = x2 = - b / (2*a)
... else:
...      x1 = complex(-b, math.sqrt(-delta)/(2*a))
...      x2 = complex(-b, math.sqrt(-delta)/(2*a))
...
>>> x1
-1.425390529679106
>>> x2
0.17539052967910607
>>>
```

Control flow – `while`

- The `while` statement is the typical top-tested loop based on indentation

```
>>> i = 5
>>> factorial = 1
>>> while i > 1:
...  factorial *= i
...  i -= 1
... else:
...  print("the result is ",factorial)
...
the result is 120
>>>
```

Source: `https://docs.python.org/3/tutorial/controlflow.html/`

Flow in loops

- Python has three construct to manage the flow in loops:
  - `break`: like in C and Java breaks the loop (the `else` statement is not executed)
  - `continue`: like in C and Java, suspends the current iteration and jumps directly to the next one
  - `pass`: absent in C and Java, moves to the next block
- Now we analyse in details the following snippets

Source: `https://docs.python.org/3/tutorial/controlflow.html/`

break and continue

```
i = 0
print("break")
while i in range(10):
    i += 1
    if i == 5:
        print("i is 5!")
        break
        print("break: I should not get here!")
    print("Standard printout for iteration ",i)
else:
    print("End of loop break")
i = 0
print("continue")
while i in range(10):
    i += 1
    if i == 5:
        print("i is 5!")
        continue
        print("continue: I should not get here!")
    print("Standard printout for iteration ",i)
else:
    print("End of loop continue")
```

pass

```python
i = 0
print("pass")
while i in range(10):
    i += 1
    if i == 5:
        print("i is 5!")
        pass
        print("pass: I should not get here!")
    print("Standard printout for iteration ",i)
else:
    print("End of loop pass")
```

Output (1/2)

```
break
Standard printout for iteration  1
Standard printout for iteration  2
Standard printout for iteration  3
Standard printout for iteration  4
i is 5!
continue
Standard printout for iteration  1
Standard printout for iteration  2
Standard printout for iteration  3
Standard printout for iteration  4
i is 5!
Standard printout for iteration  6
Standard printout for iteration  7
Standard printout for iteration  8
Standard printout for iteration  9
Standard printout for iteration  10
End of loop continue
```

Output (2/2)

```
pass
Standard printout for iteration  1
Standard printout for iteration  2
Standard printout for iteration  3
Standard printout for iteration  4
i is 5!
pass: I should not get here!
Standard printout for iteration  5
Standard printout for iteration  6
Standard printout for iteration  7
Standard printout for iteration  8
Standard printout for iteration  9
Standard printout for iteration  10
End of loop pass
```

`iterator` (1/2)

- This is a case when superclasses are very useful
- `iterator` is a class supporting iterations over collections, that is, referring to a collection of objects, sequentializing and indexing them, and with a method `__next__()` that:
    - returns one by one the elements of the object
    - updaties the state of the `iterator` so that it always refers to *next* element in the sequence
    - raises an exception `StopIteration` when there are no more elements to point to
- Please notice the mix of scripting and object orientation

Source: `https://stackoverflow.com/questions/9884132/what-are-iterator-iterable-and-iteration#:~:text=An%20iterable%20is%20a%20object,__next__()%20in%203/`

iterator (2/2)

```
>>> string = "iter"
>>> stringIterator = iter(string)
>>> next(stringIterator)
'i'
>>> next(stringIterator)
't'
>>> stringIterator.__next__()
'e'
>>> stringIterator.__next__()
'r'
>>> stringIterator.__next__()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
StopIteration
>>>
```

Source: https://stackoverflow.com/questions/9884132/what-are-iterator-iterable-and-iteration#:~:text=An%20iterable%20is%20a%20object,__next__()%20in%203/

iterable

- An `iterable` is the base class for anything that can be iterated over
- It has a method `__iter__()` that returns an `iterator`
- This is also what is done by the global function `iter()` (see slide **??**)
- Notice the duality global functions and member functions, like for the global function `next()` and member function `__next__()`
- The duality `iterable` – `iterator` is heavily used in `for` loops, list comprehension etc (see later)

```
>>> string = "iter"
>>> stringIterator = string.__iter__()
>>> next(stringIterator)
'i'
```

Source: `https://stackoverflow.com/questions/9884132/what-are-iterator-iterable-and-iteration`

for loop

- The for loop in Python iterates over an iterator
- At every step in the loop there is an implicit call to the `__next__()` member function of the iterator
- At the last step there is an implicit catch of the StopIteration exception
- else, break, continue, and pass work like in a while loop

```
>>> string = "iter"
>>> for i in string:
...     print(i)
... else:
...     print("end of string")
...
i
t
e
r
end of string
```

Source: https://wiki.python.org/moin/ForLoop

Command line (1/2)

- Command line arguments work like in Java with `argv`
- In addition there is the function `getopt` that helps parsing the arguments one by one

```
import sys, getopt
print("Argument line: ",sys.argv)
print("Number of arguments: ",len(sys.argv))
i=0
for arg in sys.argv:
        print("argument ",i," : ",arg)
        i += 1
options, arguments = getopt.getopt(sys.argv[1:],"nh:o:")
for opt, val in options:
        if opt=="-h" : print ("Help: ",val)
        elif opt=="-o" : print ("Other: ",val)
        elif opt=="-n" : print ("n means ", end=""); print("\t no arguments")
        else : print(opt, " and ", val, " are not acceptable")
print("The other arguments are ", arguments)
```

Source: https://docs.python.org/3/library/getopt.html

Command line (2/2)

- The output is:

```
% python3 commandLine.py -o xxx -h help -n a b c
Argument line:  ['commandLine.py', '-o', 'xxx', '-h', 'help', '-n', 'a', 'b', 'c
     ']
Number of arguments:  9
argument  0  :  commandLine.py
argument  1  :  -o
argument  2  :  xxx
argument  3  :  -h
argument  4  :  help
argument  5  :  -n
argument  6  :  a
argument  7  :  b
argument  8  :  c
Other:  xxx
Help:  help
n means   no arguments
The other arguments are  ['a', 'b', 'c']
```

Source: https://docs.python.org/3/library/getopt.html

Python as an imperative language

Functions (1/4)

- In Python there are functions with parameters and return values

```
# exampleFunction.py
import math
def secondOrderEquation(a, b= 3, c= 0.5):
   delta = b*2 -4*a*c
   x1 = (-b - math.sqrt(delta))/(2*a)
   x2 = (-b + math.sqrt(delta))/(2*a)
   return a, b, c, x1, x2

print(secondOrderEquation(1, 6, 1))
print(secondOrderEquation(1, 6))
print(secondOrderEquation(1))
print(secondOrderEquation(1, c=-1))

% python3 exampleFunction.py
(1, 6, 1, -4.414213562373095, -1.5857864376269049)
(1, 6, 0.5, -4.58113883008419, -1.4188611699158102)
(1, 3, 0.5, -2.5, -0.5)
(1, 3, -1, -3.08113883008419, 0.08113883008418976)
```

Functions (2/4)

- Parameters are all passed by values and values can be references, as in Java
- But there are mutable and immutable objects!
- Functions can be parameters of other functions

```
# higherOrder.py
def apply(f,a):
   return f(a)
def increment(x):
   return x+1
def square(x):
   return x**2
def main():
   x = apply(increment,3)
   y = apply(square,4)
   print(x, y)
if __name__ == "__main__":
   main()
% python3 higherOrder.py
4 16
```

Functions (3/4)

- There are anonymous functions
- They are called `lambda` as they resemble lambda expressions

```
# exampleLambda.py
def apply(f,a):
   return f(a)
def main():
   x = apply(lambda x: x+1,3)
   y = apply(lambda x: x**2,4)
   print(x, y)
if __name__ == "__main__":
   main()
% python3 higherOrder.py
4 16
```

Functions (4/4)

- There is a *kind of* `main` function
- Every module has an internal variable, `__name__`
  - this value is set to `__main__` if the module is the one invoked directly in the command line
- Otherwise, it is set to the *name of the module*, that is, the name of the file without the suffix `.py`
- There is a convention to call a function `main()` as the first function to be executed by a module that is directly called in the command line

```
if __name__ == "__main__":
   main()
```

Nested functions

- Functions can be nested, like in Pascal

```
# nested.py

def outer(x) :
   y = 10
   def inner(z):
      return z + y
   w = inner(x)
   return w

if __name__ == "__main__":
   print(outer(3))

% python3 nested.py
13
```

Scoping rules (1/5)

- LEGB scoping
  1. Local
  2. Enclosing
  3. Global
  4. Builtin
- The keyword `global` declares a variable as global
- The keyword `nonlocal` declares a local variable in an inner scope associated to the outer scope

Scoping rules (2/5)

- Without a `global` or a `nonlocal` declaration:
    - if a variable is initialized with a name already used in an outer scope, then it is treated as a new local variable, which then hides the global one
    - if a variable is used with a name already used in an outer scope, but
        - then if its value is then changed inside the scope
        - an error is raised, as
        - it is treated as a local variable that previously was used without being initialized.

Scoping rules (3/5)

```
# scoping.py
x = 5
def testScope(a):
   y = x + a
   global z
   z = y + 1
   return y + z
def main():
   print (testScope(5) + z)
if __name__ == "__main__" :
   main()
% python3 scoping.py
32
```

Scoping rules (4/5)

```
# nonLocalScoping.py
x = 1; y = 2; w = 3; z = 4
def testScope():
   y = 20; w = 30; k = z;
   def testInnerScope():
      w = 300
      global x
      nonlocal y
      x = 100; y = 200; z = 400
      print("testInnerScope: x=",x,",y=",y,",w=",w,",z=",z)
   testInnerScope()
   print("testScope: x=",x,",y=",y,",w=",w,",z=",z)
def main() :
   testScope()
   print("main: x=",x,", y=",y,", w=",w,", z=",z)
if __name__ == "__main__" :
   main()
% python3.11 nonLocalScoping.py
testInnerScope: x= 100 ,y= 200 ,w= 300 ,z= 400
testScope: x= 100 ,y= 200 ,w= 30 ,z= 4
main: x= 100 ,y= 2 ,w= 3 ,z= 4
```

Scoping rules (5/5)

```
# simpleScopingError.py
x = 1
y = 2
z = 3
w = 0
def testScope():
   global x
   y = 4
   z = 5 + w
   global z
   w = -1
def main() :
   print("in main x =",x,", y =",y)

global z
^^^^^^^^
SyntaxError: name 'z' is assigned to before global declaration
z = 5 + w
        ^
UnboundLocalError: cannot access local variable 'w' where it is not associated
     with a value
```

Default parameters as static (1/3)

- Default parameters are evaluated only once, at the first call
  - they are like static local variables in C
  - normally objects are immutable
  - but when objects are mutable something unexpected may happen

Default parameters as static (2/3)

```
# defaultParametersStatic.py
i = 1
def f(a=[50]):
   global i
   print("Call ", i, "At the beginning of f a is:",a)
   a[0] +=1
   print("At the end of f a is:",a)
   i+=1
def main():
   x = [2]
   print("Before the first call to f x is: ",x)
   f(x)
   print("After the first call to f x is: ",x)
   f()
   print("After the second call to f x is: ",x)
   f()
   print("Before the third call to f x is: ",x)
   f(x)
   print("Before the third call to f x is: ",x)
if __name__=="__main__":
   main()
```

Default parameters as static (3/3)

```
% python3.11 defaultParametersStatic.py
Before the first call to f x is:  [2]
Call  1 At the beginning of f a is: [2]
At the end of f a is: [3]
After the first call to f x is:  [3]
Call  2 At the beginning of f a is: [50]
At the end of f a is: [51]
After the second call to f x is:  [3]
Call  3 At the beginning of f a is: [51]
At the end of f a is: [52]
Before the third call to f x is:  [3]
Call  4 At the beginning of f a is: [3]
At the end of f a is: [4]
Before the third call to f x is:  [4]
```

Modules (1/3)

- Python structure the code quite like C
- Every file is a module
  - the name of the module is the name of the file without the extension `.py`
  - it is stored in the variable `__name__`
  - such name is changed to `__main__` if the module is the one directly invoked
- A module is an object in Python

Source: `https://docs.python.org/3/tutorial/modules.html`

Modules (2/3)

- To access the module you need to specify the instruction `import amodule`
  - where `amodule.py` is the file where the module is located
  - such file must reside in a location specified by the environmental variable `PYTHONPATH`
  - and any name to use from such module has to be prefixed by the name of the module
  - that is, to use function `goofy()`, the full name `amodule.goofy()` must be specified

Source: `https://docs.python.org/3/tutorial/modules.html`

Modules (3/3)

- To load the names of the module inside the current namespace: `from amodule import goofy`
- To import all the names inside `amodule.py`: `from amodule import *`, in which case only the names starting with an _ will not be directly accessible
  - in this way it is possible just to call `goophy()`
- Be careful, but is also possible to rename an entity or module as
  - `import amodule as unmodulo`, leading to calls like `unmodulo.goophy()` or even
  - `from amodule import goofy as pippo`, leading to calls like `amodule.pippo()`

Source: `https://docs.python.org/3/tutorial/modules.html`

Namespaces

- A namespace is the set of all names associated to objects visible at a certain time and place
- The current namespace is accessible with the instruction `dir()`
- It is also possible to view the namespace of a specific module with `dir(amodule)`

Source: `https://py-pkgs.org/04-package-structure.html`

Packages (1/2)

- A package is a collection of modules
- From a system viewpoint, a package is a directory:
  - inside the list specified by `sys.path`
  - with a `__init__.py` file, which can also be empty but must exist
- From an internal perspective, a package is a module object
- The `import` statement applies for packages like for modules
- A subpackage is a directory of a (sub)packages with a with a `__init__.py` file
- The `.` separates a package from subpackages and modules

Source: https://stackoverflow.com/questions/4881897/python-project-and-package-directories-layout and https://py-pkgs.org/04-package-structure.html

Packages (2/2)

- When a package is loaded, its `__init__.py` is executed
- It acts as a kind of constructor of the package
- packages can contain references to other packages using absolute or relative paths
- using relative paths
  - the `.` refers to the current directory
  - the `..` refers to the parent directory

Source: https://stackoverflow.com/questions/4881897/python-project-and-package-directories-layout and https://py-pkgs.org/04-package-structure.html

Importing elements (1/3)

- `import` is the statement defines the connection between the current module to the one containing the entities we are interested
- when the statement `import A` is executed:
  - the runtime looks for
    - a file named `A.py` (a module) or
    - a directory named `A` with a file `__init__.py` (a packages)

    in a list of directories specified in the `sys.path` variable
- if the results is a module, then the names inside it become visible
- if the result is a package, then the names inside it become visible and `__init__.py` is executed

Source: `https://chrisyeh96.github.io/2017/08/08/definitive-guide-python-imports.html`

Importing elements (2/3)

- The `import` directive has many variants
  - `import <module or package>`
  - `from <package> import <module or (sub)package or object>`
  - `from <module> import <object>`
- *in Python functions are objects!*
- The structure of the naming after an `import` of `X` is:
  - if `X` is a module or a package:
    - `X.entity`
  - if `X` is a variable:
    - `X` is used as is

Source: `https://chrisyeh96.github.io/2017/08/08/definitive-guide-python-imports.html`

Importing elements (3/3)

- if `X` is a function:
  - the invocation is `X()`
- The imported entity can be renamed placing after the `import X` directive the `as Y`
  - That is:
    - `import <module or package> as Y`
    - `from <package> import <module or (sub)package or object> as Y`
    - `from <module> import <object> as Y`
- From such point on, `Y` must be used instead of `X`

Source: https://chrisyeh96.github.io/2017/08/08/definitive-guide-python-imports.html

Python as a functional language

- Already covered
- Lambda expressions
- Some kind of referential transparency
  - Immutable objects
  - Unchangeable (by default) global variables inside local scopes

About overloading of functions (1/3)

- In Python there is not a full overloading of functions as we know it in Java or C++
- If we define multiple times a function, only its latest definition will be used

```
>>> def f(a):
...     return a
>>> f(3)
3
>>> def f(a,b):
...     return (a,b)
>>> f(3,4)
(3, 4)
>>> f(3)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: f() missing 1 required positional argument: 'b'
```

Source: https://www.geeksforgeeks.org/python-method-overloading/

About overloading of functions (2/3)

- The standard way to do it is via classes (see later)
- Default parameters may help
- They can be coupled with a defaulting to `None`
- Or we can use "decorators" (also explained later) but with care
- To use the required decorator we first need to install the suitable package `multipledispatch`

```
% pip3 install multipledispatch
Collecting multipledispatch
Downloading multipledispatch-1.0.0-py3-none-any.whl.metadata (3.8 kB)
Downloading multipledispatch-1.0.0-py3-none-any.whl (12 kB)
Installing collected packages: multipledispatch
Successfully installed multipledispatch-1.0.0
```

Source: `https://www.geeksforgeeks.org/python-method-overloading/`

About overloading of functions (3/3)

```
>>> from multipledispatch import dispatch
>>> @dispatch(int)
... def f(a):
...     return a
>>> @dispatch(int, int)
... def f(a,b):
...     return a+b
>>> f(3,4)
7
>>> f(3)
3
>>> def f(a,b):
...     return a-b
>>> f(3,4)
-1
>>> f(3)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: f() missing 1 required positional argument: 'b'
```

Source: `https://www.geeksforgeeks.org/python-method-overloading/`

Functions are first class citizens

```
>>> def aFunction(a):
...     return a+1
>>> aFunction(3)
4
>>> x = aFunction
>>> x(3)
4
>>> l = [x, aFunction, 88, "bye"]
>>> l[0]
<function aFunction at 0x100ff0d60>
>>> l[1]
<function aFunction at 0x100ff0d60>
>>> l[2]
88
>>> l[3]
'bye'
>>> type(x)
<class 'function'>
```

Source: https://realpython.com/python-functional-programming/

Functions as parameters

- There are also predefined functions for this, such as `map`, `filter`, and `reduce`, which are used with the *map-reduce* pattern present in big data
- `map` returns an iterator

```
>>> def apply(f,x):
...     return f(x)
>>> def incr(x):
...     return x+1
...
>>> apply(incr,3)
4
>>> x = map(incr,[1,2,3,4])
>>> x
<map object at 0x100b9bf40>
>>> list(x)
[2, 3, 4, 5]
```

Source: `https://realpython.com/python-functional-programming/`

`map` plays a pivotal role

- It may take a different form using polymorphism
- Notice the polymorphic structure of the operator `+`
- `map` can be computed in constant time if there are enough processors, also taking advantage of a data-parallel approach

```
>>> def f(a,b,c):
...   return a+b+c
>>> f(1,2,3)
6
>>> f("a","b","c")
'abc'
>>> list(map(f,["a","b","c","d"],["e","f","g","h"],["i","j","k","l"]))
['aei', 'bfj', 'cgk', 'dhl']
>>>
```

Source: `https://realpython.com/python-functional-programming/`

filter selects elements

- The elements of a filter can be selected via the filter
- Inside filter the lambda functions are particularly handy
- filter returns an iterator
- Also filter can be computed in constant time if there are enough processors

```
>>> def f(a):
...     return a>10
>>> f(3)
False
>>> f(11)
True
>>> filter(f,[8,9,10,3,11,2,100,-11])
<filter object at 0x1006815d0>
>>> list(filter(f,[8,9,10,3,11,2,100,-11]))
[11, 100]
>>> list(filter(lambda x: x>10,[8,9,10,3,11,2,100,-11]))
[11, 100]
>>>
```

reduce synthesises elements

- The elements of an iterator can be folded in one with `reduce`
- They can be the result of a `map` and/or a `filter`
- The function for the reduction must have two elements, where the second must be of the type of the elements of the iterator
- `reduce` can be computed in log time if there are enough processors

```
>>> from functools import reduce
>>> def f(a,b):
...     return a+b
...
>>> reduce(f,[1,2,3,4,5])
15
>>> reduce(lambda x,y: x+y,[1,2,3,4,5])
15
>>> reduce(lambda x,y: x+y,map(lambda x: x**2,filter(lambda x: x %
    2!=0,[1,2,3,4,5])))
35
>>>
```

Lazy evaluation (1/3)

- Python has an eager evaluation of parameters passed to functions
- Python provides some form approximating lazy evaluation
- There are objects supplying a large stream of data one element at a time *on demand*, using the statement `yield` instead of the usual `return`
- This is very similar on how the elements of a list are accessed via iteration
- They can also be expanded in other data structures, like tuples
- Note that, once expanded, they are completely consumed, that is, lost

Source: `https://docs.python.org/3/howto/functional.html`

Lazy evaluation (2/3)

```
>>> l = [2,4,6,8,10,12]
>>> y = iter(l)
>>> y
<list_iterator object at 0x100681390>
>>> next(y)
2
>>> next(y)
4
>>> tuple(y)
(6, 8, 10, 12)
>>> tuple(y)
()
```

Source: `https://docs.python.org/3/howto/functional.html`

Lazy evaluation (3/3)

```
>>> def generateIntegers(N):
...     for i in range(N):
...         yield i
...
>>> x = generateIntegers(10)
>>> x
<generator object generateIntegers at 0x1002caf60>
>>> next(x)
0
>>> next(x)
1
>>> t = tuple(x)
>>> t
(2, 3, 4, 5, 6, 7, 8, 9)
>>> tuple(x)
()
>>> t
(2, 3, 4, 5, 6, 7, 8, 9)
```

Source: https://docs.python.org/3/howto/functional.html

List comprehension

- Python has very effective means to generate lists, as several functional languages; such means are collectively referred to with the term redlist comprehension
- Iterators are at the base of list comprehension
- List comprehension is heavily used in Python, as it is a very compact and expressive

```
>>> [x for x in range(10)]
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
>>> [x*x for x in (filter(lambda l: l%2==0,range(5,12)))]
[36, 64, 100]
>>> [x*x for x in range(5,12) if x%2==0]
[36, 64, 100]
>>> [x*x  if x%2==0 else -x*x for x in range(5,12)]
[-25, 36, -49, 64, -81, 100, -121]
```

Source: https://realpython.com/list-comprehension-python/ and https://www.w3schools.com/python/python_lists_comprehension.asp

Beyond List comprehension

- There are also *set comprehension* and *dictionary comprehension*
  - dictionary comprehension requires the pairs with :
- we could have nested or zip-ed comprehension
  - zip returns an iterator of tuples

```
>>> [x**2 for x in range(-3,3)]
[9, 4, 1, 0, 1, 4]
>>> {x**2 for x in range(-3,3)}
{0, 9, 4, 1}
>>> [(i,j) for i in range(3) for j in range(3)]
[(0, 0), (0, 1), (0, 2), (1, 0), (1, 1), (1, 2), (2, 0), (2, 1), (2, 2)]
>>> [(i,j) for (i,j) in zip(range(3),range(3))]
[(0, 0), (1, 1), (2, 2)]
>>> {i:j[::-1] for (i,j) in zip(range(1,4),["one","two","three"])}
{1: 'eno', 2: 'owt', 3: 'eerht'}
```

Source: https://www.freecodecamp.org/news/dictionary-comprehension-in-python-explained-with-examples/ and https://www.w3schools.com/python/ref_func_zip.asp

Python as an object oriented language (1/5)

- Python is an object oriented language (to a certain extent)
- Classes are defined with `class` and with the usual indentation
- The reference to the object itself is `self`
- Instance methods requires are identified by having as parameter `self`, which is then omitted when calling
- The initializer (a kind of constructor) is `__init__`
- Instance variables are *usually* defined in the constructor

```
class Animal:
    def __init__(self):
        self.name=""
    def setName(self,name):
        self.name=name
if __name__ == '__main__':
    animal = Animal()
    animal.setName("Pippo")
```

Python as an object oriented language (2/5)

- Class variables are defined globally in the class
- Class methods are defined with the `@classmethod` *decoration*, with a reference to the class, `cls`, and with the usual indentation

```
class Animal:
    numberOfAnimals = 0
    def __init__(self):
        Animal.numberOfAnimals += 1
        self.name=""
    def setName(self,name):
        self.name=name
    @classmethod
    def getNumberOfAnimals(cls):
        return cls.numberOfAnimals
if __name__ == '__main__':
    animal = Animal()
    animal.setName("Pippo")
    i = Animal.getNumberOfAnimals()
```

Python as an object oriented language (3/5)

- There are static methods non containing any reference to the class and defined with the `@staticmethod` decoration
  - Static methods exist only for naming reasons
- Protected methods and data start with the single underscore `_`
- Private methods and data start with the double underscore `__`
- However, both can be accessed outside the class with *name mangling*, that is, prefixing its name with `_ClassName`

```python
class Animal:
    numberOfAnimals = 0
    def __init__(self, name):
        Animal.numberOfAnimals += 1
        self.name=name
        self.__private = 1
        self._protected = 1
        self.public = 1
```

Source: https://www.geeksforgeeks.org/private-methods-in-python/ and https://jellis18.github.io/post/2022-01-15-access-modifiers-python/

Python as an object oriented language (4/5)

```
    def identifyYourself(self):
        print("Hello! I am a generic animal and my name is " + self.name)

    def __privateChangeName(self, name):
        self.name = name

    @classmethod
    def getNumberOfAnimals(cls):
        return cls.numberOfAnimals

    @staticmethod
    def increment(i):
        return i+1
```

Python as an object oriented language (5/5)

```
if __name__ == '__main__':
    animal = Animal("Mistery")
    animal.identifyYourself()
    # animal.__privateChangeName("pippo")
    animal._Animal__privateChangeName("MoreMistery")
    i = Animal.getNumberOfAnimals()
    i = Animal.increment(i)
    animal._Animal_protected = i
    print(animal._Animal_protected)
    print(animal.name)
2
MoreMistery
```

Inheritance in Python

- Python supports single and multiple inheritance
- Every class without a superclass is implicitly derived from the class `object`
- `object` is then of type of `type`
- When a new object is created the initialized method `__init__` is called
- Here below a summary of a derived class

```python
class Dog(Animal):

    def __init__(self, name):
        super().__init__(name)

    def identifyYourself(self):
        print("Hello! I am a dog and my name is " + self.name)
```

About `__init__` (1/2)

- Remember that `__init__` is an initializer, therefore, by default the creation of a derived class does not trigger the `__init__` of the base class
  - If an initialization from the superclass is needed, it needs to be explicitly called explicitly
- However, if there is no `__init__` in the derived class, the system will look for the closest one going up the hierarchy, since it is a virtual function

```python
class Animal:
    def __init__(self):
        print("Creating an animal")

class Penguin(Animal):
    def __init__(self):
        print("Creating a penguin")
```

About __init__ (2/2)

```
class Parrot(Animal):
    def __init__(self):
        super().__init__()
        print("Creating a parrot")

class Dove(Animal):
        pass

if __name__ == "__main__":
    a = Animal()
    pe = Penguin()
    pa = Parrot()
    d = Dove()
```

- And therefore the output is:

```
Creating an animal
Creating a penguin
Creating an animal
Creating a parrot
Creating an animal
```

Operator overloading (1/5)

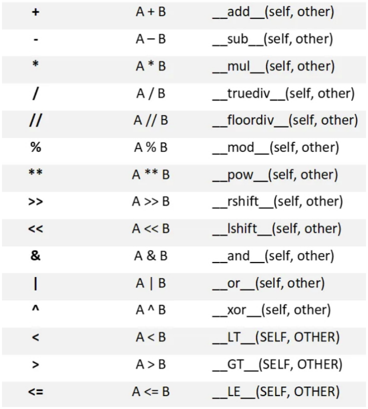
- A special kind of such member functions are those supporting operator overloading
- There is a specific mapping between names of functions and operator that is overloaded
- Such functions are “special functions” or “double underscore functions” or “magic methods”, such as `__add__()`

```python
class Animal:

    def __add__(self,anotherAnimal):
        return Animal(self.name+anotherAnimal.name)

if __name__ == '__main__':
    animal = Animal("Mistery")
    anotherAnimal = Animal("BigMistery")
    thirdAnimal = animal + anotherAnimal
```

https://www.programiz.com/python-programming/operator-overloading/

Operator overloading (2/5)

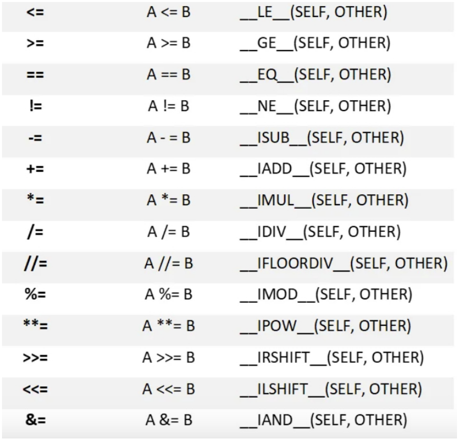
- A list of the standard mapping of names and operator is presented in this and the following slide



+	A + B	__add__(self, other)
-	A – B	__sub__(self, other)
*	A * B	__mul__(self, other)
/	A / B	__truediv__(self, other)
//	A // B	__floordiv__(self, other)
%	A % B	__mod__(self, other)
**	A ** B	__pow__(self, other)
>>	A >> B	__rshift__(self, other)
<<	A << B	__lshift__(self, other)
&	A & B	__and__(self, other)
|	A | B	__or__(self, other)
^	A ^ B	__xor__(self, other)
<	A < B	__LT__(SELF, OTHER)
>	A > B	__GT__(SELF, OTHER)
<=	A <= B	__LE__(SELF, OTHER)

Source of the picture
`https://faun.pub/the-right-way-to-overload-methods-and-operators-in-python-2f93232af031/`

Operator overloading (3/5)



<=	A <= B	__LE__(SELF, OTHER)
>=	A >= B	__GE__(SELF, OTHER)
==	A == B	__EQ__(SELF, OTHER)
!=	A != B	__NE__(SELF, OTHER)
-=	A - = B	__ISUB__(SELF, OTHER)
+=	A += B	__IADD__(SELF, OTHER)
*=	A *= B	__IMUL__(SELF, OTHER)
/=	A /= B	__IDIV__(SELF, OTHER)
//=	A //= B	__IFLOORDIV__(SELF, OTHER)
%=	A %= B	__IMOD__(SELF, OTHER)
**=	A **= B	__IPOW__(SELF, OTHER)
>>=	A >>= B	__IRSHIFT__(SELF, OTHER)
<<=	A <<= B	__ILSHIFT__(SELF, OTHER)
&=	A &= B	__IAND__(SELF, OTHER)

Source of the picture
`https://faun.pub/the-right-way-to-overload-methods-and-operators-in-python-2f93232af031/`

Operator overloading (4/5)

- There are additional “double underscore” functions mimicking the structure of C++, such as
  - `__getitem__(self,index)` for subscripting in the rhs, that is the `x = anObject[index]`
  - `__setitem__(self,index)` for subscripting in the lhs, that is the `anObject[index] = x`
  - `__contains__(self,index)` for the `in` operator
  - `__repr__(self)` to convert an object in a string, used in `print` with the template pattern
  - `__iter__(self)` to generate an iterable, like `iter(anObject)` to use then, say, in a `for`
  - `__enter__(self)` and `__exit__(self,...)` to handle entering and exiting blocks

https://www.analyticsvidhya.com/blog/2021/08/explore-the-magic-methods-in-python/

Operator overloading (5/5)

- `__call__(self,whatever)` for *functional objects*, that is for managing structures like `anObject(whatever)`
    - It is also used to create objects as discussed later
- `__new__(...)` for allocating space for objects
- `__init__(...)` for initializing objects

https://www.analyticsvidhya.com/blog/2021/08/explore-the-magic-methods-in-python/

Understanding the `object` in Python (1/2)

- In Python an object has:
  - an identity
  - a value or a state, defined by the values of its attributes
  - a type
  - one or more bases, something similar to a superclass

```
>>> type(3)
<class 'int'>
>>> type(animal)
<class '__main__.Animal'>
>>> type(dog)
<class '__main__.Dog'>
>>> type(int)
<class 'type'>
>>> type(Animal)
<class 'type'>
>>> type(Dog)
<class 'type'>
```

Source: Shalabh Chaturvedi "Python Types and Objects"
https://www.eecg.toronto.edu/~jzhu/csc326/readings/metaclass-class-instance.pdf/

Understanding the `object` in Python (2/2)

- Also the `object` has a type
- And also the `type`!

```
>>> type(object)
<class 'type'>

>>> type(type)
<class 'type'>
```

Source: Shalabh Chaturvedi "Python Types and Objects"
https://www.eecg.toronto.edu/~jzhu/csc326/readings/metaclass-class-instance.pdf/

The notion of `object` (1/4)

- There is some duality to explore between type and base class, which requires some deepening
- First of all, we notice the reflection primitives, `type` and `dir`

```
>>> dir(3)
['__abs__', '__add__', '__and__', '__bool__', '__ceil__', '__class__', '
    __delattr__', '__dir__', ...]
>>> dir(int)
['__abs__', '__add__', '__and__', '__bool__', '__ceil__', '__class__', '
    __delattr__', '__dir__', ...]
>>> dir(animal)
['_Animal__private', '_Animal__privateChangeName', '_Animal_protected', '
    __class__', '__delattr__', '__dict__', '__dir__', '__doc__', '__eq__', '
    __format__', '__ge__', '__getattribute__', '__getstate__', '__gt__', '
    __hash__', '__init__', '__init_subclass__', '__le__', '__lt__', '__module__
    ', '__ne__', '__new__', '__reduce__', '__reduce_ex__', '__repr__', '
    __setattr__', '__sizeof__', '__str__', '__subclasshook__', '__weakref__', '
    _protected',  'getNumberOfAnimals', 'identifyYourself', 'increment', 'name'
    ,  'public']
```

Source: Shalabh Chaturvedi "Python Types and Objects"
`https://www.eecg.toronto.edu/~jzhu/csc326/readings/metaclass-class-instance.pdf/`

The notion of object (2/4)

```
>>> dir(dog)
['_Animal__private', '_Animal__privateChangeName', '__class__', '__delattr__', '
    __dict__', '__dir__', '__doc__', '__eq__', '__format__', '__ge__', '
    __getattribute__', '__getstate__', '__gt__', '__hash__', '__init__', '
    __init_subclass__', '__le__', '__lt__', '__module__', '__ne__', '__new__',
    '__reduce__', '__reduce_ex__', '__repr__', '__setattr__', '__sizeof__', '
    __str__', '__subclasshook__', '__weakref__', '_protected',  '
    getNumberOfAnimals', 'identifyYourself', 'increment', 'name', '
    numberOfAnimals','public']
```

- To rationalize our understanding we need to explore the meaning of the attributes `__base__` and `__class__`
- We will use reflection again

Source: Shalabh Chaturvedi "Python Types and Objects"
https://www.eecg.toronto.edu/~jzhu/csc326/readings/metaclass-class-instance.pdf/

The notion of `object` (3/4)

```
>>> animal.__class__
<class '__main__.Animal'>
>>> type(animal.__class__)
<class 'type'>
>>> animal.__class__.__base__
<class 'object'>
>>>type(animal.__class__.__base__)
<class 'type'>

>>> dog.__class__
<class '__main__.Dog'>
>>> type(dog.__class__)
<class 'type'>
>>> dog.__class__.__base__
<class '__main__.Animal'>
>>>type(dog.__class__.__base__)
<class 'type'>
```

Source: Shalabh Chaturvedi "Python Types and Objects"
https://www.eecg.toronto.edu/~jzhu/csc326/readings/metaclass-class-instance.pdf/

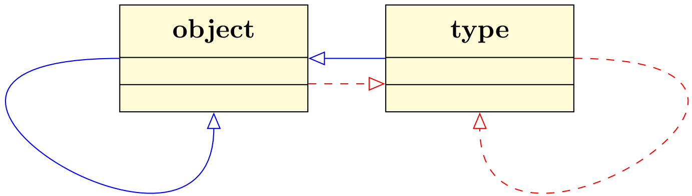
The notion of `object` (4/4)

- Now we can explore the objects `object` and `type`

```
>>> object.__class__
<class 'type'>
>>> type(object.__class__)
<class 'type'>
>>> object.__class__.__base__
<class 'object'>
>>> type(object.__class__.__base__)
<class 'type'>

>>> type.__class__
<class 'type'>
>>> type(type.__class__)
<class 'type'>
>>> type.__class__.__base__
<class 'object'>
>>> type(type.__class__.__base__)
<class 'type'>
```

Source: Shalabh Chaturvedi “Python Types and Objects”
https://www.eecg.toronto.edu/~jzhu/csc326/readings/metaclass-class-instance.pdf/

A view of `object` and `type` in UML



Revising our objects (1/5)

- *(Class)* `Animal`
  - identity (`Animal.__name__`) : `Animal`
  - a type (`Animal.__class__`) : `type`
  - a base (`Animal.__base__`) : `object`
- *(Object)* `animal`
  - there is no attribute `animal.__name__`
  - a type (`Animal.__class__`) : `__main__.Animal`
  - there is no attribute `animal.__base__`

Revising our objects (2/5)

- *(Class)* `Dog`
  - identity (`Dog.__name__`) : `Dog`
  - a type (`Dog.__class__`) : `type`
  - a base (`Dog.__base__`) : `__main__.Animal`
- *(Object)* `dog`
  - there is no attribute `dog.__name__`
  - a type (`dog.__class__`) : `__main__.Dog`
  - there is no attribute `dog.__base__`

Revising our objects (3/5)

- *(Object)* `object`
  - identity (`object.__name__`) : `object`
  - a type (`object.__class__`) : `type`
  - a base (`object.__base__`) : `None`
- *(Class)* `object`
  - identity (`object.__class__.__name__`) : `type`
  - a type (`object.__class__.__class__`) : `type`
  - a base (`object.__class__.__base__`) : `None`

Revising our objects (4/5)

- *(Base class of object)* aka `object.__base__` `None`
  - there is no attribute `object.__base__.__name__`
  - a type (`object.__base__.__class__`) : `NoneType`
  - there is no attribute `object.__base__.__base__`
- *(Type of the base class of object)* aka `None.__base__` aka `object.__base__.__class__`: `NoneType`
  - identity (`object.__base__.__class__.__name__`) : `NoneType`
  - type (`object.__base__.__class__.__class__`) : `type`
  - there is no attribute `object.__base__.__class__.__base__`

Revising our objects (5/5)

- *(Object)* `type`
  - identity (`type.__name__`) : `type`
  - a type (`type.__class__`) : `type`
  - a base (`type.__base__`) : `object`
- *(Class of)* `type`
  - identity (`object.__class__.__name__`) : `object`
  - a type (`object.__class__.__class__`) : `type`
  - a base (`object.__class__.__base__`) : `type`
  - **It is the `object`, but with some inconsistency!!**

Putting the pieces together

- We have the structure of the Abstract Factory
- Everything is (derived of) an `object`
- Every object has a `type`
- A `type` is an object and derived (also indirectly) from `object`
- The `type` is identified by the `__base__` attribute
- The base class is identified by the `__class__` attribute
- A metaclass is a class whose instances are still classes
- Metaclasses play an important role in the creation/instantiation process

Source: Shalabh Chaturvedi "Python Types and Objects"
https://www.eecg.toronto.edu/~jzhu/csc326/readings/metaclass-class-instance.pdf/

Instantiation of new objects

- The reference for creating new objects is the clone design pattern
- New objects can be created by subclassing

```
class Dog(Animal):

    def __init__(self, name):
        super().__init__(name)
```

new object of type `type` has been instantiated with base class `object` (the full specs in slide ??)New objects can be created by applying the operator () to an object of type `type`

```
dog = Dog()
o = object()
animal = Animal()
```

- Source: Shalabh Chaturvedi "Python Types and Objects"
https://www.eecg.toronto.edu/~jzhu/csc326/readings/metaclass-class-instance.pdf/

Instantiation of new types (1/2)

- Types can be created on the fly
- Extreme care is required

```
>>> Cat = type("Cat",(Animal,),{"nickname":"Prr", "weight":10})
>>> c = Cat("Garfield")
>>> print(c)
<__main__.Cat object at 0x11148fa90>
>>> print(c.nickname)
Prr
>>> print(c.weight)
10
>>> print(c.name)
Garfield
>>> print(c.somethingElse)
    print(c.somethingElse)
          ^^^^^^^^^^^^^^^

AttributeError: 'Cat' object has no attribute 'somethingElse'
>>> c.somethingElse=2
>>> print(c.somethingElse)
2
```

Source: https://realphysics.info/Theory%20of%20Python/classes.html/

Instantiation of new types (2/2)

- Types can be returned from functions

```
    def generateCongruent(something):
        return type(something)
    t = generateCongruent(c)
    x = t("Garfield2, the revenge")
    type(x)
    Cat   Garfield2, the revenge
    type(x.something)
    ^^^^^^^^^^^^
AttributeError: 'Cat' object has no attribute 'something'
```

Source: `https://realphysics.info/Theory%20of%20Python/classes.html/`

The creation process (1/2)

- The creation of an object takes two (plus one) steps:
  - `__new__()`, in principle to allocate memory
  - `__init__()`, in principle to initialize data
- The original object is taken as a reference
- It is also possible to modify the creation of objects using metaclasses
  - Using metaclasses it is possible to alter the creation process of objects
  - In this case, a rigid protocol is employed, using the template pattern, again, based on overriding / late binding

Source: Shalabh Chaturvedi "Python Types and Objects"
https://www.eecg.toronto.edu/~jzhu/csc326/readings/metaclass-class-instance.pdf/,
https://www.datacamp.com/tutorial/python-metaclasses, and
https://stackoverflow.com/questions/56514586/arguments-of-new-and-init-for-metaclasses

The creation process (2/2)

- Overall we see three methods clearly involved in the protocol
  - `__call__()`, the orchestrator, called every time an object type is invoked to create a new object, like in

```
dog = Dog()
```

  - `__new__()`, called to allocate memory, as mentioned
  - `__init__()`, called to initialize the data, as mentioned
- `__call__()` calls the other two, therefore imposing a structure on the number and types of parameters
- this is why we may see typing error if they are not properly structured

Source: Shalabh Chaturvedi “Python Types and Objects”
https://www.eecg.toronto.edu/~jzhu/csc326/readings/metaclass-class-instance.pdf/,
https://www.datacamp.com/tutorial/python-metaclasses, and
https://stackoverflow.com/questions/56514586/arguments-of-new-and-init-for-metaclasses

Inside the creation (1/5)

- The creation process involves metaclasses
- `type` is acting as the "metametaclass"
- `*` and `**` allow arbitrary number of parameters:
  - `*` implies that the argument (here, `args`) is a tuple
  - `**` implies that the argument (here, `kw`) is a dictonary
  - Here we see the equivalent in Python of the real C code (taken from the reference below)

```
class type:
    def __call__(cls, *args, **kw):
        instance = cls.__new__(cls, *args, **kw)
        # __new__ is actually a static method -
        # cls has to be passed explicitly
        if isinstance(instance, cls):
            instance.__init__(*args, **kw)
        return instance
```

Source: https://www.datacamp.com/tutorial/python-metaclasses, and https://stackoverflow.com/questions/56514586/arguments-of-new-and-init-for-metaclasses

Inside the creation (2/5)

- Substantially `__new__()` and `__init__()` ought to be redefined
- Let's see an implementation of the singleton pattern

```python
class Singleton:
    singleObject = None
    @staticmethod
    def __new__(cls):
        if Singleton.singleObject is not None:
            return Singleton.singleObject
        else:
            Singleton.singleObject = super().__new__(cls)
            return Singleton.singleObject

    def __init__(self):
        self.aValue = 1

    def increment(self):
        self.aValue += 1
```

Inside the creation (3/5)

- What is the output?

```
>>> if __name__ == "__main__":
>>>     x = Singleton()
>>>     print(x.aValue)
>>>     x.increment()
>>>     print(x.aValue)
>>>     y = Singleton()
>>>     print(x.aValue)
>>>     print(y.aValue)
>>>     print(x==y)
```

Inside the creation (4/5)

```
>>> if __name__ == "__main__":
>>>     x = Singleton()
>>>     print(x.aValue)
1
>>>     x.increment()
>>>     print(x.aValue)
2
>>>     y = Singleton()
>>>     print(x.aValue)
1
>>>     print(y.aValue)
1
>>>     print(x==y)
True
```

- `__init__()` is still called!!
- We need some refinement
  - Remember that for `type` we cannot modify the sequence of calling first `__init__()` and then `__new__()`
    - it is built inside the language

Inside the creation (5/5)

```
    def __init__(self):
        if Singleton.numberOfItems == 0:
            Singleton.numberOfItems = 1
            self.aValue = 1

>>> if __name__ == "__main__":
>>>     x = Singleton()
>>>     print(x.aValue)
1
>>>     x.increment()
>>>     print(x.aValue)
2
>>>     y = Singleton()
>>>     print(x.aValue)
2
>>>     print(y.aValue)
2
>>>     print(x==y)
True
```

Metaclasses (1/9)

- Remember that in Python everything is an object, including classes
- As mentioned,
  - a metaclass is a class whose instances are still classes
  - the creation process involves metaclasses
  - `type` is acting as the "metametaclass"
- The instruction

```
class Animal:
    def __init__(self):
        print("Creating an animal")
```

results in the creation (instantiation) of:

  - a class `Animal` implicitly derived from class `object`
  - an object `Animal` instance of the class `type`

Source: `https://www.datacamp.com/tutorial/python-metaclasses`

Metaclasses (2/9)

- Moreover, with this code

```
animal = Animal()
```

  the object `Animal` creates an instance of class `Animal` and returns its value to `animal`
  - This is clearly an use of the method `__call__()`
- So the question is whether it is possible for the class `Animal` to produce also other classes
- This is the core of metaclasses

Source: https://www.datacamp.com/tutorial/python-metaclasses

Metaclasses (3/9)

- We start with defining a subclass of class `type`

```
class AnimalType(type):
    pass
```

- As usual here we create
  - a class `AnimalType` explicitly derived from class `type`
  - an object `AnimalType` instance of the class `type`

Source: `https://www.datacamp.com/tutorial/python-metaclasses`

Metaclasses (4/9)

- Then we use such class to proceed

```
class Animal(metaclass=AnimalType):
    pass
```

- And here we create
  - a class `Animal` with:
    - meta-class class `AnimalType`, meaning that its associated object is instance of class `AnimalType`, and
    - implicitly derived from class `object`
  - an object `Animal` instance of the class `AnimalType`, as mentioned above

Source: `https://www.datacamp.com/tutorial/python-metaclasses`

Metaclasses (5/9)

- Metaclassing allows the manipulation of the class as a whole, especially its creation process
- We now consider an example

```
class AnimalType(type):
    def __init__(cls, name, bases, dct):
        print("__init__ of AnimalType")
    def __call__(self, *args, **kwargs):
        print("__call__ of AnimalType")
        return super().__call__(self, *args, **kwargs)
    def __new__(cls, name, *args, **kwargs):
        print("__new__ of AnimalType")
        return super().__new__(cls, name, *args, **kwargs)
 class Animal(metaclass=AnimalType):
    def __init__(self,*args):
        print("__init__ of Animal")
    def __new__(cls, *args, **kwargs):
        print("__new__ of Animal")
        return super().__new__(cls)
```

Source: https://www.datacamp.com/tutorial/python-metaclasses

Metaclasses (6/9)

```
__new__ of AnimalType # To create the object AnimalType at the beginning of the
    module
__init__ of AnimalType # To initialize the object AnimalType
>>> if __name__ == '__main__':
>>>     print("Now creating an Animal")
Now creating an Animal
>>>     a = Animal()
__call__ of AnimalType # This is the result of the call Animal(
__new__ of Animal # Called by AnimalType.__call__
__init__ of Animal # Called by AnimalType.__call__
```

- The `__call__()` of the metaclass (in our example class `AnimalType`) orchestrates the overall creation process of the objects of class `Animal`
  - It is an application of the *Template Method* design pattern
- This allows a fine-grained control of the creation process

Source: `https://www.datacamp.com/tutorial/python-metaclasses`

Metaclasses (7/9)

- The `__call__()` of the metaclass calls of the target class `__new__()` and `__init__()`
- Therefore, the metaclass has its own:
    - `__call__(cls, *args, **kwargs)`, called when an instance of the metaclass is called, for instance when creating an object of the class, like in `a = Animal()`
        - `cls` is the reference to the metaclass
        - `args` is the list of positional arguments
        - `kwargs` is the list of the keyword arguments

Source:
https://www.datasciencecentral.com/understanding-the-complexity-of-metaclasses-and-their-practical-2/

Metaclasses (8/9)

- … therefore, the metaclass has its own:
  - `__new__(mcs, name, bases, namespace)`, where
    - `mcs` is the reference to the metaclass
    - `name` is the name to the metaclass
    - `bases` is the list of the superclasses, which will become the `__base__` attribute of the new class
    - `namespace` is the namespace in the form of a dictionary, which will become the `__dict__` attribute of the new class

Source:
https://www.datasciencecentral.com/understanding-the-complexity-of-metaclasses-and-their-practical-2/

Metaclasses (9/9)

- . . . therefore, the metaclass has its own:
    - `__init__(cls, name, bases, namespace, **kwargs)`
        - `mcs` is the reference to the metaclass
        - `name` is the name to the metaclass
        - `bases` is the list of the superclasses, which will become the `__base__` attribute of the new class
        - `namespace`is the namespace in the form of a dictionary, which will become the `__dict__` attribute of the new class
        - `kwargs` is the list of the keyword arguments
- There is also a `__prepare__()` method, called as the first method to prepare the namespace

Source:
https://www.datasciencecentral.com/understanding-the-complexity-of-metaclasses-and-their-practical-2/

Singleton with metaclasses (1/4)

- We can use it for an alternative implementation of the Singleton pattern

```
class AnimalType(type):
    singleAnimal=None
    def __init__(cls, name, bases, dct):
        print("__init__ of AnimalType")

    def __call__(cls, *args, **kwargs):
        print("__call__ of AnimalType")
        if AnimalType.singleAnimal is None:
            print("Creating the unique animal")
            AnimalType.singleAnimal = cls.__new__(cls, *args, **kwargs)
            AnimalType.singleAnimal.__init__(*args, **kwargs)
        else:
            print("The unique animal already exists")
        return AnimalType.singleAnimal

    def __new__(cls, name, *args, **kwargs):
        print("__new__ of AnimalType")
        return super().__new__(cls, *args, **kwargs)
```

Singleton with metaclasses (2/4)

```
class Animal(metaclass=AnimalType):
    def __init__(self,*args):
        print("__init__ of Animal")
        print(f'self = {self}; args = {args}')
        self.weight=10
        print(f'self.weight = {self.weight}; args = {args}')

    def __new__(cls, *args, **kwargs):
        print("__new__ of Animal")
        if AnimalType.singleAnimal is  None:
            print("Creating the unique singleton")
            AnimalType.singleAnimal = super().__new__(cls, *args, **kwargs)
        return AnimalType.singleAnimal
```

Singleton with metaclasses (3/4)

- Now we start the execution

```
__new__ of AnimalType # The object AnimalType is created
__init__ of AnimalType
>>> if __name__ == '__main__':
>>>     print("Now creating an Animal")
Now creating an Animal
>>>     print(type(AnimalType))
<class 'type'>
>>>     print(type(Animal))
<class '__main__.AnimalType'>
>>>     a = Animal() # This is a call to the singleton;
>>>.    # there is no need of a method called getSingleton
__call__ of AnimalType
Creating the unique animal
__new__ of Animal
Creating the unique singleton
__init__ of Animal
```

Singleton with metaclasses (4/4)

```
>>>     print(a)
<__main__.Animal object at 0x106f24ed0>
>>>     print(a.weight)
10
>>>     a.weight = 20
>>>     print(a.weight)
20
>>>     b = Animal() # Having overloaded AnimalType.__call__(),
>>>.    # no new object is created but the singleton is returned
The unique animal already exists
>>>     print(b)
<__main__.Animal object at 0x106f24ed0>
>>>     print(a==b)
True
>>>     b.weight = 300
>>>     print(a.weight)
300
```

Generalization of Singleton (1/2)

- It is possible to create a general meta class to use when we need a singleton of any class

```
class Singleton(type):
    _instances = {}

    def __call__(cls, *args, **kwargs):
        if cls not in cls._instances:
            cls._instances[cls]=super(type(cls), cls).__call__(*args, **kwargs)
        return cls._instances[cls]
```

- Here we let `__call__` invoke the `__call__` of the superclass only if no instances of `cls` have already been created

Source: https://itnext.io/deciding-the-best-singleton-approach-in-python-65c61e90cdc4

Generalization of Singleton (2/2)

- Now suppose that we want to create a specialization of a Database class allowing only an instance of it

```
class Database():
    def __init__(self, url):
        self.url = url

    def connect(self):
        if 'https' not in self.url:
            raise ValueError("invalid url: it must be encrypted")
        return True

class DatabaseSingleton(Database, metaclass=Singleton):
    pass
```

- Specifying as metaclass `Singleton` we have achieved our goal

Source: `https://itnext.io/deciding-the-best-singleton-approach-in-python-65c61e90cdc4`

Structure of the execution

- Python is executed on a virtual machine with packages that are loaded at run time
- In this it is similar to Java
- `https://leanpub.com/insidethepythonvirtualmachine/read`

String formatting

- f-syntax

Reflection and Introspection

- basics

Taken from https://betterprogramming.pub/python-reflection-and-introspection-97b348be54d8 and https://betterprogramming.pub/python-reflection-and-introspection-97b348be54d8

Decorators

- basics

Taken from https://www.geeksforgeeks.org/decorators-in-python/

Generics

- basics

Taken from `https://www.tutorialspoint.com/python/python_generics.htm/`

Type Hints

- basics

Taken from `https://www.pythontutorial.net/python-basics/python-type-hints/`

Structure of the virtual machine

- As said, Python is executed on a virtual machine with packages that are loaded at run time
- In this it is similar to Java
- `https://leanpub.com/insidethepythonvirtualmachine/read`

Inversion of Control

- basics

Taken from `https://python-dependency-injector.ets-labs.org/introduction/di_in_python.html`

Questions?

End of the introductory lectures on Python.