301AA - Advanced Programming

Lecturer: Andrea Corradini

andrea@di.unipi.it

http://pages.di.unipi.it/corradini/

AP-26: Functions, Decorators and OOP
We have seen:

- Installing Python & main documentation
- Useful commands
- Modules: importing and executing
- Basics of the language
- Sequence datatypes
- Dictionaries
- Boolean expressions
- Control flow
- List Comprehension
Next topics

- Function definition
- Positional and keyword arguments of functions
- Functions as objects
- Higher-order functions
- Namespaces and Scopes
- Object Oriented programming in Python
- Inheritance
- Iterators and generators
Functions in Python - Essentials

• Functions are first-class objects
• All functions return some value (possibly None)
• Function call creates a new namespace
• Parameters are passed by object reference
• Functions can have optional keyword arguments
• Functions can take a variable number of args and kwargs
• Higher-order functions are supported
Function definition (1)

• Positional/keyword/default parameters

```python
def sum(n, m):
    """ adds two values """
    return n + m

>>> sum(3, 4)
7
>>> sum(m=5, n=3)  # keyword parameters
8

#--------------------------------------

def sum(n, m=5):  # default parameter
    """ adds two values, or increments by 5 """
    return n + m

>>> sum(3)
8
```
Function definition (2)

- Arbitrary number of parameters (varargs)

```python
def print_args(*items):
    # arguments are put in a tuple
    print(type(items))
    return items

>>> print_args(1,"hello",4.5)
<class 'tuple'>
(1, 'hello', 4.5)

#--------------------------------------

def print_kwargs(**items):
    # args are put in a dict
    print(type(items))
    return items

>>> print_kwargs(a=2,b=3,c=3)
<class 'dict'>
{'a': 2, 'b': 3, 'c': 3}
```
Functions are objects

- As everything in Python, also functions are object, of class `function`

```python
def echo(arg): return arg

type(echo)  # <class 'function'>
hex(id(echo))  # 0x1003c2bf8
print(echo)  # <function echo at 0x1003c2bf8>
foo = echo
hex(id(foo))  # '0x1003c2bf8'
print(foo)  # <function echo at 0x1003c2bf8>
isinstance(echo, object)  # => True
```
Function documentation

• The comment after the functions header is bound to the `__doc__` special attribute

```python
def my_function():
    """Summary line: do nothing, but document it.
    Description: No, really, it doesn't do anything.
    """
    pass

print(my_function.__doc__)
# Summary line: Do nothing, but document it.
# # Description: No, really, it doesn't do anything.
```
Higher-order functions

- Functions can be passed as argument and returned as result
- Main combinators *(map, filter)* predefined: allow standard functional programming style in Python
- Heavy use of iterators, which support laziness
- Lambdas supported for use with combinators

  `lambda arguments: expression`

  - The body can only be a single expression
Map

>>> print(map.__doc__)  # documentation
map(func, *iterables)  -->  map object
Make an iterator that computes the function using arguments from each of the iterables. Stops when the shortest iterable is exhausted.

>>> map(lambda x:x+1, range(4))  # lazyness: returns
<map object at 0x10195b278>  # an iterator
>>> list(map(lambda x:x+1, range(4)))
[1, 2, 3, 4]

>>> list(map(lambda x, y : x+y, range(4), range(10)))
[0, 2, 4, 6]  # map of a binary function

>>> z = 5  # variable capture

>>> list(map(lambda x : x+z, range(4)))
[5, 6, 7, 8]
Map and List Comprehension

- **List comprehension** can replace uses of `map`

```python
>>> list(map(lambda x:x+1, range(4)))
[1, 2, 3, 4]
>>> [x+1 for x in range(4)]
[1, 2, 3, 4]
>>> list(map(lambda x, y : x+y, range(4), range(10)))
[0, 2, 4, 6]  % map of a binary function
>>> [x+y for x in range(4) for y in range(10)]
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 1, 2, 3, 4, 5,... % NO!
>>> [x+y for (x,y) in zip(range(4),range(10))]] % OK
[0, 2, 4, 6]
>>> print(zip.__doc__)
zip(iter1 [,iter2 [...]]) -- zip object
Return a zip object whose __next__() method returns a tuple where
the i-th element comes from the i-th iterable argument. The
__next__() method continues until the shortest iterable in the
argument sequence is exhausted and then it raises StopIteration.
```
Filter (and list comprehension)

```python
>>> print(filter.__doc__)  # documentation
filter(function or None, iterable) --> filter object
Return an iterator yielding those items of iterable for which function(item) is true. If function is None, return the items that are true.

>>> filter(lambda x: x % 2 == 0, [1, 2, 3, 4, 5, 6])
<filter object at 0x102288a58>  # lazyness
>>> list(_)
[2, 4, 6]
>>> [x for x in [1, 2, 3, 4, 5, 6] if x % 2 == 0]
[2, 4, 6]  # same using list comprehension
% How to say "false" in Python
```

```python
>>> list(filter(None, [1, 0, -1, '', "Hello", None, [], [1], (), True, False]))
[1, -1, 'Hello', [1], True]
```
More modules for functional programming in Python

- **functools**: Higher-order functions and operations on callable objects, including:
  - `reduce(function, iterable[, initializer])`

- **itertools**: Functions creating *iterators* for efficient looping. Inspired by constructs from APL, Haskell, and SML.
  - `count(10) --> 10 11 12 13 14 ...`
  - `cycle('ABCD') --> A B C D A B C D ...`
  - `repeat(10, 3) --> 10 10 10`
  - `takewhile(lambda x: x<5, [1,4,6,4,1]) --> 1 4`
  - `accumulate([1,2,3,4,5]) --> 1 3 6 10 15`
Decorators

• A **decorator** is any callable Python object that is used to modify a **function**, **method** or **class definition**.

• A decorator is passed the original object being defined and returns a modified object, which is then bound to the name in the definition.

• (Function) Decorators exploit Python **higher-order features**:
  – Passing functions as argument
  – Nested definition of functions
  – Returning function

• Widely used in Python (system) programming
• Support several features of meta-programming
Basic idea: wrapping a function

```python
def my_decorator(func):  # function as argument
    def wrapper():    # defines an inner function
        print("Something happens before the function.")
        func() # that calls the parameter
        print("Something happens after the function.")
    return wrapper # returns the inner function

def say_hello():   # a sample function
    print("Hello!")

# 'say_hello' is bound to the result of my_decorator
say_hello = my_decorator(say_hello) # function as arg

>>> say_hello()    # the wrapper is called
Something happens before the function.
Hello!
Something happens after the function.
```
Syntactic sugar: the "pie" syntax

```python
def my_decorator(func):    # function as argument
    def wrapper(): # defines an inner function
        ... # as before
        return wrapper # returns the inner function
    return wrapper

def say_hello():  ## HEAVY! 'say_hello' typed 3x
    print("Hello!")
say_hello = my_decorator(say_hello)
```

- Alternative, equivalent syntax

```python
@my_decorator
def say_hello():
    print("Hello!")
```
Another decorator: do_twice

```python
def do_twice(func):
    def wrapper_do_twice():
        func()  # the wrapper calls the
        func()  # argument twice
    return wrapper_do_twice

@do_twice  # decorate the following
def say_hello():  # a sample function
    print("Hello!")

>>> say_hello()  # the wrapper is called
Hello!
Hello!

@do_twice  # does not work with parameters!!
def echo(str):  # a function with one parameter
    print(str)

>>> echo("Hi...")  # the wrapper is called
TypErr: wrapper_do_twice() takes 0 pos args but 1 was given
>>> echo()
TypErr: echo() missing 1 required positional argument: 'str'
```
do_twice for functions with parameters

- Decorators for functions with parameters can be defined exploiting *args and **kwargs

```python
def do_twice(func):
    def wrapper_do_twice(*args, **kwargs):
        func(*args, **kwargs)
        func(*args, **kwargs)
    return wrapper_do_twice

@do_twice
def say_hello():
    print("Hello!")

>>> say_hello()
Hello!
Hello!
```

```python
@do_twice
def echo(str):
    print(str)

>>> echo("Hi... ")
Hi...
Hi...
```
General structure of a decorator

- Besides passing arguments, the wrapper also forwards the **result** of the decorated function
- Supports **introspection** redefining **__name__** and **__doc__**

```python
import functools
def decorator(func):
    @functools.wraps(func)  # supports introspection
    def wrapper_decorator(*args, **kwargs):
        # Do something before
        value = func(*args, **kwargs)
        # Do something after
        return value
    return wrapper_decorator
```
import functools
import time

def timer(func):
    """Print the runtime of the decorated function""
    @functools.wraps(func)
    def wrapper_timer(*args, **kwargs):
        start_time = time.perf_counter()
        value = func(*args, **kwargs)
        end_time = time.perf_counter()
        run_time = end_time - start_time
        print(f"Finished {func.__name__!r} in {run_time:.4f} secs")
        return value
    return wrapper_timer

@timer
def waste_some_time(num_times):
    for _ in range(num_times):
        sum([i**2 for i in range(10000)])
Other uses of decorators

• **Debugging**: prints argument list and result of calls to decorated function

• **Registering plugins**: adds a reference to the decorated function, without changing it

• In a web application, can wrap some code to check that the user is logged in

• **@classmethod** and **@staticmethod** make a function invocable on the class name or on an object of the class

• More: decorators can be nested, can have arguments, can be defined as classes...
Example: Caching Return Values

```python
import functools
from decorators import count_calls

def cache(func):
    """Keep a cache of previous function calls"""
    @functools.wraps(func)
    def wrapper_cache(*args, **kwargs):
        cache_key = args + tuple(kwargs.items())
        if cache_key not in wrapper_cache.cache:
            wrapper_cache.cache[cache_key] = func(*args, **kwargs)
        return wrapper_cache.cache[cache_key]
    wrapper_cache.cache = dict()
    return wrapper_cache

@cache
@count_calls  # decorator that counts the invocations
def fibonacci(num):
    if num < 2:
        return num
    return fibonacci(num - 1) + fibonacci(num - 2)
```
Namespaces and Scopes

• A **namespace** is a mapping from names to objects: typically implemented as a dictionary. Examples:
  – **builtins**: pre-defined functions, exception names,...
    • Created at interpreter's start-up
  – global names of a **module**
    • Created when the module definition is read
    • Note: names created in interpreter are in module `__main__`
  – local names of a **function invocation**
    • Created when function is called, deleted when it completes
  – and also names of a **class**, names of an **object**... see later

• Name **x** of a module **m** is an **attribute of m**
  – accessible (read/write) with “qualified name” **m.x**
  – if writable, it can be deleted with **del**
Namespaces and Scopes (2)

• A **scope** is a textual region of a Python program where a namespace is **directly accessible**, i.e. reference to a name attempts to find the name in the namespace.
• Scopes are determined statically, but are used dynamically.
• During execution at least three namespaces are directly accessible, searched in the following order:
  – the scope containing the **local names**
  – the scopes of any enclosing functions, containing **non-local**, but also **non-global names**
  – the next-to-last scope containing the current module’s **global names**
  – the outermost scope is the namespace containing **built-in names**
• **Assignments to names go in the local scope**
• Non-local variables can be accessed using **nonlocal** or **global**
Scoping rules

def scope_test():
    def do_local():
        spam = "local spam"

    def do_nonlocal():
        nonlocal spam
        spam = "nonlocal spam"

    def do_global():
        global spam
        spam = "global spam"

    spam = "test spam"

    do_local()
    print("After local assignment:" , spam)  # not affected
    do_nonlocal()
    print("After nonlocal assignment:" , spam)  # affected
    do_global()
    print("After global assignment:" , spam)  # not affected

scope_test()
print("In global scope:" , spam)

After local assignment: test spam
After nonlocal assignment: nonlocal spam
After global assignment: nonlocal spam
In global scope: global spam
Criticisms to Python: **scopes**

- In many languages, scopes give you power to write readable and simple code. In Python, you only get TWO simple scopes - global, and function - and even handling these scopes is painful

```python
def test():
    for a in range(5):
        b = a % 3
        print(b)
    print(b)

>>> test()
```

```python
def test(x):
    print(x)
    for x in range(5):
        print(x)
    print(x)

>>> test("Hello!")
```
Closures in Python

• Python supports closures: Even if the scope of the outer function is reclaimed on return, the non-local variables referred to by the nested function are saved in its attribute `__closure__`.

```python
def counter_factory():
    counter = 0
    def counter_increaser():
        nonlocal counter
        counter = counter + 1
        return counter
    return counter_increaser

>>> f = counter_factory()
>>> f()
1
>>> f()
2
>>> f.__closure__
(<cell at 0x1033ace88: int object at 0x10096dce0>,)
```
OOP in Python

- Typical ingredients of the Object Oriented Paradigm:
  - **Encapsulation**: dividing the code into a public **interface**, and a private **implementation** of that interface;
  - **Inheritance**: the ability to create **subclasses** that contain specializations of their parent classes.
  - **Polymorphism**: The ability to **override** methods of a Class by extending it with a subclass (inheritance) with a more specific implementation (inclusion polymorphism)

From [https://docs.python.org/3/tutorial/classes.html](https://docs.python.org/3/tutorial/classes.html):

- "Python classes provide all the standard features of Object Oriented Programming: the class inheritance mechanism allows multiple base classes, a derived class can override any methods of its base class or classes, and a method can call the method of a base class with the same name. Objects can contain arbitrary amounts and kinds of data. As is true for modules, classes partake of the dynamic nature of Python: they are created at runtime, and can be modified further after creation."
Defining a class (object)

- A class is a blueprint for a new data type with specific internal attributes (like a struct in C) and internal functions (methods).
- To declare a class in Python the syntax is the following:

```python
class className:
    <statement-1>
    ...
    <statement-n>
```

- **Statements** are assignments or function definitions
- A new namespace is created, where all names introduced in the statements will go.
- When the class definition is left, a **class object** is created, bound to `className`, on which two operations are defined: **attribute reference** and **class instantiation**.
- **Attribute reference** allows to access the names in the namespace in the usual way
Example: Attribute reference on a class object

```python
class Point:
    x = 0
    y = 0
    def str():  # no closure: needs qualified names to refer to x and y
        return "x = " + (str) (Point.x) + ", y = " + (str) (Point.y)

#--------
import ...
>>> Point.x
0
>>> Point.y = 3
>>> Point.z = 5  # adding new name
>>> Point.z
5
>>> def add(m,n):
    return m+n
>>> Point.sum = add  # adding new function
>>> Point.sum(3,4)
7
```
Creating a class instance

- A **class instance** introduces a **new namespace nested in the class namespace**: by visibility rules all names of the class are visible.
- If no **constructor** is present, the syntax of class instantiation is **className()**: the new namespace is empty.

```python
class Point:
    x = 0
    y = 0
    def str():
        return "x = " + str(Point.x) + ", y = " + str(Point.y)

#--------
>>> p1 = Point()
>>> p2 = Point()
>>> p1.x
0
>>> Point.y = 3
>>> p1.y
3
>>> p2.y
3
>>> p1.y = 5
$$\begin{array}{|c|}
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>x = 0</td>
</tr>
<tr>
<td>y = 0</td>
</tr>
<tr>
<td>str()</td>
</tr>
<tr>
<td>y = 3</td>
</tr>
<tr>
<td>p1</td>
</tr>
<tr>
<td>p2</td>
</tr>
<tr>
<td>y = 5</td>
</tr>
</tbody>
</table>
\end{array}$$
```
Instance methods

- A class can define a set of **instance methods**, which are just functions:

```python
def methodname(self, parameter1, ..., parameter_n):
    statements
```

- The first argument, usually called `self`, represents the *implicit parameter* (`this` in Java)

- A method **must** access the object's attributes through the `self` reference (eg. `self.x`) and the class attributes using `className.<attrName>` (or `self.__class__.<attrName>`) 

- The first parameter must not be passed when the method is called. It is bound to the target object. Syntax:

  ```python
  obj.methodname(arg1, ..., arg_n):
  ```

- But it can be passed explicitly. Alternative syntax:

  ```python
  className.methodname(obj, arg1, ..., arg_n):
  ```
Any function **with at least one parameter** defined in a class can be invoked on an instance of the class with the dot notation.

```python
class Foo:
    def fun(par-0, par-1, ..., par-n):
        statements
```

Since the instance `obj` is bound to the first parameter, `par-0` is usually called `self`.

A name `x` defined in the (namespace of the) instance is accessed as `par-0.x` (i.e., usually `self.x`)

A name `x` defined in the class is accessed as `className.x` (or `self.__class__.x`)
Constructors

- A constructor is a special instance method with name `__init__`. Syntax:

```python
def __init__(self, parameter_1, ..., parameter_n):
    statements
```

- Invocation: `obj = className(arg_1, ..., arg_n)`

- The first parameter `self` is bound to the new object.

- `statements` typically initialize (thus create) "instance variables", i.e. names in the new object namespace.

- Note: at most ONE constructor (no overloading in Python!)

```python
class Point:
    instances = []
    def __init__(self, x, y):
        self.x = x
        self.y = y
        Point.instances.append(self)

#--------
>>> p1 = Point(3, 4)
```

```
Point
instances = [<Point object at ...>]
p1
   x = 3
   y = 4
```
What about "methods in instances?"

- Instances are themselves namespaces: we can add functions to them.
- Applying the usual rules, they can hide "instance methods"

```python
class Point:
    def __init__(self, x, y):
        self.x = x
        self.y = y
    def move(z, t):
        self.x -= z
        self.y -= t
    self.move = move
    def move(self, dx, dy):
        self.x += dx
        self.y += dy

>>> p = Point(1,1)
>>> p.x
1
>>> p.move(1,1)
>>> p.x
0
>>> p.__class__.move(p,2,2)
>>> p.x
2
```
It is often useful to have a textual representation of an object with the values of its attributes. This is possible with the following instance method:

```python
def __str__(self):
    return <string>
```

This is equivalent to Java's `toString` (converts object to a string) and it is invoked automatically when `str` or `print` is called.
Special methods

- **Method overloading**: you can define special instance methods so that Python's built-in operators can be used with your class.

### Binary Operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Class Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td><code>__sub__</code>(self, other)</td>
</tr>
<tr>
<td>+</td>
<td><code>__add__</code>(self, other)</td>
</tr>
<tr>
<td>*</td>
<td><code>__mul__</code>(self, other)</td>
</tr>
<tr>
<td>/</td>
<td><code>__truediv__</code>(self, other)</td>
</tr>
</tbody>
</table>

### Unary Operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Class Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td><code>__neg__</code>(self)</td>
</tr>
<tr>
<td>+</td>
<td><code>__pos__</code>(self)</td>
</tr>
</tbody>
</table>

### Analogous to C++ overloading mechanism:
- **Pros**: very compact syntax
- **Cons**: may be more difficult to read if not used with care
(Multiple) Inheritance, in one slide

- A class can be defined as a *derived class*

```python
class derived(baseClass):
    statements
    statements
```

- No need of additional mechanisms: the namespace of *derived* is nested in the namespace of *baseClass*, and uses it as the next non-local scope to resolve names

- All instance methods are automatically virtual: lookup starts from the instance (namespace) where they are invoked

- Python supports *multiple inheritance*

```python
class derived(base1,..., basen):
    statements
    statements
```

- *Diamond problem* solved by an algorithm that linearizes the set of all (directly or indirectly) inherited classes: the Method resolution order (MRO) ➔ `ClassName.mro()`

- [www.python.org/download/releases/2.3/mro/](https://www.python.org/download/releases/2.3/mro/)
Encapsulation (and "name mangling")

- **Private** instance variables (not accessible except from inside an object) don’t exist in Python.

- **Convention:** a name prefixed with underscore (e.g. `_spam`) is treated as non-public part of the API (function, method or data member). It should be considered an implementation detail and subject to change without notice.

**Name mangling** ("storpiatura")

- Sometimes class-private members are needed to avoid clashes with names defined by subclasses. Limited support for such a mechanism, called **name mangling**.

- Any name with at least two leading underscores and at most one trailing underscore like e.g. `__spam` is textually replaced with `_class__spam`, where `class` is the current class name.
Example for name mangling

- Name mangling is helpful for letting subclasses override methods without breaking intraclass method calls.

```python
class Mapping:
    def __init__(self, iterable):
        self.items_list = []
        self.__update(iterable)

    def update(self, iterable):
        for item in iterable:
            self.items_list.append(item)

    __update = update  # private copy of update() method

class MappingSubclass(Mapping):

    def update(self, keys, values):
        # provides new signature for update()
        # but does not break __init__() method
        for item in zip(keys, values):
            self.items_list.append(item)
```
Static methods and class methods

- **Static methods** are simple functions defined in a class with no `self` argument, preceded by the `@staticmethod` decorator.
- They are defined inside a class but they cannot access instance attributes and methods.
- They can be called through both the class and any instance of that class!
- **Benefits of static methods**: they allow subclasses to customize the static methods with inheritance. Classes can inherit static methods without redefining them.

- **Class methods** are similar to static methods but they have a first parameter which is the class name.
- Definition must be preceded by the `@classmethod` decorator.
- Can be invoked on the class or on an instance.
Iterators

- An **iterator** is an object which allows a programmer to traverse through all the elements of a collection (**iterable** object), regardless of its specific implementation. In Python they are used implicitly by the **FOR** loop construct.

- Python iterator objects required to support two methods:
  - `__iter__` returns the iterator object itself. This is used in **FOR** and **IN** statements.
  - The `next` method returns the next value from the iterator. If there is no more items to return then it should raise a **StopIteration** exception.

- Remember that an iterator object can be used only once. It means after it raises **StopIteration** once, it will keep raising the same exception.

- Example:

```python
>>> list = [1,2,3]
>>> it = iter(list)
>>> it
<listiterator object at 0x00A1DB50>
>>> it.next()
1
>>> it.next()
2
>>> it.next()
3
>>> it.next() -> raises StopIteration
```
Generators and coroutines

- **Generators** are a simple and powerful tool for creating iterators.
- They are written like **regular functions** but use the `yield` statement whenever they want to return data.
- Each time the `next()` is called, the generator resumes where it left-off (it remembers all the data values and which statement was last executed).

*Anything that can be done with generators can also be done with class based iterators (not vice-versa).*

- What makes generators so compact is that the `__iter__()` and `next()` methods are created automatically.
- Another key feature is that the local variables and execution state are **automatically saved** between calls.
Generators (2)

- In addition to automatic method creation and saving program state, when generators terminate, they automatically raise `StopIteration`.

- In combination, these features make it easy to create iterators with no more effort than writing a regular function.

```python
def reverse(data):
    for index in range(len(data)-1, -1, -1):
        yield data[index]

#-----------------

>>> for char in reverse('golf'):
...     print(char)
...
floloog
```
Miscellaneous

• Duck typing
• Overloading
• Overriding
• Generics