Advanced python features - part II

Computing Methods for Experimental Physics and Data Analysis

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Functions inside functions

- Functions in python are first class object
- The name is a bit misleading, but what it actually means is that functions can be passed as argument to other functions and returned as result from other functions
- This shouldn't surprise you much: functions are objects of a '*function*' class, so they behave like any other vairable in Python
- Another thing you can (and sometimes want to) do is *defining* a function inside another.
- Let's see how it works

Functions inside functions

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/inner_outer.py

```
def outer():
    def inner(): # Defining the inner function inside the outer function
        print('Inner function')
        return # End of the inner function
    return inner # Inner is the output of outer

my_func = outer() # my_func is now referncing 'inner'
print(my_func.__name__)
my_func() # Calling my_func is equal to calling 'inner'

def outer2():
    some_string = 'Hello!'
    def inner():
        # We have access to the variables in the outer function!
        print(some_string)
    return inner

my_other_func = outer2()
my_other_func()

[Output]
inner
Inner function
Hello!
```

- When a function is created inside another function it has access to the local variables of the outer function, even after its scope ended
- This is techincally possible because those varibales are kept in a special space of memory, the closure of the inner function
- Such variables are called free variables
- In this way, a function can mantain a state within its closure
- This makes possible the use of functions for tasks that in other languages are reserved to classes
- Let's take a look at the following example

An inefficient rotation

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/rotation_naive.py

```python
import numpy

def rotate(x, y, theta):
    """ Naive implementation. This works, but is inefficient - we have to
    calculate cos(theta) and sin(theta) for each pair (x,y)! """
    c = numpy.cos(theta)
    s = numpy.sin(theta)
    x_rot = c * x - s * y
    y_rot = s * x + c * y
    return x_rot, y_rot

x, y = 1., 0.
theta = numpy.pi/4
print(rotate(x, y, theta)) # Rotation of pi/2

def efficient_rotate(x, y, c_theta, s_theta):
    """ Efficient rotation. The user gives cos and sin, so they are not
    calculated for each pixel """
    x_rot = c * x - s * y
    y_rot = s * x + c * y
    return x_rot, y_rot

c = numpy.cos(theta)
s = numpy.sin(theta)
print(efficient_rotate(x, y, c, s)) # The syntax is very ugly!

[Output]
(0.7071067811865476, 0.7071067811865475)
(0.7071067811865476, 0.7071067811865475)
```

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/rotator.py

```python
import numpy

def create_rotator(theta):
    """ Efficient rotation. Cosinus and sinus values are saved in the closure,
    so that they are computed exactly once."""
    c = numpy.cos(theta)
    s = numpy.sin(theta)
    def rotate(x, y):
        x_rot = c * x - s * y
        y_rot = s * x + c * y
        return x_rot, y_rot
    return rotate

x, y = 1., 0.
theta = numpy.pi/4
rotate_by_theta = create_rotator(theta)
print(rotate_by_theta(x, y))

[Output]
(0.7071067811865476, 0.7071067811865475)
```

- Note: if you *assign* to a free variable in the inner function, by default a new, local variable is created instead!
- To avoid this you have to explictly declare that you want to access the variable in the closure using the nonlocal keyword
- Remember: *'Explicit is better then implicit'*

Free variables - a mistake to avoid

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/closure_wrong.py

```python
def running_average():
    total_count = 0
    num_elements = 0
    def accumulator(value):
        total_count += value # Doesn’t work! total_count is reassigned!
        num_elements += 1 # Doesn’t work! total_count is reassigned!
        return total_count/num_elements
    return accumulator

run_avg = running_average()
print(run_avg(1.))
print(run_avg(5.))
print(run_avg(2.5))

[Output]
Traceback (most recent call last):
  File "snippets/closure_wrong.py", line 11, in <module>
    print(run_avg(1.))
  File "snippets/closure_wrong.py", line 5, in accumulator
    total_count += value # Doesn’t work! total_count is reassigned!
UnboundLocalError: local variable ’total_count’ referenced before assignment
```

Free variables - the correct way

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/closure_right.py

```python
def running_average():
    total_count = 0
    num_elements = 0
    def accumulator(value):
        # We declare the relevant variables as nonlocal
        nonlocal total_count, num_elements
        # Now we can assign to them - the variables in the closure will be
        # modified, as we want!
        total_count += value
        num_elements += 1
        return total_count/num_elements
    return accumulator

run_avg = running_average()
print(run_avg(1.))
print(run_avg(5.))
print(run_avg(2.5))

[Output]
1.0
3.0
2.8333333333333335
```

Wrapping functions

- The typical use of defining a function inside a function is to create a wrapper
- A wrapper is a function that calls another one adding a layer of functionalities in between - for example it may do some pre-process of the input, or change the output in some way, or measure the execution time or whatever we want
- The techinque for creating a wrapper fucntion in Python is:
  - Pass the function that we want to wrap as argument of the outer function
  - Inside the outer function we define an inner function, which is the actual wrapper
  - The wrapper calls the wrapped function and adds its functionalities, before and/or after the call. It may return the same output or a manipulated one.
  - Then from the outer fucntion we return the wrapper

Wrapper

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/wrapper.py

```python
def some_function(a, b):
    print('Executing {} x {}'.format(a, b))
    return a * b

def add_n_wrapper(func, n): # We take the wrapped function as argument
    """ This wrapper adds n to the result of the wrapped function"""

    def wrapper(*args, **kwargs):
        """We passs the arguments as *arg, **kwargs, because this is the most
        general form in Python: we can collect any combination of arguments like
        that. Note that we have access to both 'func' and 'n', as they are stored
        in the closure of 'wrapper'"""
        result = func(*args, **kwargs) # Pass the arguments to the wrapped fucntion
        print('Adding {}'.format(n))
        return result + n # Return a modified result in this case

    return wrapper # From add_n_wrapper we return the wrapper

function_plus_five = add_n_wrapper(some_function, 5)
print('Result = {}'.format(function_plus_five(2, 3)))

[Output]
Executing 2 x 3
Adding 5
Result = 11
```

Decorators

- Often, when you wrap a function, you don't want to change it's name, so you reassign the wrapped function to its old name
- In fact, this techinque is so common that python introduced a special syntax for it: decorators
- A decorated function has simply the name of the wrapper added with a '@' on top of its declaration

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/decorator.py

```python
def print_function_info(func):
    def wrapper(*args, **kwargs):
        print('Calling function \'{}\''.format(func.__name__))
        print('Positional arguments = {}'.format(args))
        print('Keyword arguments = {}'.format(kwargs))
        return func(*args, **kwargs)
    return wrapper

@print_function_info
def some_function(a, b, c=0):
    return a * b + c

# This is equivalent to: some_function = print_function_info(some_function)

print(some_function(1, 2, c=7))
 # Inspecting the function reveals that we are calling the wrapper
print('The name of the function is \'{}\''.format(some_function.__name__))

[Output]
Calling function 'some_function'
Positional arguments = (1, 2)
Keyword arguments = 'c': 7
9
The name of the function is 'wrapper'
```

A decorator to measure execution time

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/time_measuring_decor.py

```python
import time
from functools import wraps

def clocked(func):
    """ We use functools.wraps to keep the original function name and docstring"""
    @wraps(func)
    def wrapper(*args, **kwargs):
        tstart = time.clock()
        result = func(*args, **kwargs)
        exec_time = time.clock() - tstart
        print('Function {} executed in {} s'.format(func.__name__, exec_time))
        return result
    return wrapper

@clocked
def square_list(input_list):
    """ Return the square of a list"""
    return [item**2 for item in input_list]

# Make sure the function name and docstring look the same
print('\'{}\': {}'.format(square_list.__name__, square_list.__doc__))
square_list(range(2000000))

[Output]
'square_list':  Return the square of a list
Function square_list executed in 0.372302 s
```

The @classmethod decorator

- We have already seen a built-in Python decorator: *@property*
- We used that to get proper encapsulation
- There is another built-in decorator one which is very useful for classes: *@classmethod*
- A classmethod is like a class attribute: you don't need an instance to use it
- A class method can access class attributes but not instance attributes
- The main use for class methods is to provide alternate constructors

Class method

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/classmethod.py

```
import numpy

class LabData:

  def __init__(self, times, values):
      """ Our usual constructor"""
      self.times = numpy.array(times, dtype=numpy.float64)
      self.values = numpy.array(values, dtype=numpy.float64)

  @classmethod # The classmethod decorator
  def from_file(cls, file_path): # We get the class as first argument, not self
       """ Constructor from a file"""
       print(cls)
       times, values = numpy.loadtxt(file_path, unpack=True)
       # We call the constructor of 'cls' which is our LabData
       # This is not a 'real' constructor, we need to return the object!
       return cls(times, values)

# We call the alternate constructor from the class itself, not from an instance!
lab_data = LabData.from_file('snippets/data/measurements.txt')
print(lab_data.values)

[Output]
<class '__main__.LabData'>
[15.2 12.4 11.7 13.2]
```

The @staticmethod decorator

- Another built-in decorator (though less used than *@classmethod*) is *@staticmethod*
- A static method is a method that does not receive the class or instance as first argument
- Because of that, a static method does not alter the state of the class
- In some sense a static method is only loosely coupled to the class - it is defined inside the class body just for convenience (maybe for semantical proximity) but it could be defined outside the class as well

Static method

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/staticmethod.py

```python
import math

class Angle:

    # A bunch of useful methods....

    @staticmethod
    def rad2deg(rad):
        # No self argument here
        return rad * 180./math.pi

    @staticmethod
    def deg2rad(deg):
        # No self argument here
        return deg * math.pi / 180.

print(Angle.rad2deg(math.pi/2))
print(Angle.deg2rad(45.))

[Output]
90.0
0.7853981633974483
```

Passing arguments to a decorator

- Making a decorator that accepts arguments is somewhat more complex
- The basic idea is that you need to add yet another level: a *decorator factory* function
- So you now end up with three levels:
  - The decorator factory that takes the parameters for the decorators, creates it and retruns it
  - The decorator that takes as input a function and returns the wrapper
  - The wrapper that implements the actual additional functionalities; usually takes as input the same parameters as the decorated/wrapped function and returns its results (if any)

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/decorator_factory.py

```python
from functools import wraps

# This is how a generic decorator with arguments looks like

def decorator_factory(*params): # The signature can be anything
    def decorator(function):
        @wraps(function)
        def wrapper(*args, **kwargs):
            print(f'Decorator arguments: {params}')
            # some preprocess here
            result = function(*args, **kwargs)
            # some post-process here
            return result
        return wrapper
    return decorator

# usage
@decorator_factory(1, 2, 3)
def f(x):
    return x**2

f(5)

[Output]
Decorator arguments: (1, 2, 3)
```

Repeat

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/decorator_repeat.py

```
from functools import wraps

def repeat(num_times):
    """ Repeat a function call a given number of times"""
    def decorator(function):
        @wraps(function)
        def wrapper(*args, **kwargs):
            for _ in range(num_times):
                function(*args, **kwargs)
        return wrapper
    return decorator

# usage
@repeat(num_times=4)
def greet():
    print('Hello!')

greet()

[Output]
Hello!
Hello!
Hello!
Hello!
```

Chaining decorators

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/decorator_chain.py

```python
from decorator_samples import clocked, repeat, print_function_info

""" To chain the effect of more than one decorator just stack them above the
function definition """

@print_function_info
@repeat(num_times=3)
@clocked
def greet(name):
    print(f'Hello {name}')

greet('Bob')

[Output]
Calling function 'greet'
Positional arguments = ('Bob',)
Keyword arguments =
Hello Bob
Function greet executed in 4.000000000000531e-06 s
Hello Bob
Function greet executed in 2.000000000002e-06 s
Hello Bob
Function greet executed in 2.000000000002e-06 s
```

A recap excercise

- As an exercise to recap the previous lessons, we want to write a small class for representing a sequence of measurements
- In this case they are voltages taken at different times
- The features that our class needs to have are summarized by the following test module (not a real unittest):

Test of functionalities

https://github.com/lucabaldini/cmepda/tree/master/slides/latex/snippets/test_voltage_data.py

```
from voltage_data import VoltageData
from matplotlib import pyplot as plt

def run_tests(): # This is not a proper unittest module!
    # Test constructor from data file
    data_file = VoltageData.from_file('snippets/data/sample_data_file.txt')
    # Column access by simple name
    t = data_file.timestamps
    v = data_file.voltages
    print(t[0], v[0])

    # Iterable by row
    for row in data_file:
        pass

    # Proper representation and printing
    print(repr(data_file))
    print(data_file)

    # Item access with slicing
    print(data_file[1:5, :])

    # Constructor from iterables (list, tuple, array)
    data_file_2 = VoltageData(list(t), tuple(v))
    # Check that the forst row is the same
    assert((data_file_2[0] == data_file[0]).all())
    # Plotting
    data_file_2.plot()
    plt.show()
```

File we want to read

sample_data_file.txt
~/computing/cmepda/slides/latex

```
# Time[s] V[mV]
0.1 0.24
0.2 0.39
0.3 0.58
0.4 0.77
0.5 0.84
0.6 0.95
0.7 1.00
0.8 1.02
0.9 0.95
1.0 0.94
1.1 0.83
1.2 0.87
1.3 0.48
1.4 0.21
1.5 0.04
```

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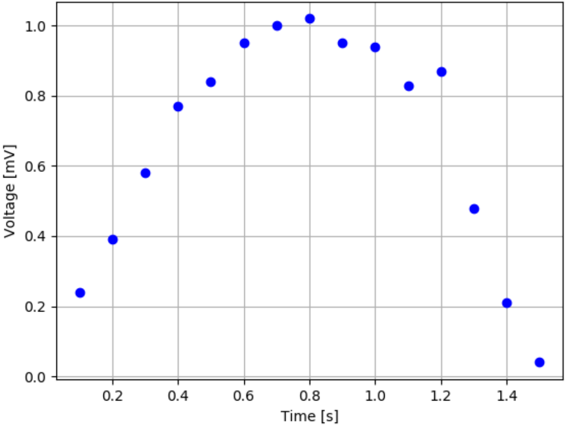
Output plot



Put yourself to test

- Manage a third column - optional - with voltage errors
- Write a proper unittest module for the class
- The full current version of the class is in snippets/voltage_data.py