

# Introduction to Scientific Python

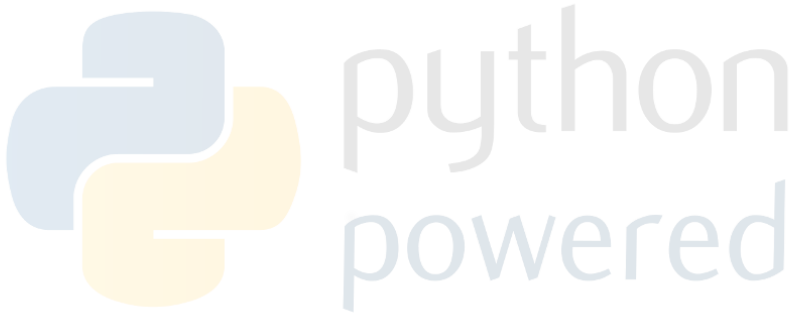
Iñigo Aldazabal Mensa – Centro de Física de Materiales  
(CSIC-UPV/EHU)

## Software Carpentry Workshop

*CFM, San Sebastian, 23<sup>rd</sup> January 2020*



# Why Python?



```
print("Hello, world!")
```

# Why Python?

Python is inherently slow compared to C/C++ or FORTRAN, so why Python for Scientific Computing?

Python is slow, but...

Syntactically, Python code looks like executable pseudo code:

- A Python program can have 5-10 times less lines than its C or FORTRAN counterpart
- Thus, program development using Python is 5-10 times faster than using C/C++...

and...

The number of bugs in a program scales linearly with the number of lines of the program.

# Why Python?

*We should forget about small efficiencies, say about 97% of the time:  
**premature optimization is the root of all evil** (in programming).*

*– Computer Programming as an Art (1974), Donald Knuth*

In software engineering, it is a good approximation that 90% of the execution time of a computer program is spent executing 10% of the code

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*The best approach is often to write only the performance-critical parts of the application in C++ or Java, and use Python for all higher-level control and customization.*

*– Guido van Rossum*

# Why Python?

## We have (for free)

- A general purpose language with a huge spectrum of freely available libraries for almost anything you can think of.
- A very easy to learn (and read) language that smoothly interfaces with C/C++ and FORTRAN (eg. calculation kernels).
- Lots of wrappers for well established, fast and long time tested numerical packages.
- Lots of high level utility libraries for scientific computing: plotting, data analysis, parallelization, ...

# Why Python? Batteries Included

## computing in SCIENCE & ENGINEERING

May/June 2007

Computing in Science & Engineering is a peer-reviewed, joint publication of the IEEE Computer Society and the American Institute of Physics



## PYTHON: BATTERIES INCLUDED

# Python Scientific Computing Environment



SciPy (pronounced "Sigh Pie") is a Python-based ecosystem of open-source software for mathematics, science, and engineering. In particular, these are some of the core packages:



NumPy  
Base  
N-dimensional  
array package



SciPy library  
Fundamental  
library for scientific  
computing



Matplotlib  
Comprehensive 2D  
Plotting



IPython  
Enhanced  
Interactive Console



Sympy  
Symbolic  
mathematics



pandas  
Data structures &  
analysis



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# NumPy



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NumPy is the fundamental package for scientific computing with Python. It contains among other things:

- a powerful N-dimensional array object
- sophisticated (broadcasting) functions
- tools for integrating C/C++ and Fortran code
- useful linear algebra, Fourier transform, and random number capabilities

# NumPy



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```
import numpy as np

# Create a numpy array, x
x = np.array( [1.1, 1.3, 1.5] )
y = np.sin(x)

# create a random two dimensional numpy array, A
A = np.random.rand(3,3)

A.transpose()
A.trace()
```

# SciPy



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SciPy is a collection of mathematical algorithms and convenience functions built on the Numpy extension of Python.

Much of SciPy is a thin layer of code on top of the C and FORTRAN scientific routines that are freely available at <http://www.netlib.org/>.

Provides the user with high-level commands and classes for manipulating and visualizing data.

With SciPy an interactive Python session becomes a data-processing and system-prototyping environment rivaling systems such as MATLAB, IDL, Octave, R-Lab, and SciLab.

# SciPy



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## SciPy subpackages (some of them)

- constants: Physical and mathematical constants
- fftpack: Fast Fourier Transform routines
- integrate: Integration and ordinary differential equation solvers
- interpolate: Interpolation and smoothing splines
- linalg: Linear algebra
- optimize: Optimization and root-finding
- signal: Signal processing
- special: Special functions
- ...

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```
import numpy as np
from scipy.special import gamma

x = np.array( [1.1, 2., 3.] )
y = gamma(x)

print (y)
```

```
[ 0.95135077,  1. ,  2. ]
```

# matplotlib



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matplotlib is a Python 2D plotting library which produces publication quality figures in a variety of hardcopy formats and interactive environments across platforms.

matplotlib can be used in Python scripts, the IPython shell, Jupyter Notebooks (ala MATLAB® or Mathematica®), and several graphical user interface toolkits.

For simple plotting the `pyplot` interface provides a MATLAB-like interface, particularly when combined with the IPython / Jupyter environment.

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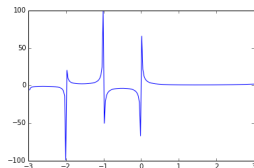


iPython  
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```
import numpy as np
from scipy.special import gamma
import matplotlib.pyplot as plt

x = np.linspace( start=-3., stop
                 =3., num=200 )
y = gamma(x)

plt.plot(x,y)
plt.savefig("gamma.png")
```





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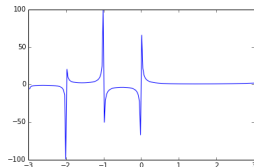


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Just google matplotlib images for examples!

# IPython / Jupyter



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IP[y]:  
IPython

IPython  
Enhanced  
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The **IPython / Jupyter Notebook** is an open-source web-based interactive computing system that enables users to create and share documents that contain live code,  $\text{L}^{\text{A}}\text{T}_{\text{E}}\text{X}$  equations, visualizations and explanatory text.

These documents contain a full record of a computation and its results and can be shared on email, Dropbox, version control systems (like git/GitHub) or with the Jupyter online notebook viewer [nbviewer.jupyter.org](http://nbviewer.jupyter.org).

# IPython / Jupyter



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IP[y]:  
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## IPython / Jupyter notebooks allows us to:

- **Edit code in the browser**, with syntax highlighting, indentation, and tab completion/introspection.
- **Run code in the browser**, with results attached to the code generating them.
- See the results with **rich media representation** as HTML, LaTeX, PDF, PNG, etc.
- Embed **interactive user interface controls** and visualization.
- Author **narrative text** using Markdown markup language.
- Build **hierarchical documents** with headings, sections, etc.
- Use **L<sup>A</sup>T<sub>E</sub>X syntax** in Markdown, rendered in the browser.

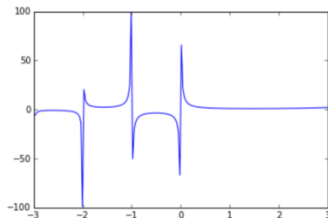
# IPython / Jupyter

```
In [45]: %matplotlib inline
import numpy as np
from scipy.special import gamma
import matplotlib.pyplot as plt

x = np.linspace( start=-3., stop=3., num=200 )
y = gamma(x)

plt.plot(x,y)
```

Out[45]: [<matplotlib.lines.Line2D at 0x7fc4ac4660b8>]



In [ ]: |



# IPython / Jupyter

jupyter spectrogram (autosaved)



File Edit View Insert Cell Kernel Help

Python 3



Markdown



CellToolbar

## Simple spectral analysis

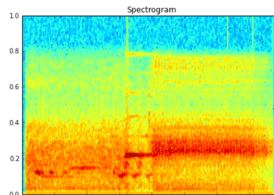
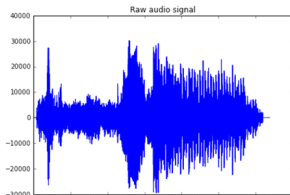
An illustration of the [Discrete Fourier Transform](#)

$$X_k = \sum_{n=0}^{N-1} x_n \exp\left(-\frac{2\pi i}{N} kn\right) \quad k = 0, \dots, N-1$$

```
In [2]: from scipy.io import wavfile
rate, x = wavfile.read('test_mono.wav')
```

And we can easily view it's spectral structure using matplotlib's builtin spectrogram routine:

```
In [5]: fig, (ax1, ax2) = plt.subplots(1,2,figsize(16,5))
ax1.plot(x); ax1.set_title('Raw audio signal')
ax2.specgram(x); ax2.set_title('Spectrogram');
```



# Python Scientific Computing Environment



Let's try it!