



Neural Data Science with **Python**

L1 : Introduction to Python : first steps

Michael Graupner

SPPIN – Saint-Pères Institute for the Neurosciences

Université de Paris, CNRS

How do YOU deal with data ?

I give you a 2d array of numbers : measurements and time points ($N=1000$).

time	0.1	0.2	0.3	0.4	0.5	0.6	...	99.8	99.9	100.0
measurment	3.2	4.3	3.8	4.5	3.7	5.1	...	8.3	8.1	9.0

- I would like to know the mean and the standard deviation of the measurements.
- I would like to see the data displayed, i.e., plotted as measurement vs time.

→ **How would you do that today ?**

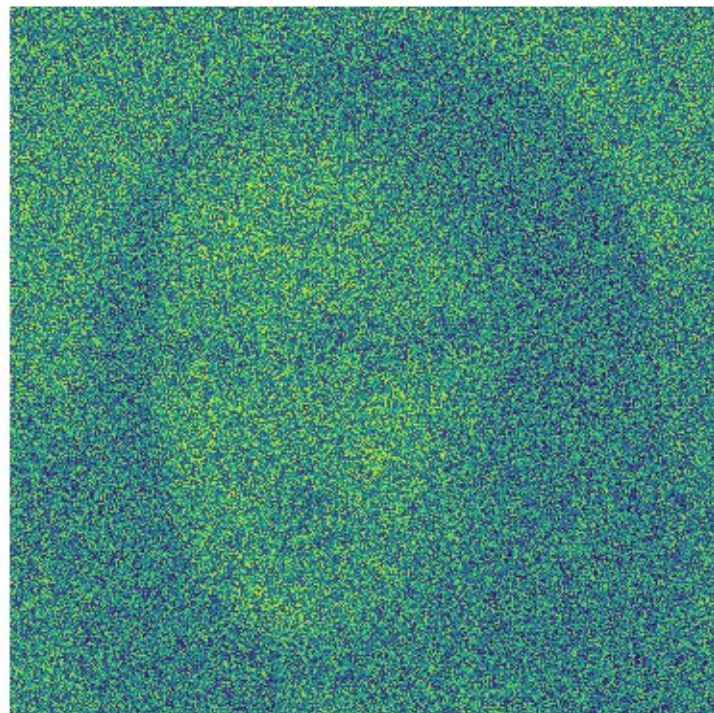
942	509	688	1093	703	416	664	762	664	822	457	400	614	648	243	218	852	459	524	660
158	503	226	1016	322	632	168	419	1015	772	893	774	765	237	161	575	351	244	806	584
692	817	305	168	139	693	507	1121	868	181	943	310	622	345	391	609	1060	1058	1002	401
1050	826	399	1002	1031	140	310	750	394	924	321	425	524	225	428	633	439	686	587	413
787	1103	1012	157	839	632	917	256	677	631	419	1014	239	398	951	223	1042	637	577	843
781	512	994	343	1084	941	343	632	234	518	850	1021	367	310	726	773	672	493	914	506
516	240	575	790	159	657	983	587	933	170	1010	1106	601	868	872	337	1032	533	452	963
464	902	456	976	943	279	797	1008	341	679	585	1011	569	584	775	740	505	497	690	944
179	295	928	549	593	850	375	1068	343	436	535	171	931	557	382	1083	781	536	902	781
1119	648	590	617	221	622	149	978	487	154	763	1088	942	941	1032	411	642	912	199	958
443	150	619	614	747	452	415	502	240	767	160	1066	907	978	1043	382	240	563	939	904
278	684	1080	582	291	580	1100	701	957	287	650	453	573	730	714	412	311	407	1048	275
813	520	997	277	308	1069	1082	235	230	1031	972	658	1033	805	869	344	228	586	144	665
1027	540	1067	293	851	269	274	435	1069	869	941	208	163	1079	887	974	265	733	223	1009
610	546	628	732	218	184	827	412	942	492	624	348	950	676	471	1114	515	355	821	264
621	328	734	905	340	875	1056	1102	1038	130	338	918	945	174	931	1005	884	1054	158	767
511	209	1108	378	1064	478	203	739	868	615	541	641	697	571	920	430	908	299	666	638
728	151	217	404	481	884	231	705	301	908	295	1091	865	169	806	757	1098	913	1082	942
221	715	474	329	560	738	1044	672	531	412	224	284	1127	198	602	464	393	385	293	608
778	1045	1005	689	328	718	395	202	656	1040	489	756	459	582	1010	951	442	731	540	1023

...

⋮

942	509	688	1093	703	416	664	762	664	822	457	400	614	648	243	218	852	459	524	660
158	503	226	1016	322	632	168	419	1015	772	893	774	765	237	161	575	351	244	806	584
692	817	305	168	139	693	507	1121	868	181	943	310	622	345	391	609	1060	1058	1002	401
1050	826	399	1002	1031	140	310	750	394	924	321	425								
787	1103	1012	157	839	632	917	256	677	631	419	1014								
781	512	994	343	1084	941	343	632	234	518	850	1021								
516	240	575	790	159	657	983	587	933	170	1010	1106								
464	902	456	976	943	279	797	1008	341	679	585	1011								
179	295	928	549	593	850	375	1068	343	436	535	171								
1119	648	590	617	221	622	149	978	487	154	763	1088								
443	150	619	614	747	452	415	502	240	767	160	1066								
278	684	1080	582	291	580	1100	701	957	287	650	453								
813	520	997	277	308	1069	1082	235	230	1031	972	658								
1027	540	1067	293	851	269	274	435	1069	869	941	208								
610	546	628	732	218	184	827	412	942	492	624	348								
621	328	734	905	340	875	1056	1102	1038	130	338	918								
511	209	1108	378	1064	478	203	739	868	615	541	641								
728	151	217	404	481	884	231	705	301	908	295	1091								
221	715	474	329	560	738	1044	672	531	412	224	284								
778	1045	1005	689	328	718	395	202	656	1040	489	756								

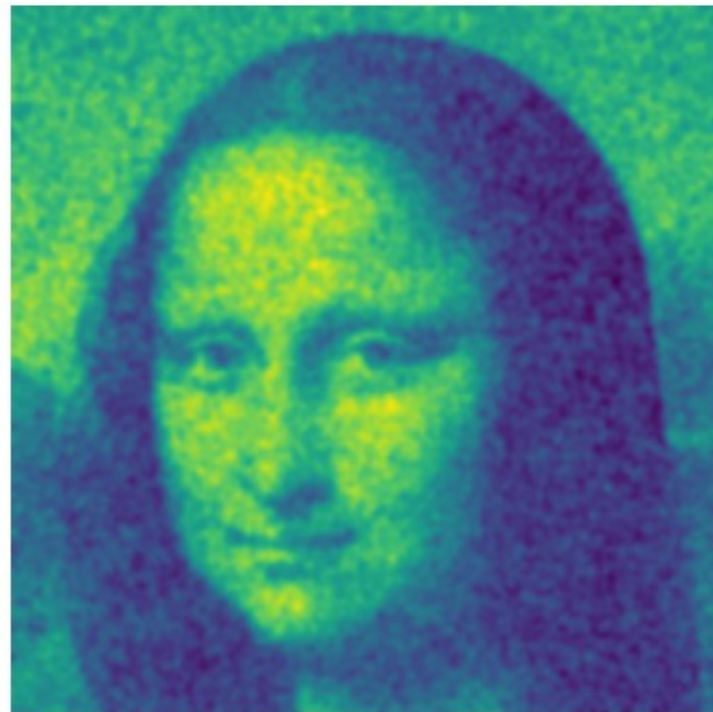
⋮



2D plot

942	509	688	1093	703	416	664	762	664	822	457	400	614	648	243	218	852	459	524	660
158	503	226	1016	322	632	168	419	1015	772	893	774	765	237	161	575	351	244	806	584
692	817	305	168	139	693	507	1121	868	181	943	310	622	345	391	609	1060	1058	1002	401
1050	826	399	1002	1031	140	310	750	394	924	321	425								
787	1103	1012	157	839	632	917	256	677	631	419	1014								
781	512	994	343	1084	941	343	632	234	518	850	1021								
516	240	575	790	159	657	983	587	933	170	1010	1106								
464	902	456	976	943	279	797	1008	341	679	585	1011								
179	295	928	549	593	850	375	1068	343	436	535	171								
1119	648	590	617	221	622	149	978	487	154	763	1088								
443	150	619	614	747	452	415	502	240	767	160	1066								
278	684	1080	582	291	580	1100	701	957	287	650	453								
813	520	997	277	308	1069	1082	235	230	1031	972	658								
1027	540	1067	293	851	269	274	435	1069	869	941	208								
610	546	628	732	218	184	827	412	942	492	624	348								
621	328	734	905	340	875	1056	1102	1038	130	338	918								
511	209	1108	378	1064	478	203	739	868	615	541	641								
728	151	217	404	481	884	231	705	301	908	295	1091								
221	715	474	329	560	738	1044	672	531	412	224	284								
778	1045	1005	689	328	718	395	202	656	1040	489	756								

⋮



smoothing + 2D plot

Python code for the above operations

Python code

```
img = plt.imread('image-noise.tif')
```

→ read image

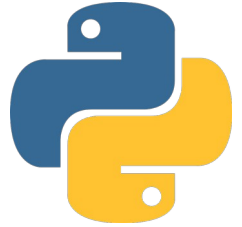
```
imgNew = gaussian_filter(img, sigma=10)
```

→ apply Gaussian filter

```
ax.imshow(imgNew)
```

→ plot/display image


What is Python ?



- modern programming language (since 1991)
- interpreted language (no compilation necessary)
- emphasis is put on the readability of the code
- concepts can be expressed in less lines compared to C/C++ or Java
- extensive libraries available
- build-in visualization

Python - modern programming language

Most popular programming languages in 2020



Rank	Language	Type	Score
1	Python	🌐 🖥️ ⚙️	100.0
2	Java	🌐 📱 🖥️	96.3
3	C	📱 🖥️ ⚙️	94.4
4	C++	📱 🖥️ ⚙️	87.5
5	R	🖥️	81.5
6	JavaScript	🌐	79.4
7	C#	🌐 📱 🖥️ ⚙️	74.5
8	Matlab	🖥️	70.6
9	Swift	📱 🖥️	69.1
10	Go	🌐 🖥️	68.0

[Source : IEEE Spectrum]

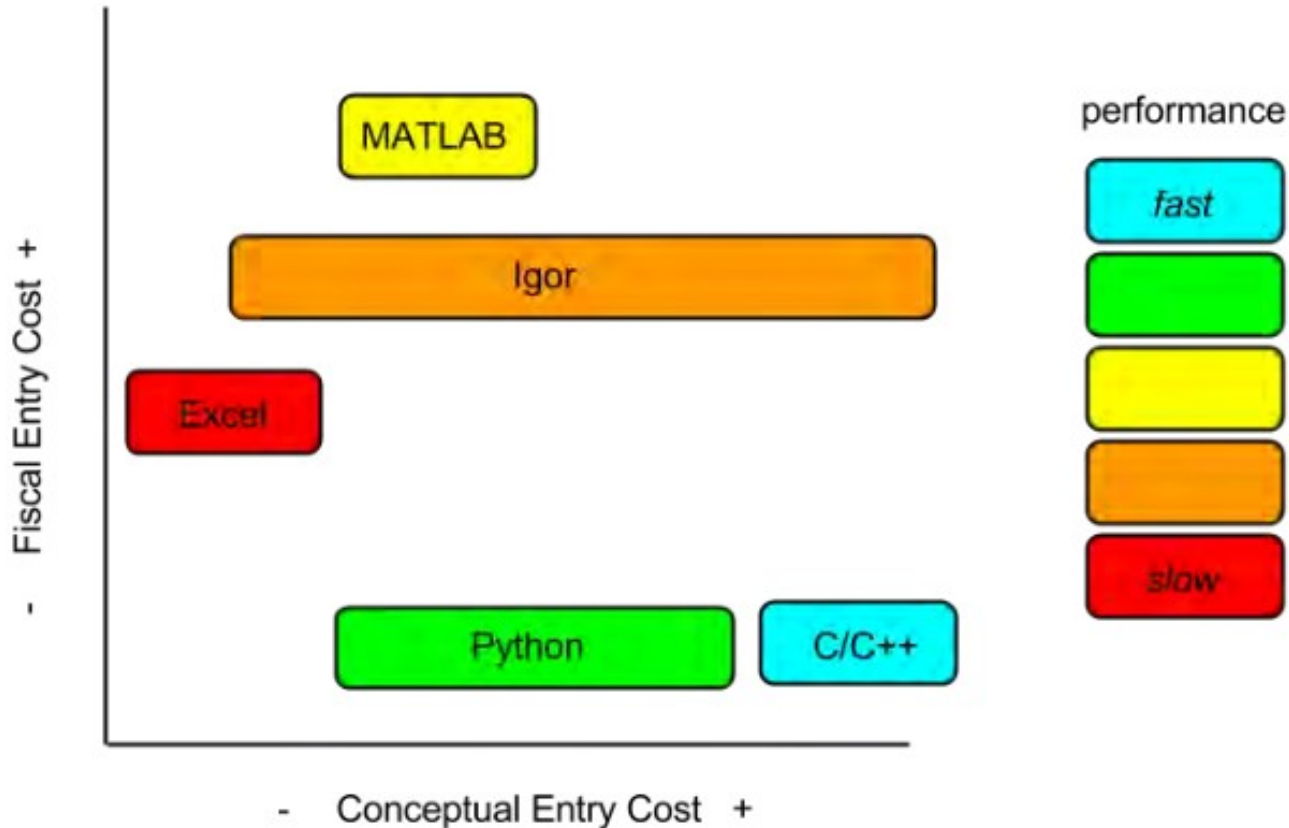
Clear and readable syntax → easy to learn

```
In [1]: 1 # import modules
        2 import numpy as np
        3
        4 # function declaration
        5 def update_values(x):
        6     return x+1
        7
        8 x = 1
        9 if x>0:
       10     print('Hello World!')
       11     x = update_values(x)
       12
       13 print(x)
```

Hello World!

2

Python - free and easy to learn



Extensive standard and third-party libraries

- **wxPython** : graphical toolbox library for GUI development
- **SymPy** : library for symbolic mathematics : can do algebraic evaluations, differentiation, expansions, complex numbers, etc.
- **Pygame** : library for 2D game development
- **Twisted** : major tool for development of network applications
- **OpenCV** : library for extensive computer vision applications

Python modules for Neuroscience applications

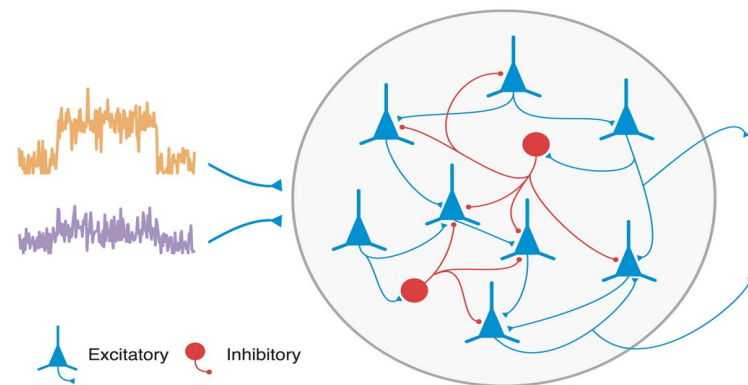
- simulators and simulator interfaces
- data collection and analysis
- sharing, re-use, storage and databasing of data and models
- stimulus generation
- parameter search and optimization
- visualization
- VLSI (very-large-scale integration) hardware interfacing
- machine learning

Python in Neuroscience : network simulator

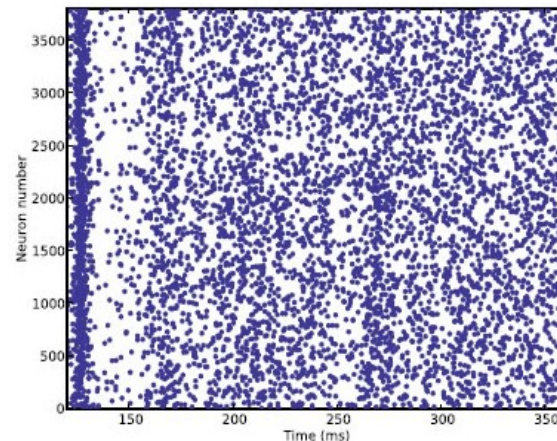
BRIAN

spiking neural network simulator

randomly connected,
recurrent network of
excitatory and inhibitory
neurons



```
1 from brian import *
2 eqs = '''
3 dv/dt = (ge+gi-(v+49*mV))/(20*ms) : volt
4 dge/dt = -ge/(5*ms) : volt
5 dgi/dt = -gi/(10*ms) : volt
6 '''
7 P = NeuronGroup(4000, eqs, threshold=-50*mV, reset=-60*mV)
8 P.v = -60*mV+10*mV*rand(len(P))
9 Pe = P.subgroup(3200)
10 Pi = P.subgroup(800)
11 Ce = Connection(Pe, P, 'ge', weight=1.62*mV, sparseness=0.02)
12 Ci = Connection(Pi, P, 'gi', weight=-9*mV, sparseness=0.02)
13 M = SpikeMonitor(P)
14 run(1*second)
15 raster_plot(M)
16 show()
```

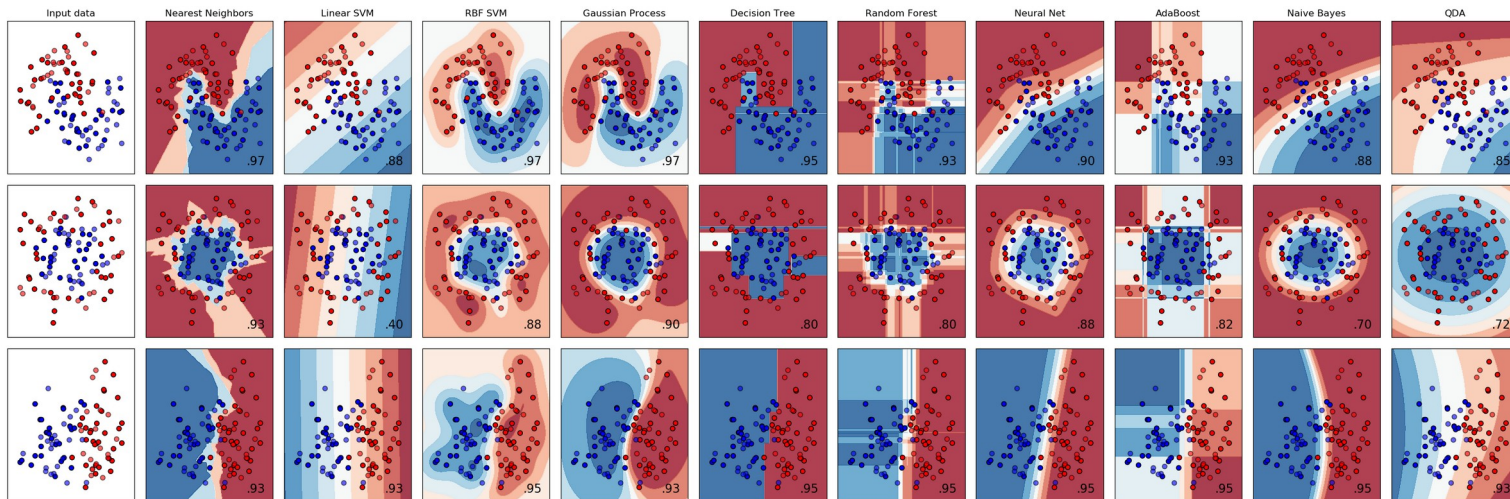


Python in Neuroscience : machine learning



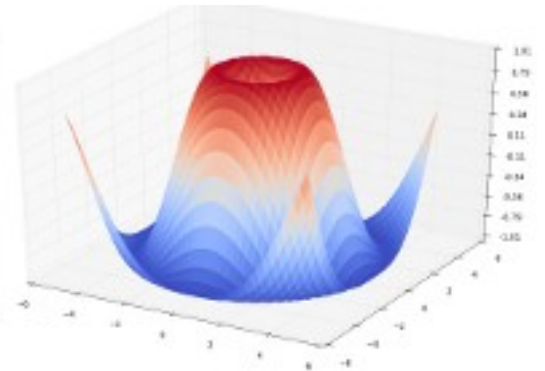
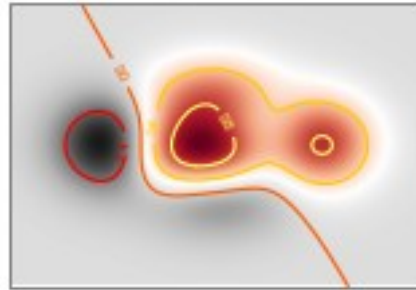
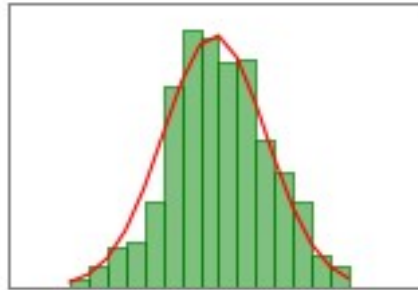
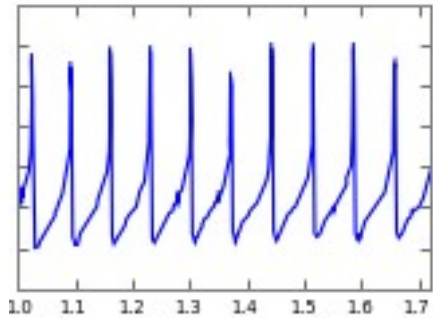
Machine Learning in Python. Simple and efficient tools for data mining and data analysis

e.g. classification
using several
classifiers



Python in Neuroscience : visualization

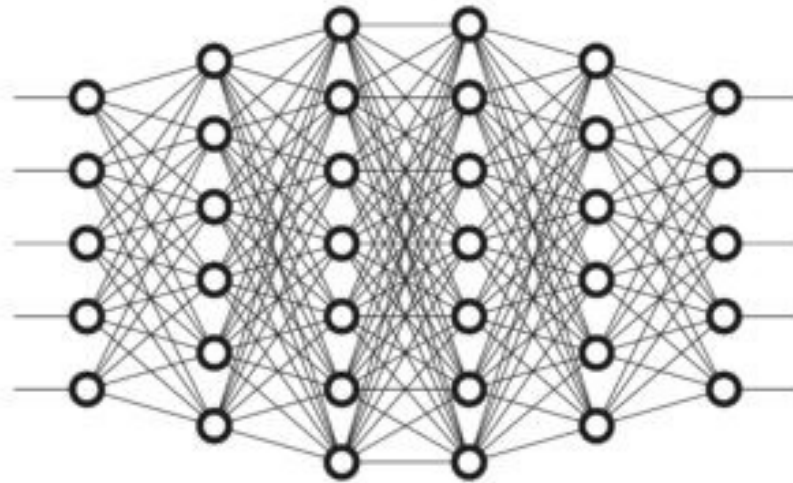
e.g. matplotlib library



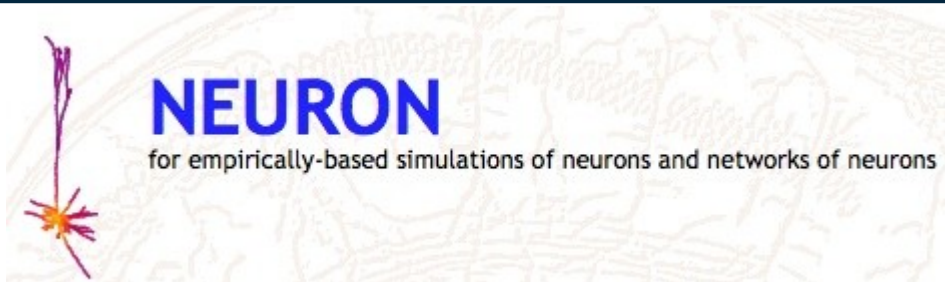
Python in Neuroscience : deep learning/networks



simulate multi-layer networks for deep-learning applications

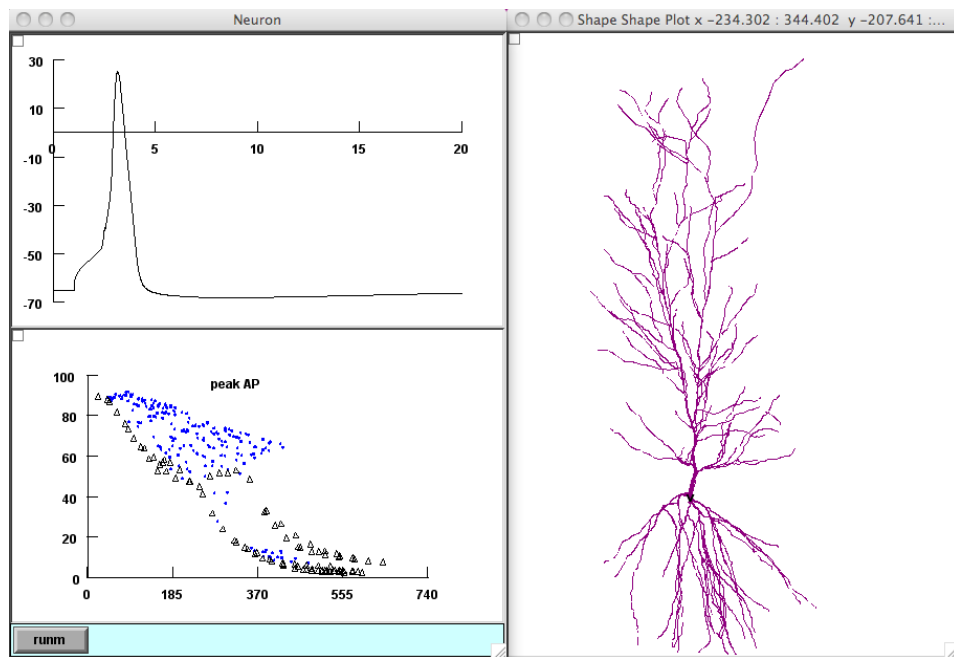


Python in Neuroscience : single neuron simulator



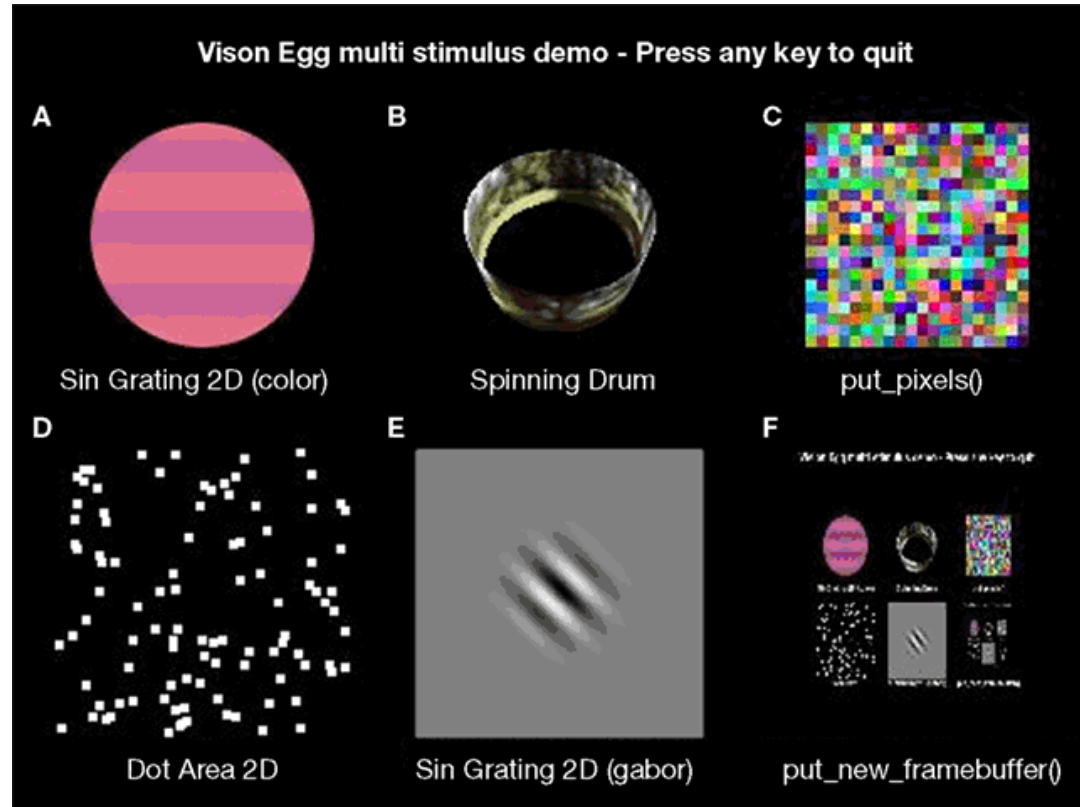
Python interface for NEURON

compartmental model of a
single neurons simulating
the propagation of the
membrane potential



Python in Neuroscience : stimulus generation

e.g. Vision EGG, or PsychoPy



Getting started : Python installation

- Debian + Ubuntu Linux

```
apt-get install python-numpy python-scipy python-matplotlib \
ipython
```

- Windows, Mac OS X (distributions for package handling)

- **Anaconda** from Continuum Analytics : <https://www.continuum.io/downloads>
- Enthought Python : <https://www.enthought.com/>
- Python(x,y) : <http://python-xy.github.io/>

- Mac OS X : Install Fink, then

```
fink install scipy-core-py25 scipy-py25 matplotlib-py25 ipython-py25
```

Getting started : interpreter and IDEs

- **ipython**
 - command line interpreter : interactive shell for enhanced introspection, code highlighting and tab completion
- **Jupyter Notebook**
 - command line interpreter in the browser
 - combines code execution, rich text, and visualizations
- **Spyder** : Scientific PYthon Development EnviRonment
- **PyCharm** : code development environment

IDE ... Integrated Development Environment

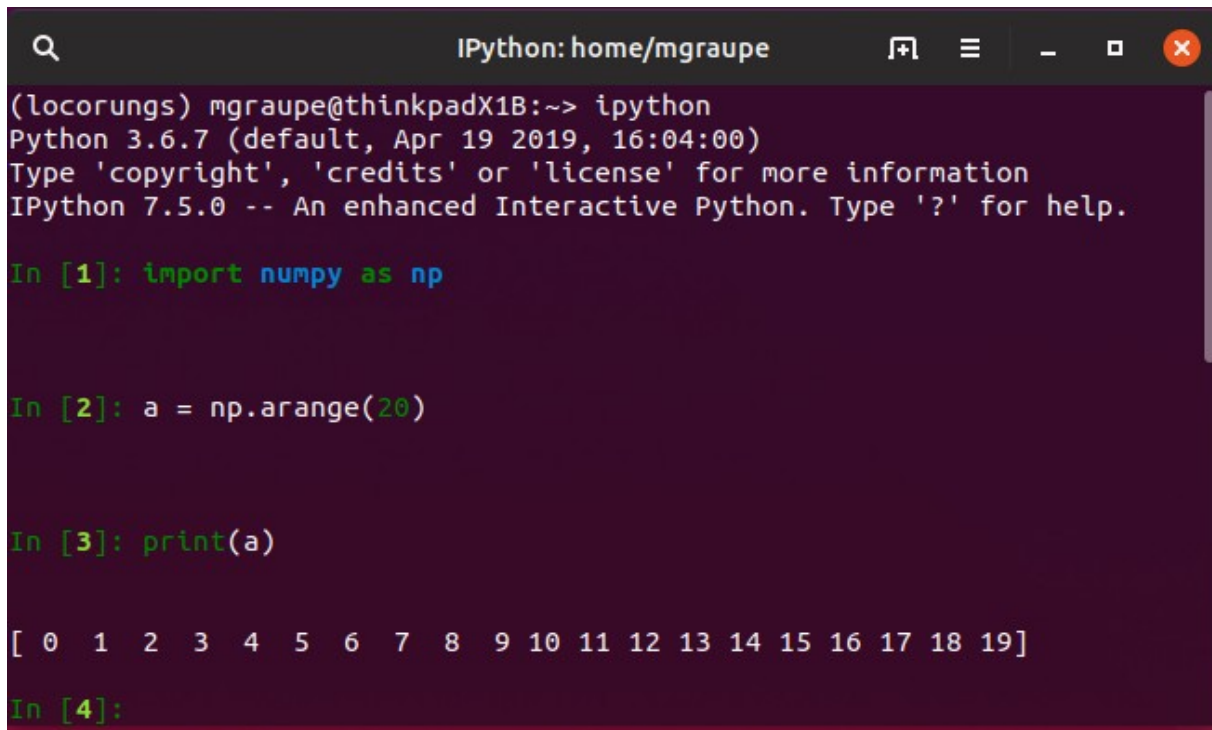
iPython

IP[y]: IPython
Interactive Computing

- Started by typing and executing (by pressing *enter*) **ipython** in the *terminal* application

```
mgraupe@thinkpadx1:~$ ipython
```

- useful for short explorations
- tab completion!

A screenshot of a terminal window titled "IPython: home/mgraupe". The window shows the execution of the 'ipython' command, which starts a Python 3.6.7 shell. The user enters three lines of code: 'import numpy as np', 'a = np.arange(20)', and 'print(a)'. The output of the third line is a list of integers from 0 to 19. The fourth line 'In [4]:' is partially visible at the bottom.

```
(locorungs) mgraupe@thinkpadX1B:~> ipython
Python 3.6.7 (default, Apr 19 2019, 16:04:00)
Type 'copyright', 'credits' or 'license' for more information
IPython 7.5.0 -- An enhanced Interactive Python. Type '?' for help.

In [1]: import numpy as np

In [2]: a = np.arange(20)

In [3]: print(a)

[ 0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19]

In [4]:
```

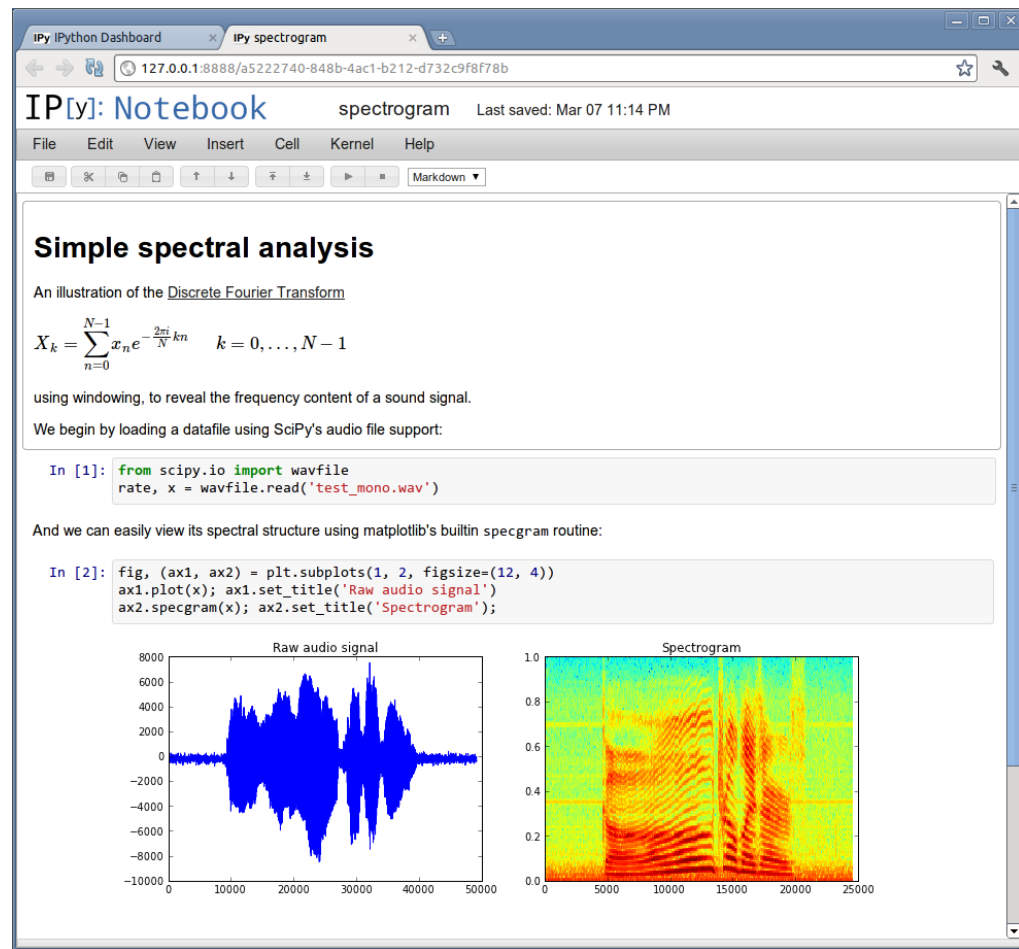
Jupyter Notebook

- Started by typing and executing (by pressing *enter*)

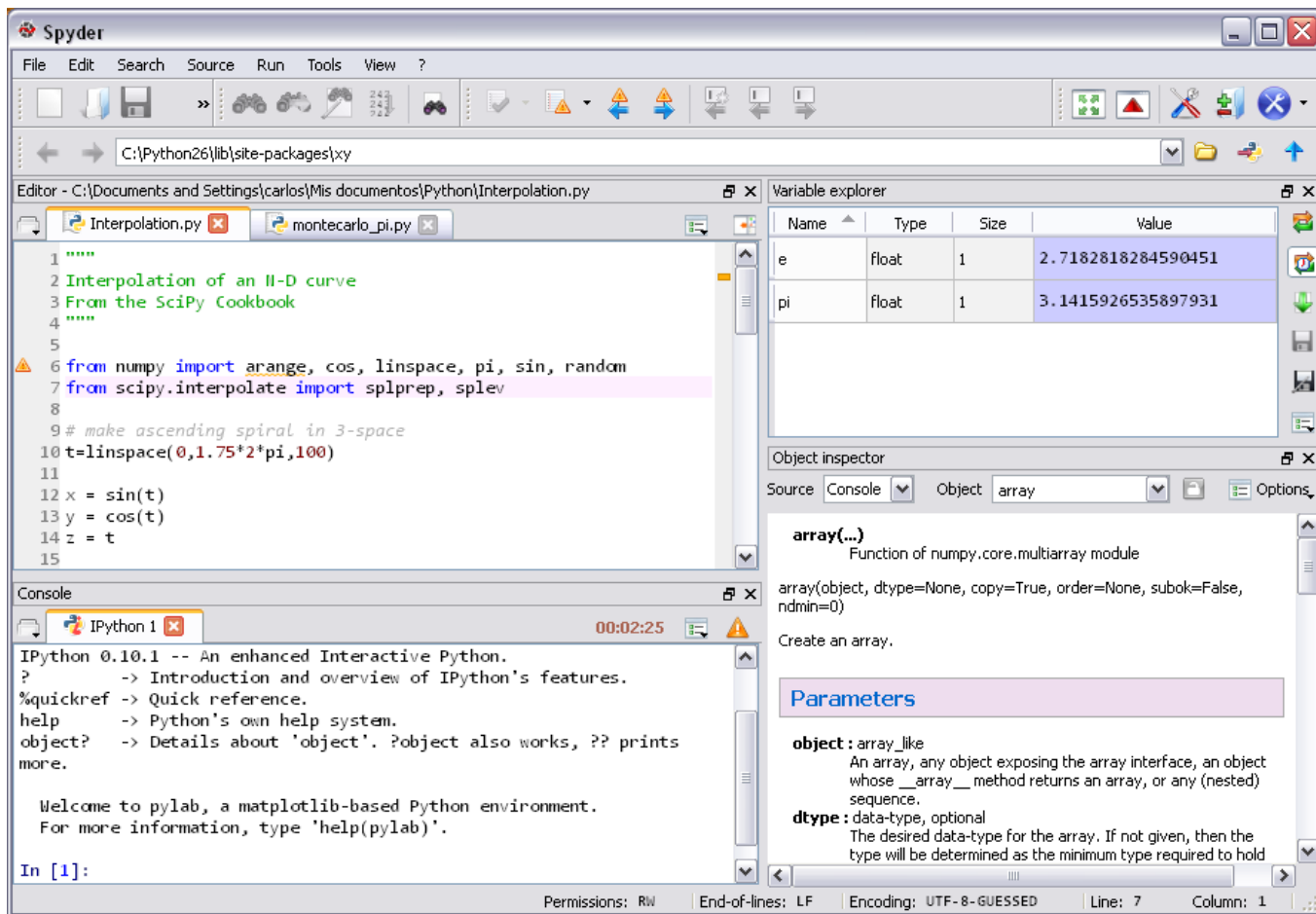
jupyter-notebook in the *terminal* application :

```
mgraupe@thinkpadx1:~$ jupyter-notebook
```

- launched and accessed in a browser (firefox, chrome, safari ...) window



Spyder



The screenshot displays the Spyder Python IDE interface. The main window is titled "Spyder" and contains several panes:

- Editor:** Shows a Python script named "Interpolation.py" with the following code:

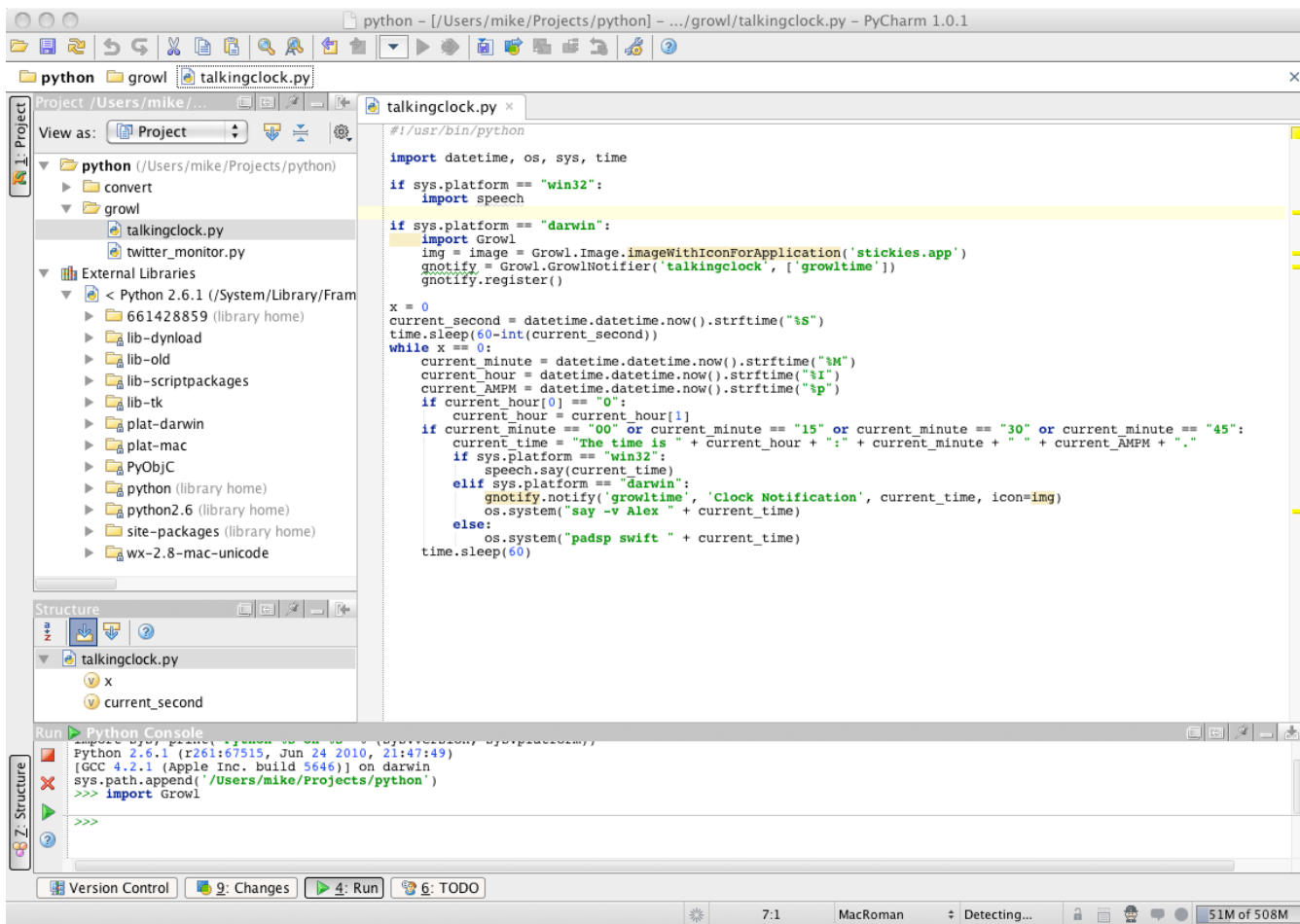
```
1 """
2 Interpolation of an H-D curve
3 From the SciPy Cookbook
4 """
5
6 from numpy import arange, cos, linspace, pi, sin, random
7 from scipy.interpolate import splprep, splev
8
9 # make ascending spiral in 3-space
10 t=linspace(0,1.75*2*pi,100)
11
12 x = sin(t)
13 y = cos(t)
14 z = t
15
```
- Variable explorer:** A table showing variables in the current namespace:

Name	Type	Size	Value
e	float	1	2.7182818284590451
pi	float	1	3.1415926535897931
- Object inspector:** Shows the details of the selected object, "array(...)". It includes the source (Console), object type (array), and a description: "Function of numpy.core.multiarray module". It also lists parameters: "object: array_like" and "dtype: data-type, optional".
- Console:** Displays the IPython 0.10.1 prompt and output. The output includes the IPython version, a list of commands and their descriptions, and a welcome message to pylab.

The status bar at the bottom indicates: Permissions: RW, End-of-lines: LF, Encoding: UTF-8-GUESSED, Line: 7, Column: 1.



PyCharm



Executing Python programs

- Python programs can be run either interactively or as scripts stored in a file
- An interpreter is started by calling **ipython** (or plain **python**, or **jupyter-notebook**)

```
mgraupe@atp:~$ ipython3
Python 3.5.7 (default, Apr  4 2019, 12:02:34)
Type "copyright", "credits" or "license" for more information.

In [1]: print('Hello World!')
Hello World!
In [2]: x = 3
In [3]: print(x+5)
8
In [4]: exit
mgraupe@atp:~$
```

- Scripts are supplied as arguments to the interpreter

```
mgraupe@thinkpadx1:~> python hello_world.py
Hello world!
```

Online resources : introductions and references

- The Python documentation index :
<https://docs.python.org/3.6/>
- Python library reference :
<https://docs.python.org/3.6/library/>
- Dive into Python :
<http://histo.ucsf.edu/BMS270/diveintopython3-r802.pdf>
- Activestate Python [popular Python recipes] :
<http://code.activestate.com/recipes/langs/python/>
- Python tutorial :
<https://docs.python.org/3.6/tutorial/index.html>
- Numpy tutorial :
<http://www.time.mk/trajkovski/teaching/imi/2010-fall/NumPy/Tentative%20NumPy%20Tutorial%20-.html>
- Scipy reference :
<http://docs.scipy.org/doc/scipy/reference/genindex.html>

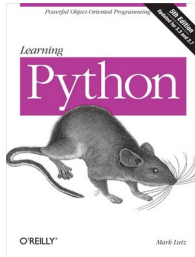
Online resources : general

- a simple Google search :
 - use the keyword “python”
 - specify your operating system (*window, linux, mac*) for package installation, importing queries
 - use the “correct” terminology for code questions
 - common sites for useful help : *stackoverflow, askubuntu, github*

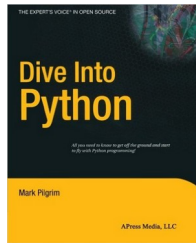
Online resources : Neuroscience

- Front Neuroinform 2015 – *Python in Neuroscience*
<http://journal.frontiersin.org/article/10.3389/fninf.2015.00011/full>
- BCCN cours - *Advanced Scientific Programming in Python* :
<https://python.g-node.org/wiki/schedule>
- Brian simulator :
<http://briansimulator.org/>

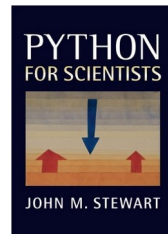
General Python books



- Learning Python, 5th Edition
Mark Lutz
ISBN : 978-1-4493-5573-9

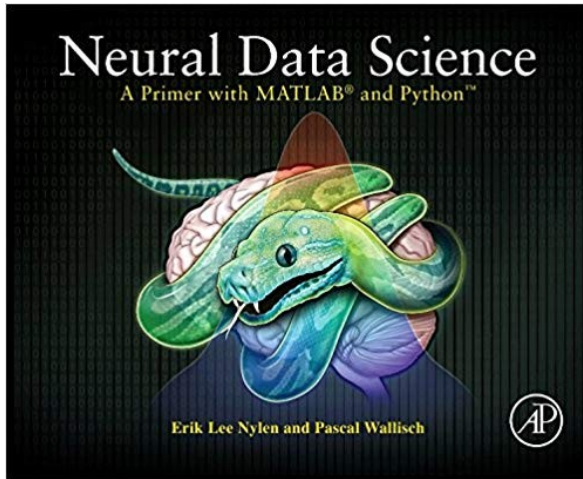


- Dive Into Python (3)
Mark Pilgrim
ISBN: 978-1590593561 (978-1430224150)




- Python for Scientists
John M. Stewart
ISBN: 978-1107686427

Neuroscience specific book




- Neural Data Science
A primer with Matlab and Python
Erik Lee Nylen (Author), Pascal Wallisch (Author)
ISBN-10: 9780128040430

Workflow of the course lecture

- 1) All course material** (.pdf file of lecture; .ipynb for tutorial; .ipynb for homework assignment) can be accessed on github (code repository site) :
<https://github.com/mgraupe/DataSciPy2020>
- 2) Visit course website** : Launch the browser ( “Navigateur Web”) and navigate to the link above
- 3) Download lecture** : Click on lecture link and hit the **Download** button (file will be downloaded automatically to the downloads – Téléchargements – folder); annotate lecture PDF

Workflow of the course tutorial

- 1) **Tutorial material** : can be accessed on github, launch the browser (Navigateur Web) and got to:
<https://github.com/mgraupe/DataSciPy2020>
- 2) **Save tutorial file** : Click on the tutorial link, hit the **Raw** button (the raw file content will be displayed), save (Enregistrer sous ...) the raw file to your computer, make sure that the file ending remains **.ipynb**
- 3) **Launch jupyter-notebook** : Start the **terminal** application ( “Emulateur de Terminal”) on your computer, launch the notebook environment by typing and executing **\$ jupyter-notebook** , the jupyter environment starts up in the browser in the directory in which it was started
- 4) **Load the jupyter-notebook file** : In the jupyter environment, you first see the directory and file structure on your computer (relative to the directory in which jupyter was started), **navigate** to the downloaded **.ipynb** file and click on it to launch it
- 5) **Start editing**