

Week 1: overview / review

**NRSC 7657 Workshop in Advanced Programming for
Neuroscientists**

Course outline

- Python and MATLAB
- Didactic and practical
 - Language specifics
 - General concepts in computing (version control, debugging, unit testing, scaling)
- Independent project
 - Work with real data; preferably your own (whatever it is!) or choose a public data set (see next slide)
 - Develop an idea; ****Schedule a meeting with Dan this week****

Week 1 – overview / review	Course overview: theory of computing, landscape of computing options. Basic usage in python and MATLAB; basic data types; environments Style guidelines (ten simple rules); git and version control
Week 2 – language fundamentals	Functions; Objects and Classes; Workspaces Typical data formats: working with tabular data, images, and time series. NeurodataWithoutBorders format
Week 3 – workflow management and outputs	Importing and exporting Plotting and visualization - from bar charts to 3D animation
Week 4 – usability	Troubleshooting and debugging; unit testing
Week 5 – scaling	Iteration and code profiling; parallel computing. Code quality-of-life topics
Week 6 – collaboration	Cloud-based tools: AWS, GCC, Colab, jupyterhub, deepnote. Overview of some available SAAS tools, python focused. Group programming time
Week 7 – applications/flex topic	Applications: image processing (ES) Group programming time
Week 8 – applications/flex topic	Applications: spike sorting (DD) Group programming time
Week 9 – applications/flex topic	Applications: flex Group programming time
Week 10 – Final presentations and code review	Final pres. and code review Final pres. and code review

Project datasets

- Yours!
- Someone from your lab

Public datasets

(Suggestions, incomplete list)

- Allen Institute for Brain Science brain-map.org
- DABI Data Archive BRAIN Initiative <https://dabi.loni.usc.edu/home>

The screenshot shows a grid of project datasets. The first row contains three items: 'Transcriptional Landscape of the Brain' (with an icon of a brain grid), 'Behavioral Circuits & Sensory Processing' (with an icon of brain waves), and 'Connectivity Matrices' (with an icon of a brain network). The second row contains two items: 'Computational Modeling & Theory' (with an icon of a brain model) and 'Cell Taxonomies' (with an icon of a brain cell). Each item has a brief description and a blue 'Explore' button.

The screenshot shows a 'MENU' bar with options like 'Explore Studies' and 'Explore by Interest'. Below it is a 'Explore Data' section with a search bar labeled 'Search Interests'. A list of studies is shown, including 'Adaptive Neurostimulation to Restore...' by University of Colorado (Thompson). A call-to-action button 'Open' is visible. On the right, there are navigation icons for 'Build Cohorts' and 'Explore by study by areas of interest'. Numbered circles (1, 2, 3) are overlaid on the bottom right corner.

What this course is ****not****

- Computational neuroscience
- Mathematics
- Computer science

What this course is

Each session:

- Some slides (0 - 60 minutes)
- Working through a notebook or interactive coding together
- Independent coding. We're going to do your science, with a computer. Maybe your computer, or maybe a cloud computer.

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Ask questions!



Goals of this course

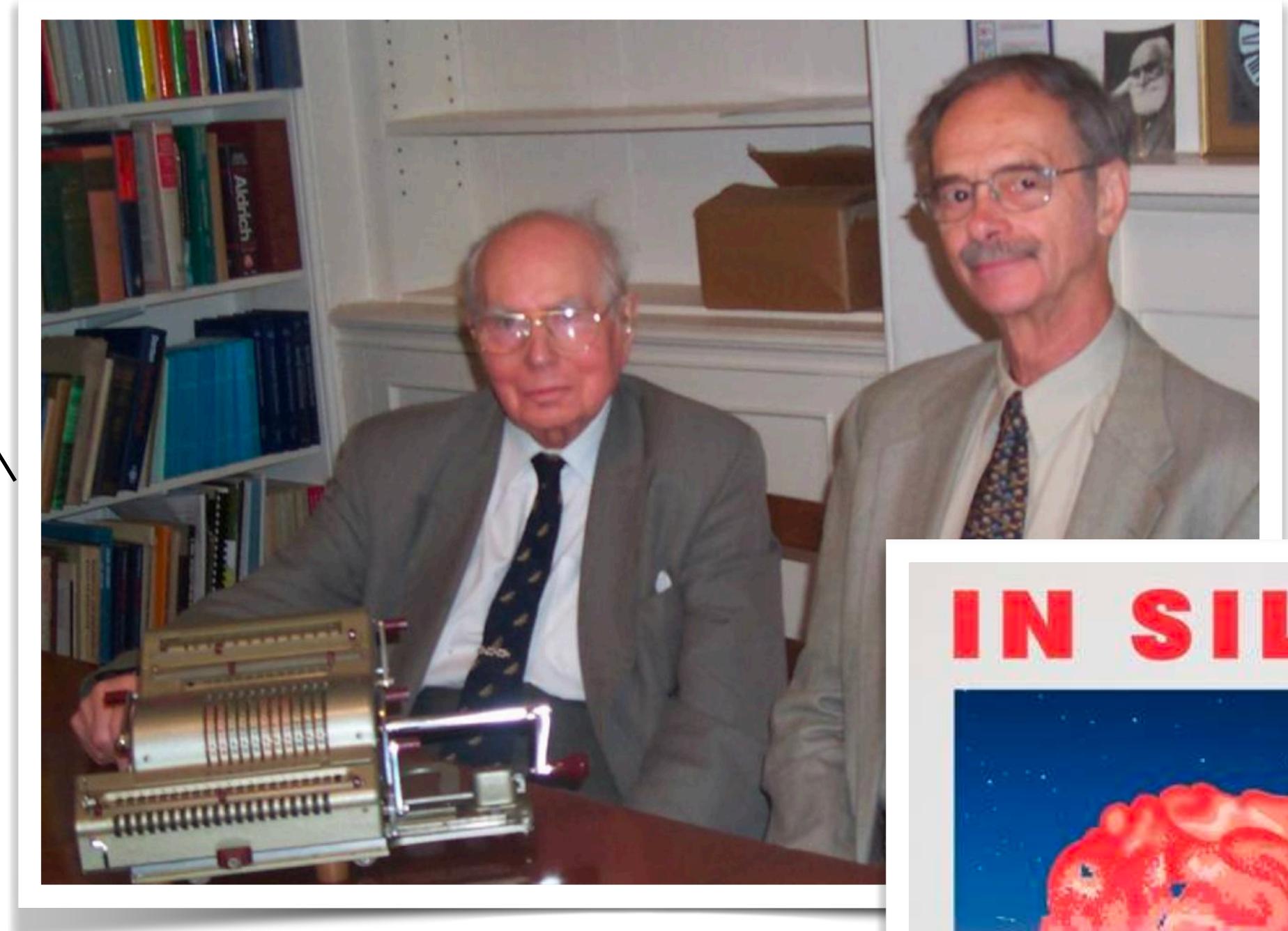
- Exposure to differing approaches in neuroscience
- Develop confidence in independent coding skills
- Complete a project using data relevant to your thesis work

Final practicalities

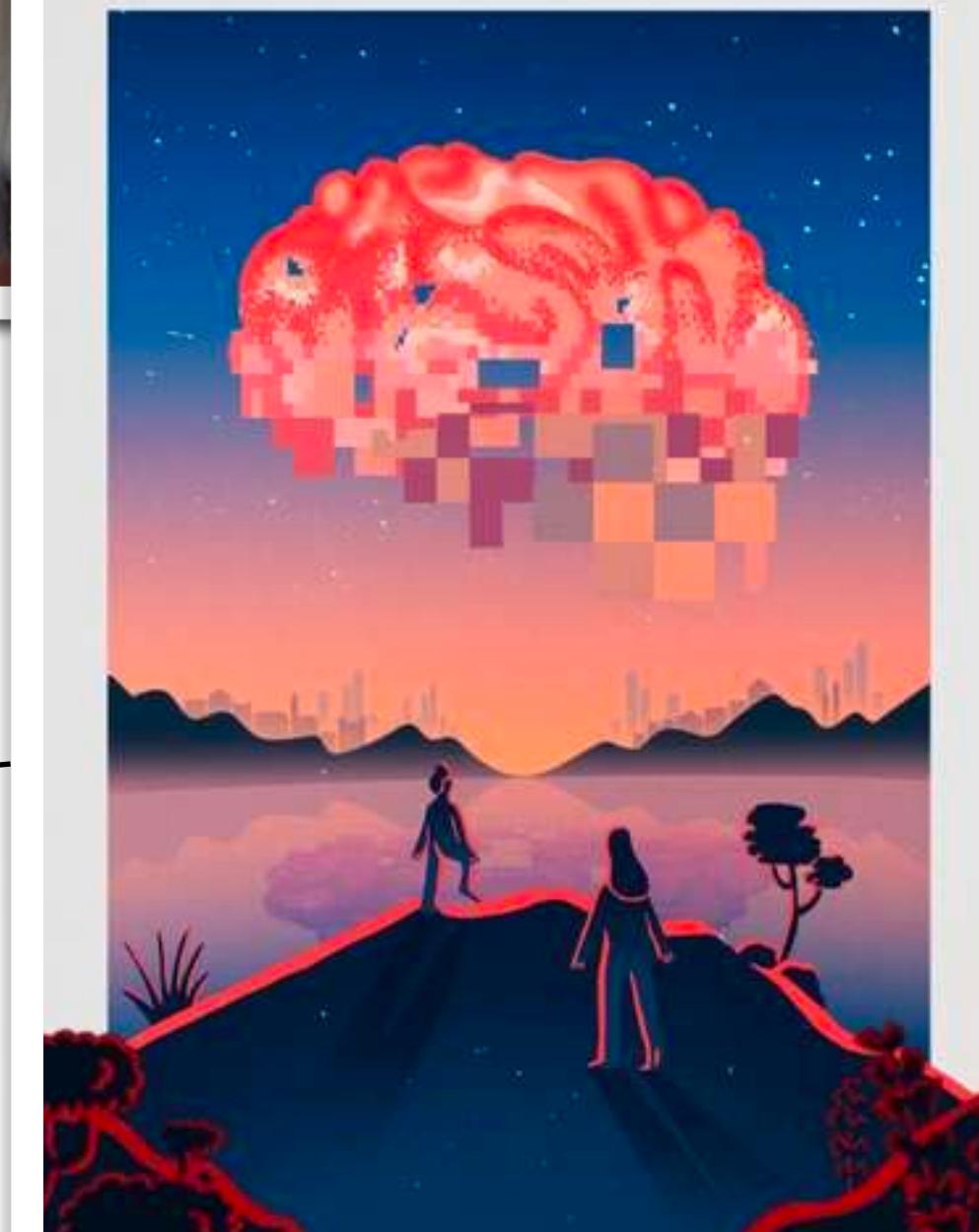
- GitHub

Computing in neuroscience

- Hodgkin-Huxley's mechanical computer
- Computer based analysis / replacing chart measurements
- NEURON simulations; single neuron modeling
- ...
- “data science”, open data
- Blue brain project, *In silico*



IN SILICO



Computing in neuroscience

An example: code written by neuroscientists for one experiment

planning

Probe trajectory: MATLAB
Model prediction: python - jupyter notebook

experimental control

Acquisition hardware: FPGA gate array programming
Acquisition software: C++; python plugin; [Julia]
Visual stimuli: python script; embedded python in React
Video monitoring: python script

“pre-processing”

Spike sorting: MATLAB
Unit quality: python - jupyter notebook
Depth: python - jupyter notebook

analysis

Histology registration to 3D brain: python
Stimulus responses: python
Population statistics: MATLAB and python

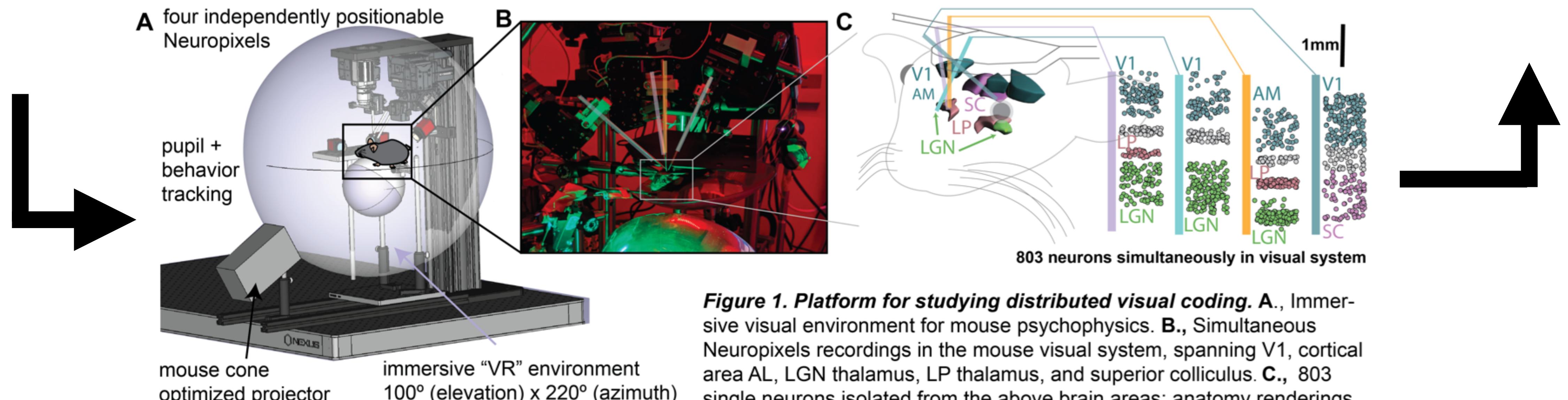


Figure 1. Platform for studying distributed visual coding. **A.**, Immersive visual environment for mouse psychophysics. **B.**, Simultaneous Neuropixels recordings in the mouse visual system, spanning V1, cortical area AL, LGN thalamus, LP thalamus, and superior colliculus. **C.**, 803 single neurons isolated from the above brain areas; anatomy renderings from the Allen Reference Atlas (brain-map.org).

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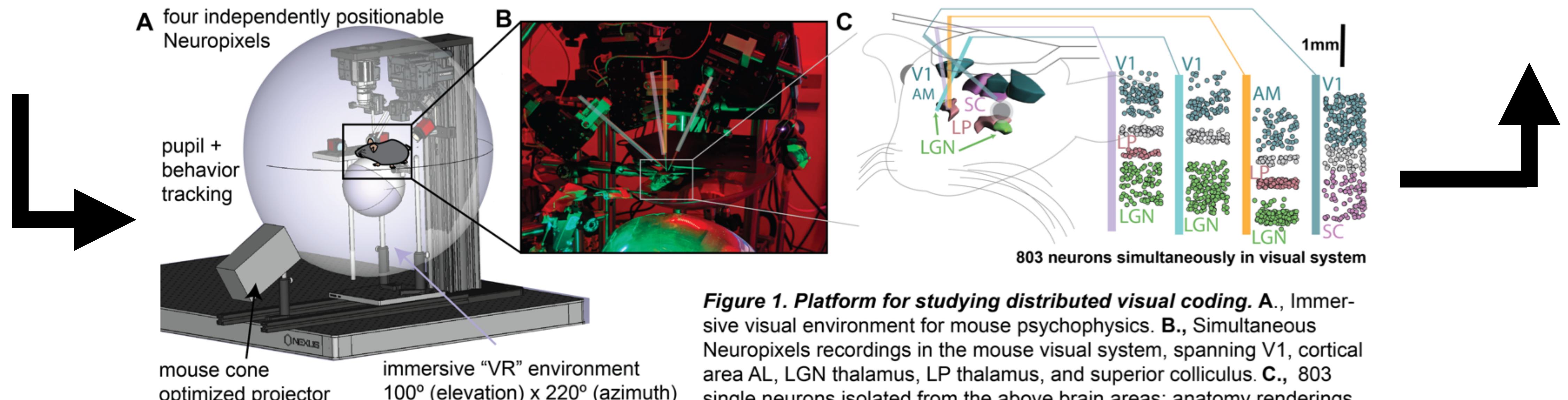


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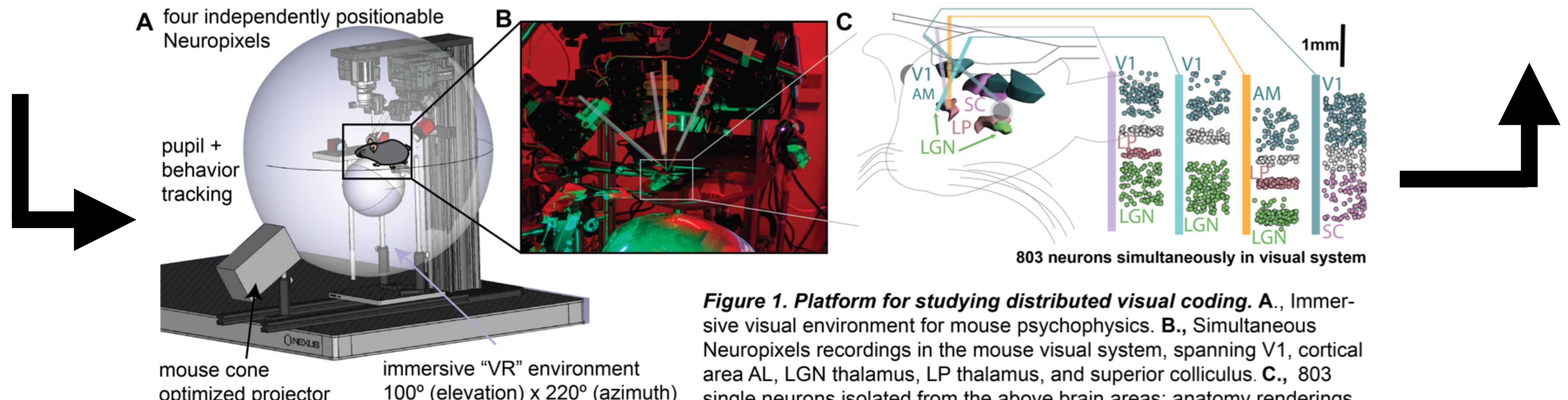
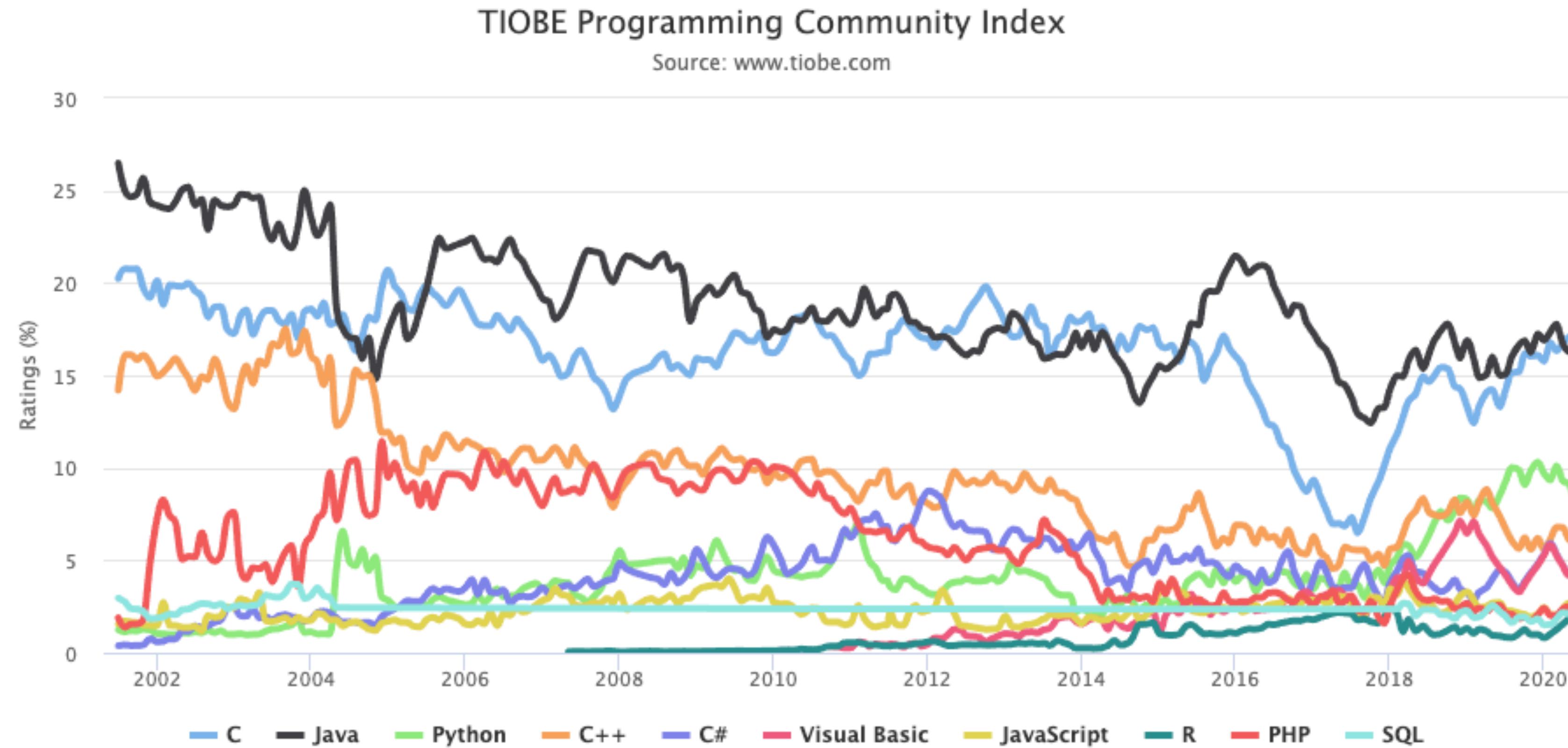


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history: languages used for neuroscience



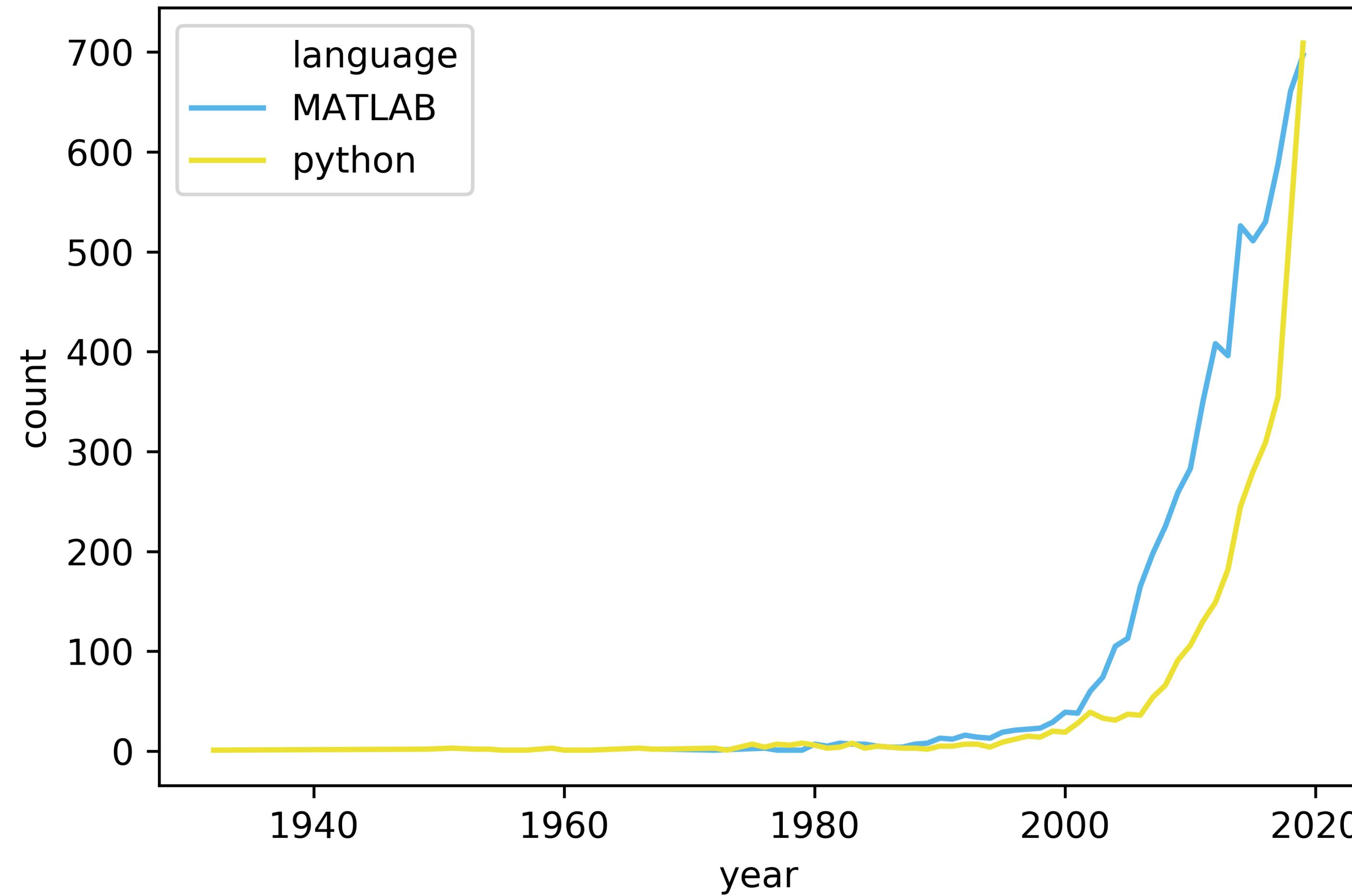
history: languages used for neuroscience

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Aug 2020	Aug 2019	Change	Programming Language	Ratings	Change
1	2	▲	C	16.98%	+1.83%
2	1	▼	Java	14.43%	-1.60%
3	3		Python	9.69%	-0.33%
4	4		C++	6.84%	+0.78%
5	5		C#	4.68%	+0.83%
6	6		Visual Basic	4.66%	+0.97%
7	7		JavaScript	2.87%	+0.62%
8	20	▲	R	2.79%	+1.97%
9	8	▼	PHP	2.24%	+0.17%
10	10		SQL	1.46%	-0.17%
11	17	▲	Go	1.43%	+0.45%
12	18	▲	Swift	1.42%	+0.53%
13	19	▲	Perl	1.11%	+0.25%
14	15	▲	Assembly language	1.04%	-0.07%
15	11	▼	Ruby	1.03%	-0.28%
16	12	▼	MATLAB	0.86%	-0.41%

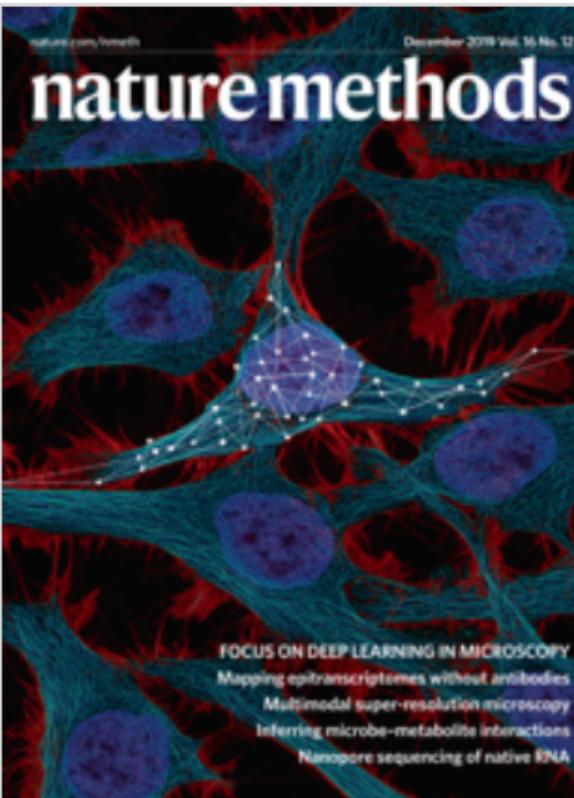
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Volume 16 Issue 12, December 2019



Focus on Deep Learning in Microscopy

Artwork representing the application of deep learning methods in microscopy.

Image: National Institutes of Health/Stocktrek Images/Getty. Cover design: Erin DeWalt

history: languages used for neuroscience

Volume 16 Issue 12, December 2019



Analysis | Published: 21 October 2019

Nucleus segmentation across imaging experiments: the 2018 Data Science Bowl

Juan C. Caicedo, Allen Goodman, Kyle W. Karhohs, Beth A. Cimini, Jeanelle Ackerman, Marzieh Haghghi, CherKeng Heng, Tim Becker, Minh Doan, Claire McQuin, Mohammad Rohban, Shantanu Singh & Anne E. Carpenter

Nature Methods 16, 1247–1253(2019) | [Cite this article](#)

3257 Accesses | 1 Citations | 41 Altmetric | [Metrics](#)

2 out top 3 entries used python

history: languages used for neuroscience

Volume 16 Issue 12, December 2019



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Artwork representing the application of deep learning methods in microscopy.

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**5/7 software papers used python
1 used R
1 used ImageJ (Java)**

history: languages used for neuroscience



nature methods

Article | Published: 27 July 2020

Cumulus provides cloud-based data analysis for large-scale single-cell and single-nucleus RNA-seq

Bo Li , Joshua Gould, Yiming Yang, Siranush Sarkizova, Marcin Tabaka, Orr Ashenberg, Yanay Rosen, Michal Slyper, Monika S. Kowalczyk, Alexandra-Chloé Villani, Timothy Tickle, Nir Hacohen, Orit Rozenblatt-Rosen & Aviv Regev

history

- First released in 1991
- A “scripting” or “high-level” language, designed for readability and productivity
 - simple syntax, use of white space
- Major release: Python 2.7, July 2010
- Use increases
- “data science” after era of “Big Data”
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but, but, biology...why code at all?

- Python was developed to make it easier for people to automate simple tasks (“scripting”)

overview

Some plusses

Some minuses

overview

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- Free
- Readable syntax
- Cross platform
- Huge community
- Used across science *and* outside of science

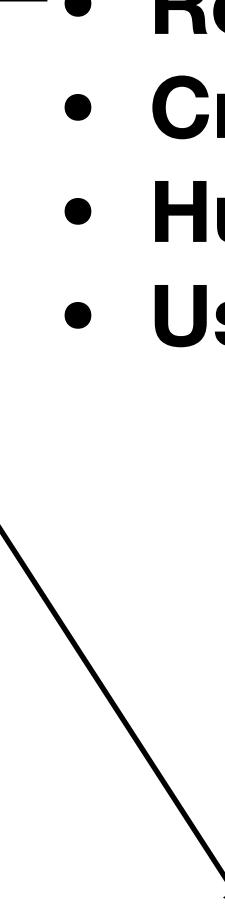
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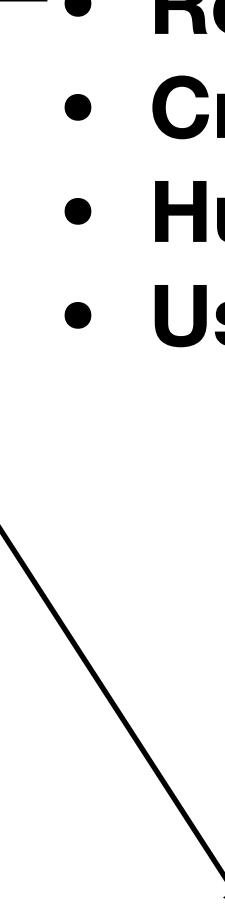
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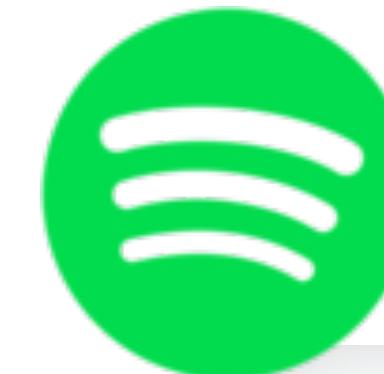
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amazon



aws



NETFLIX



You Tube

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YouTube

overview: packages

Find, install and publish Python packages
with the Python Package Index

Search projects



Or [browse projects](#)

211,372 projects

1,607,586 releases

2,417,893 files

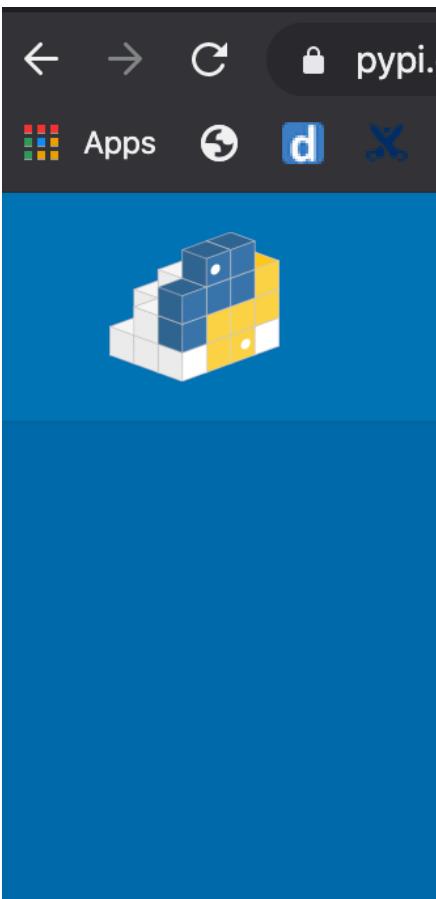
394,404 users

Packages

In addition to the standard library, the true power of python is the extensive world of packages available. These are sets of tools you can use with Python to do just about anything!

Some are general tools, the hammers or screwdrivers of using python for science:
numpy, matplotlib, pandas, seaborn

Others are specialized: **scikit-learn, PIL, scanpy, Suite2P, DeepLabCut, PyTom**



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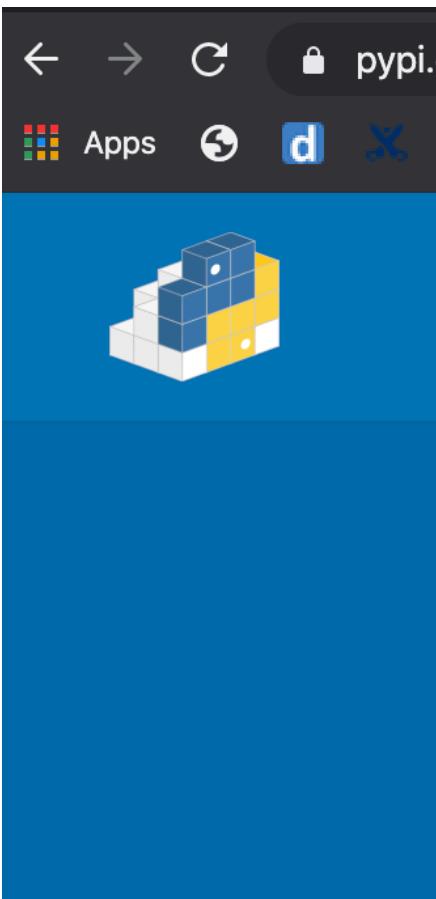
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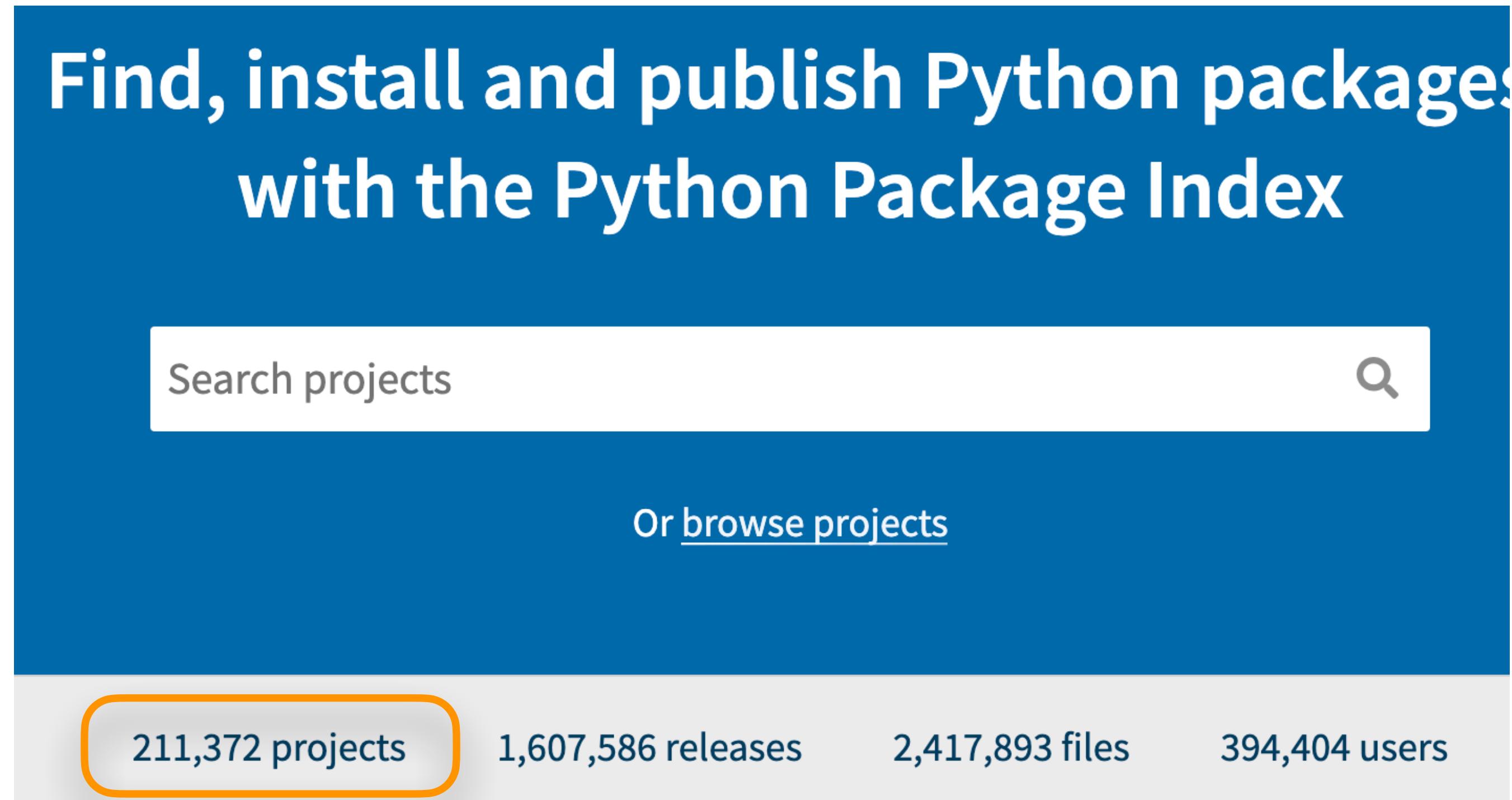
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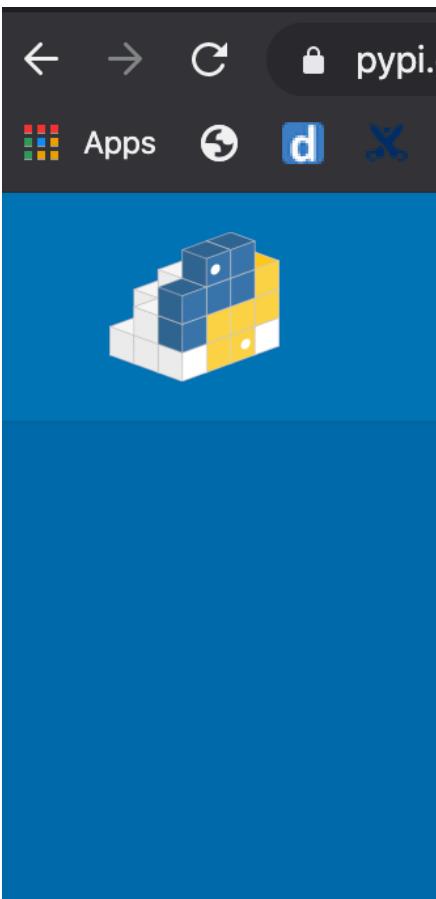


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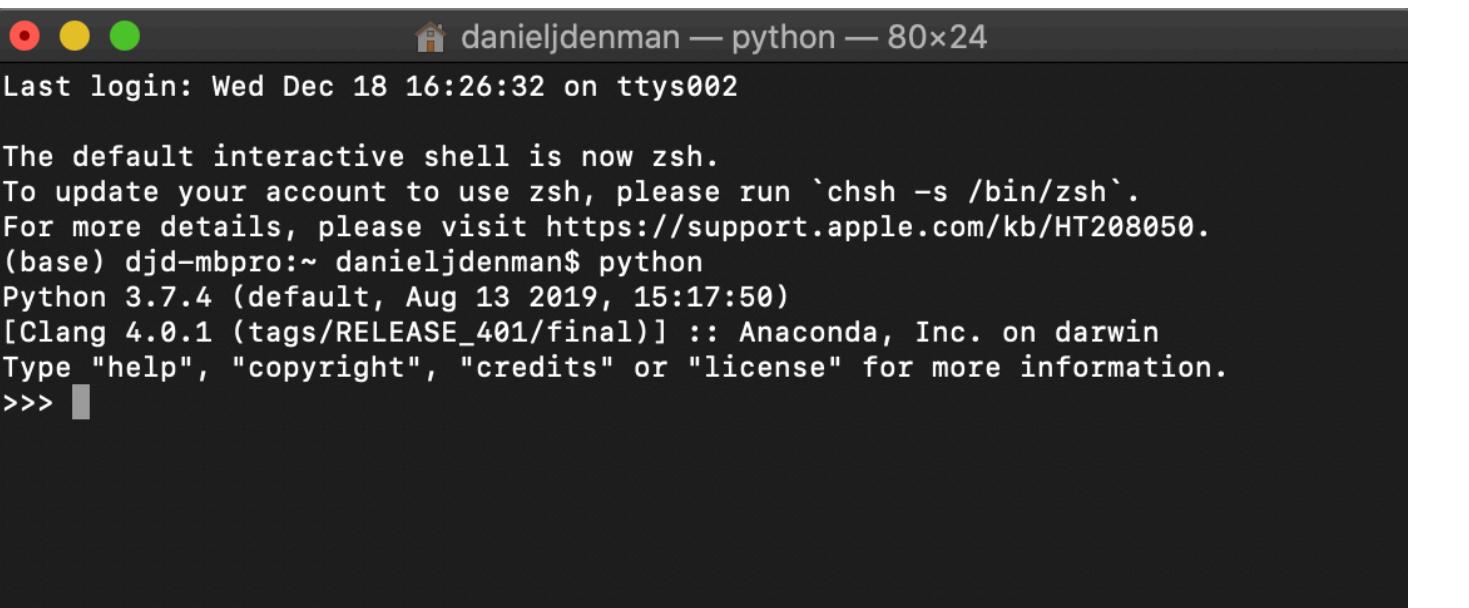


overview: levels



overview: levels

System



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The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
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Python 3.7.4 (default, Aug 13 2019, 15:17:50)
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Type "help", "copyright", "credits" or "license" for more information.
>>> 
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Native in Mac OS X, Linux; in Windows store (free)



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Package Managers Environments





overview: levels

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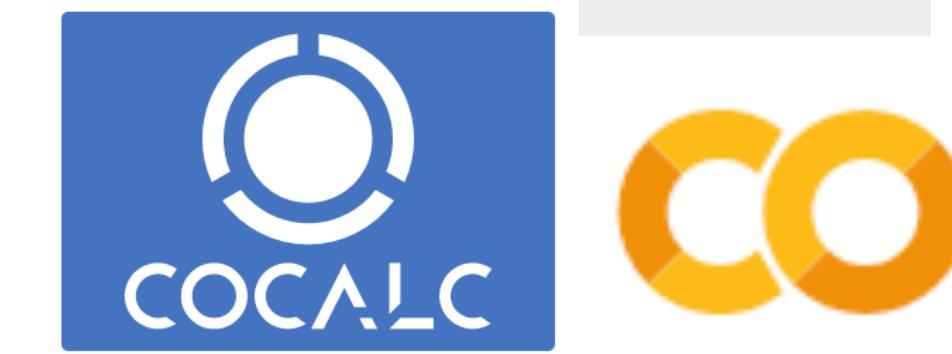
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Package Managers Environments



Containerized





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Scripts

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Users > danieljdenman > github > mouse_tunnel > mouse_tunnel_auto_CUtest.py
 1  from direct.showbase.ShowBase import ShowBase
 2  from direct.task import Task
 3  # from direct.gui.OnscreenText import OnscreenText
 4  # from direct.showbase.DirectObject import DirectObject
 5  from direct.interval.MetaInterval import Sequence
 6  from direct.interval.LerpInterval import LerpFunc
 7  from direct.interval.FunctionInterval import Func
 8  from panda3d.core import Mat4, WindowProperties, CardMaker, NodePath, TextureStage, MovieTexture, MovieVideo
 9
10 import sys,glob,time,datetime,os
11 from math import pi, sin, cos
12 from numpy.random import randint, exponential
13 from numpy import arange,concatenate
14 import numpy as np
15 from pyglet.window import key
16
17 try:
18     from toolbox.toolbox.IO.nidaq import DigitalInput,DigitalOutput, AnalogInput, AnalogOutput
19     have_nidaq=True
20 except:# Exception, e:
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24
25 MOUSE_ID = 'test'
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27 #this is used to change whether the mouse's running and licking control the rewards.
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overview: levels

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Package Managers Environments





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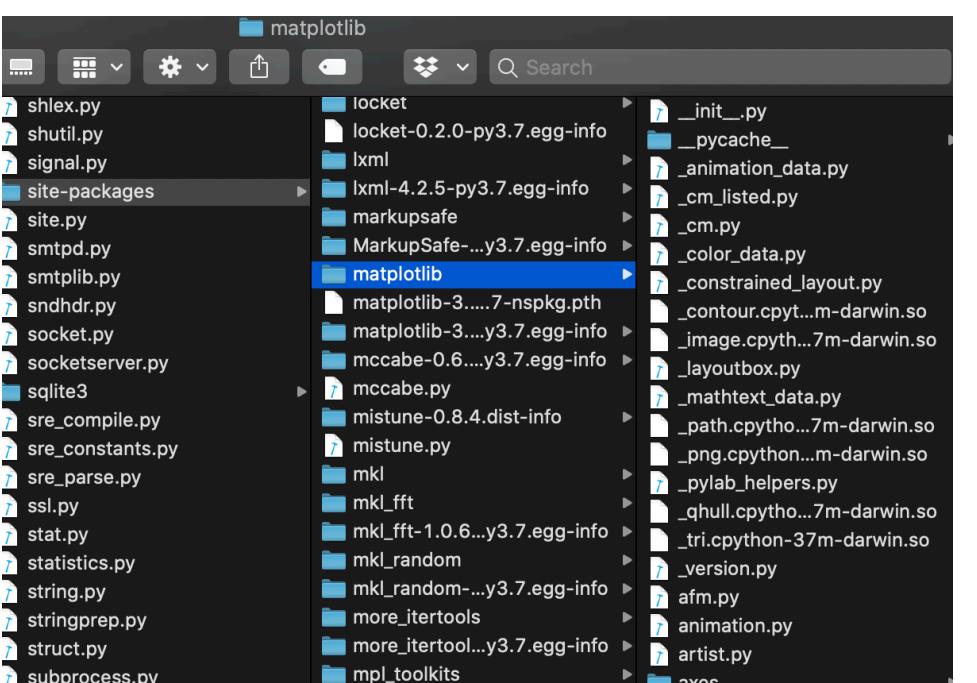
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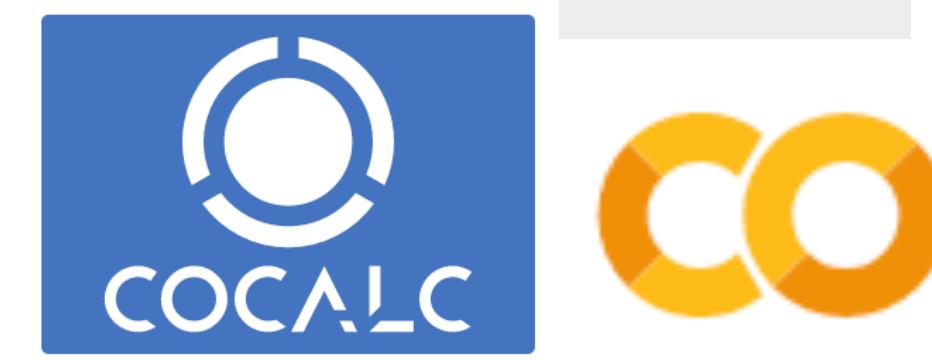


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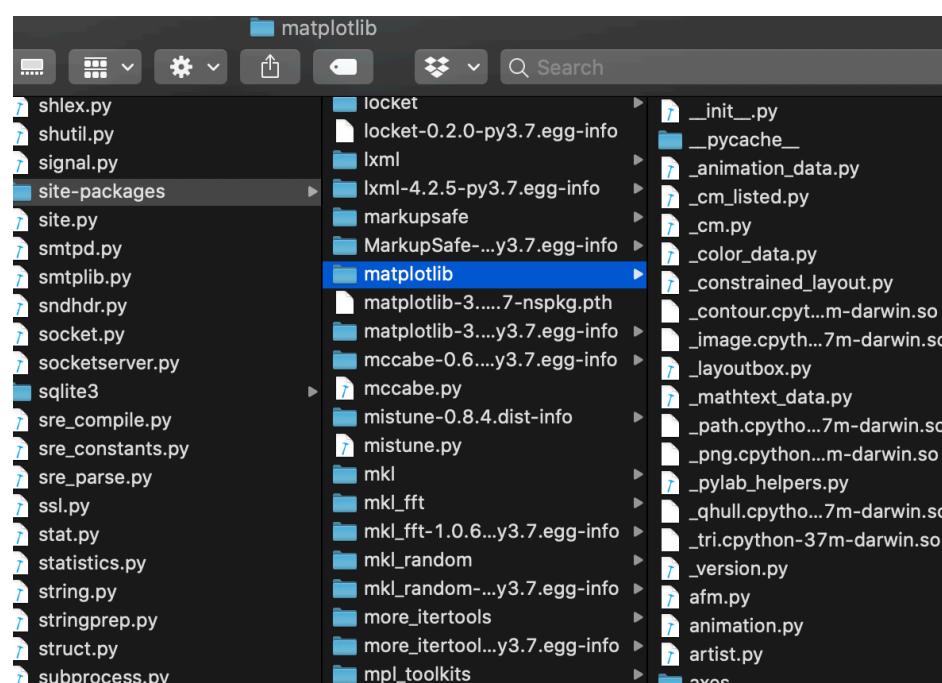
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For more details, please visit https://support.apple.com/kb/HT208050.
(base) djd-mbpro:~ danieljdenman$ python
Python 3.7.4 (default, Aug 13 2019, 15:17:50)
[Clang 4.0.1 (tags/RELEASE_401/final)] :: Anaconda, Inc. on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> 
```

Native in Mac OS X, Linux; in Windows store (free)

Scripts

```
Users > danieljdenman > github > mouse_tunnel > mouse_tunnel_auto_CUtest.py
 1  from direct.showbase.ShowBase import ShowBase
 2  from direct.task import Task
 3  # from direct.gui.OnscreenText import OnscreenText
 4  # from direct.showbase.DirectObject import DirectObject
 5  from direct.interval.MetaInterval import Sequence
 6  from direct.interval.LerpInterval import LerpFunc
 7  from direct.interval.FunctionInterval import Func
 8  from panda3d.core import Mat4, WindowProperties, CardMaker, NodePath, TextureStage, MovieTexture, MovieVideo
 9
10 import sys,glob,time,datetime,os
11 from math import pi, sin, cos
12 from numpy.random import randint, exponential
13 from numpy import arange,concatenate
14 import numpy as np
15 from pyglet.window import key
16
17 try:
18     from toolbox.toolbox.IO.nidaq import DigitalInput,DigitalOutput, AnalogInput, AnalogOutput
19     have_nidaq=True
20 except:# Exception, e:
21     print("could not import iodaq.")
22     have_nidaq=False
23
24
25 MOUSE_ID = 'test'
26
27 #this is used to change whether the mouse's running and licking control the rewards.
```

Packages

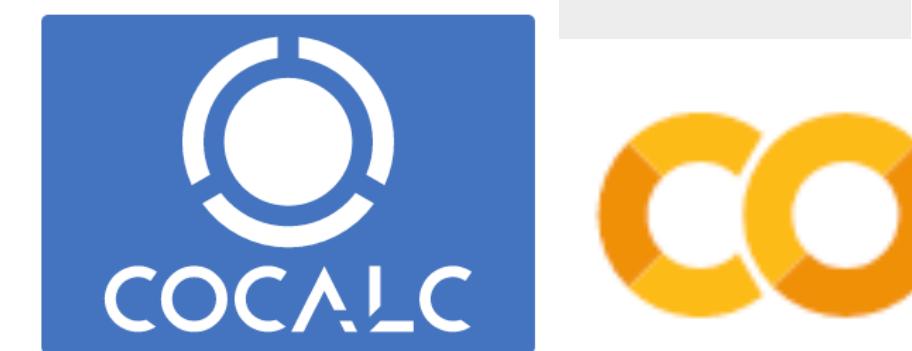


overview: levels

Containerized



Package Managers Environments



Notebooks (IPython, Jupyter, Jupyter Lab)

The screenshot shows a Jupyter Notebook interface in a web browser. The title bar says 'JupyterLab' and the address bar shows 'localhost:8888/lab'. The notebook contains a single cell with the following code:

```
Introduction to Python (for Neuroscientists)
a guided tour of data analysis with python
10 Jan 2019
NRS C 7601 Systems Neuroscience
Daniel J Denman
University of Colorado Anschutz

Important: this is not meant to be a comprehensive guide. Use the internet! Python documentation, Stack Overflow, Google, Markdown cheatsheets (e.g. this one) all are your friends.

Here, we are using a Jupyter notebook environment to run a Python 3.7 kernel
First, let's get our bearings in a Jupyter notebook
In a Jupyter notebook, we can iteratively explore data, do computations, make plots, and define functions and objects.
The notebook will contain a mix of code, markdown (a simple way to make formatted text) that might explain what is going on in the code, and outputs. The outputs will be in the form of printed statements and plots.
The fundamental unit of the Jupyter notebook is the cell. Here is an empty code cell:
```

• You can see the empty brackets on the left; this bracket is empty until the cell is executed
• Cells can be "code", "markdown", or "raw". This cell, for example, is a "markdown cell". When I execute it (by pressing Shift + Enter), it renders the text I have entered.
• In the cell below, a code cell, we will enter some code. To execute it, enter that cell and press Shift + Enter.

```
[13]: message = 'Hello world! time to do some science' #define a variable, this variable is a string, because we put the value in '
print(message)
Hello world! time to do some science
```

The empty brackets on the left have now been filled with a number, which is the order in which the cell was executed. This will forever increment until the this bracket is empty until the kernel for Jupyter



System

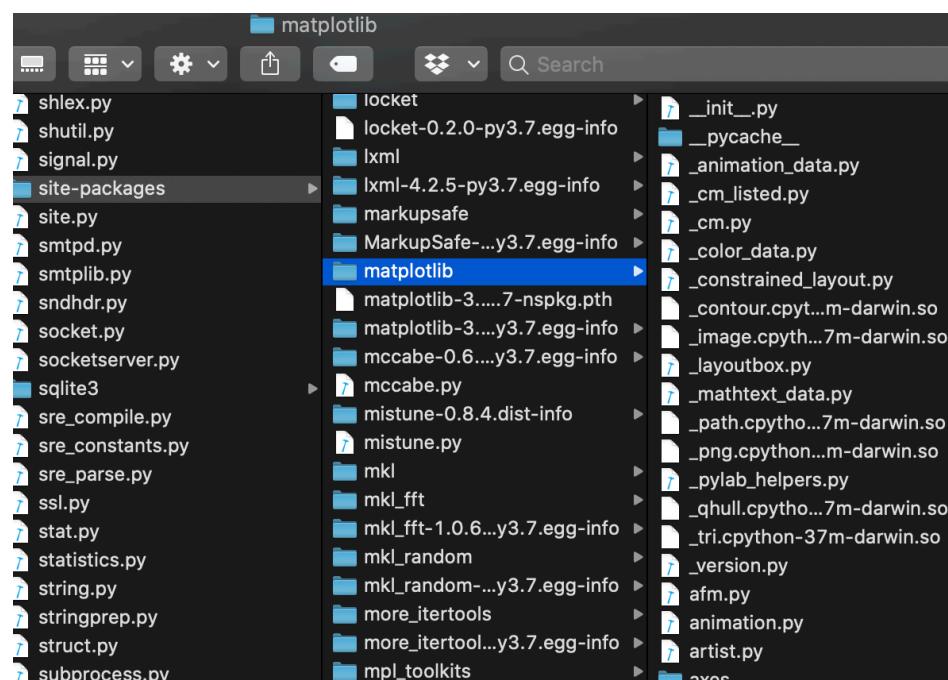
```
Last login: Wed Dec 18 16:26:32 on ttys002
The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
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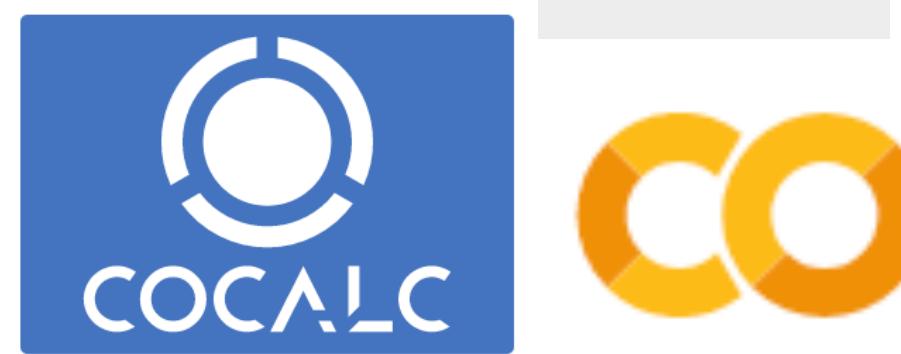


overview: levels

Package Managers Environments



Containerized



Notebooks (IPython, Jupyter, Jupyter Lab)

The screenshot shows a Jupyter Notebook interface in a web browser. The title bar says 'JupyterLab' and the address bar shows 'localhost:8888/lab'. The notebook has two tabs: 'Settings' and 'NRC7601_intro.ipynb'. The main area contains a section titled 'Introduction to Python (for Neuroscientists)' with the subtitle 'a guided tour of data analysis with python'. It includes a date '10 Jan 2019', author 'NRSC 7601 Systems Neuroscience Daniel J Denman University of Colorado Anschutz', and a note: 'Important: this is not meant to be a comprehensive guide. Use the internet! Python documentation, Stack Overflow, Google, Markdown cheatsheets (e.g. this one) all are your friends.' Below this is a code cell with the text 'Here, we are using a Jupyter notebook environment to run a Python 3.7 kernel'. The cell content is 'First, let's get our bearings in a Jupyter notebook'. It explains what a Jupyter notebook is and how it works. A code cell is shown with the text 'message = "Hello world! time to do some science" #define a variable, this variable is a string, because we put the value in '''. The output of the cell is 'Hello world! time to do some science'. At the bottom, there is a note: 'The empty brackets on the left have now been filled with a number, which is the order in which the cell was executed. This will forever increment until the this bracket is empty until the kernel for Jupyter'.

why is it good for doing neuroscience?

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- Do analyses that would be a whole PhD to implement yourself (i.e., ML)
 - automate boring stuff / use other people's hard work
- packages!

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also it is free —> democratizing science

in this realm, cloud resources (data, compute) also open science to a wider group that aren't collecting their own data and running their own super computers

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RaspberryPi

Arduino

PyDAQMX

PsychoPy

...many APIs...

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Google Colab
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Week 2

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Week 5

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Week 5
Week 6

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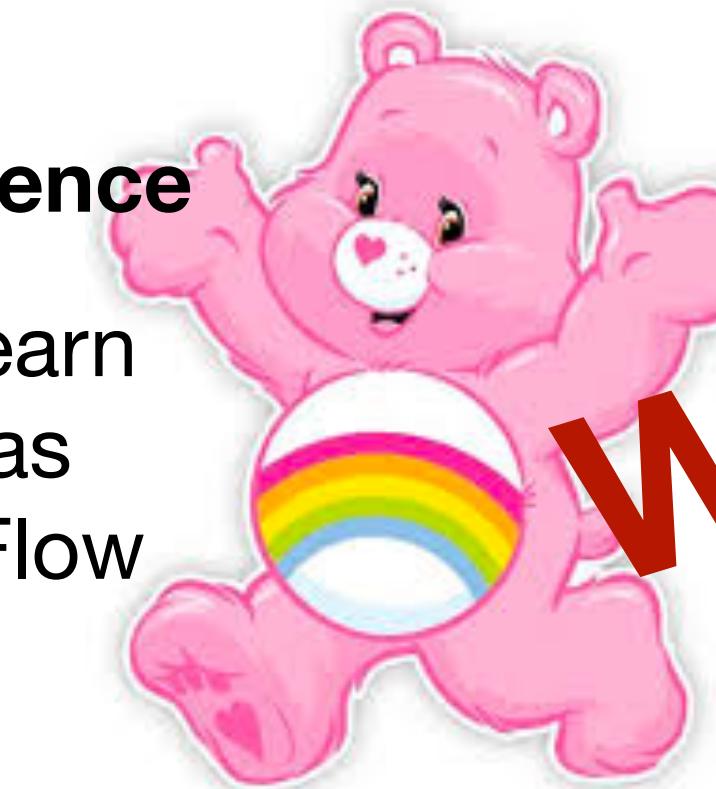
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Weeks 7-9



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Week 2

Week 5

Week 6

MATLAB

- At this time, some understanding of both Python and MATLAB is extremely useful. We use both in the Denman Lab, but my primary expertise is in Python
- John T going to be MATLAB point person for the course

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Week 1

- **Anaconda environments and where python is on your computer**
- **Command line: git, starting a jupyter notebook, running a script**
- **Basics and syntax**

Style and philosophy

- Don't overoptimize; get it done first
- Do document as you go
- Pay attention to variable names
- There is a slippery slope from the minimal functional code to unusable/unshareable code
- Read this PLoS paper this week!

PLOS COMPUTATIONAL BIOLOGY

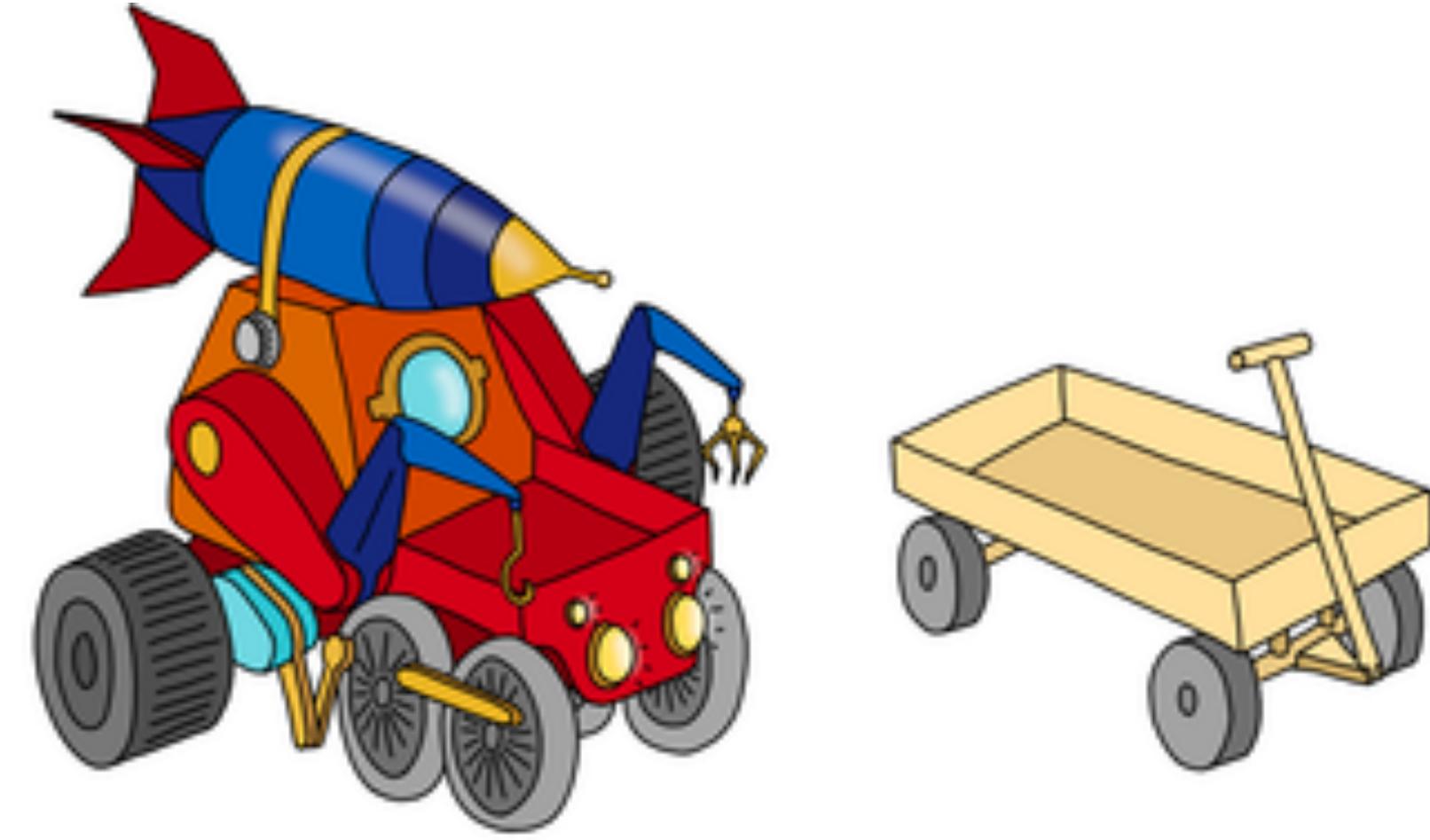
OPEN ACCESS

EDITORIAL

Ten simple rules for quick and dirty scientific programming

Gabriel Balaban, Ivar Grytten, Knut Dagestad Rand, Lonneke Scheffer, Geir Kjetil Sandve 

Published: March 11, 2021 • <https://doi.org/10.1371/journal.pcbi.1008549>



[https://journals.plos.org/ploscompbiol/
article?id=10.1371/journal.pcbi.1008549](https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1008549)

git

- This is important. And not intuitive.
- Version control is not optional; if you don't use git for version control, you are going to use something else (analysis_script_v1.py, analysis_script_v2.py, analysis_script_v2_20210622.py, analysis_script_v3_07142021.py, analysis_script_final.py, analysis_script_final2.py, ..., analysis_script_final2_for.py)
- Making it a part of your workflow can simplify and provide redundancy and flexibility; more advanced features also makes sharing simpler.
- git comes with unix systems (Mac), will have to install it on Windows.
- **We're going to go over git interactively.**

git

- Git clone the repo on student's computers
- Git push a script from dan's computer
- Git pull to student's computers
-