

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****

<https://zcal.co/i/TnPlYgEZ>

Schedule

~~June 5- Aug 14 2023 | Mondays 1 – 4PM | No class Monday July 3~~
~~June 12~~

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, J 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	Group programming time Group programming time / Final pres. and code review (if big class)
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)

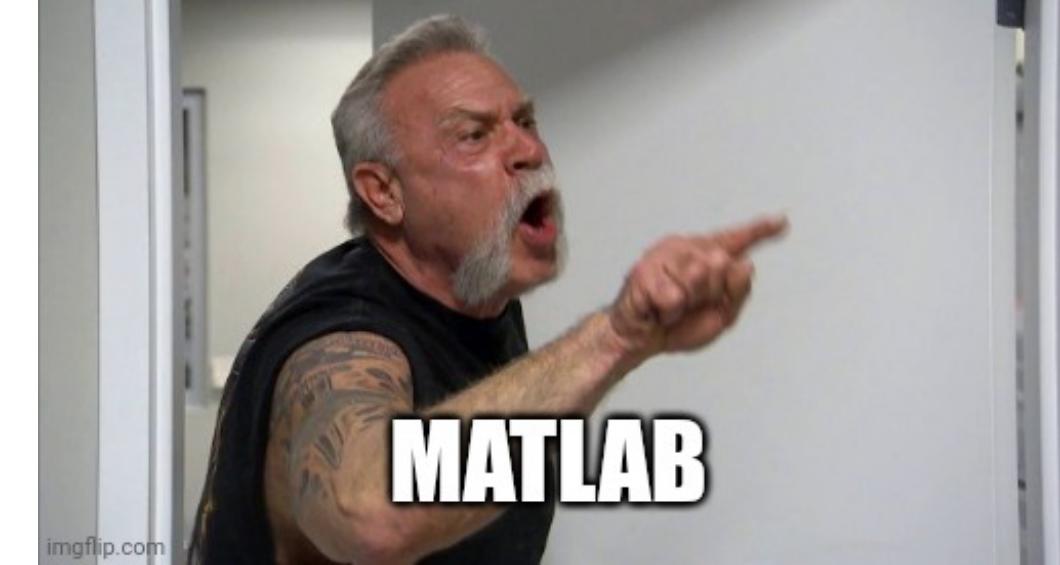
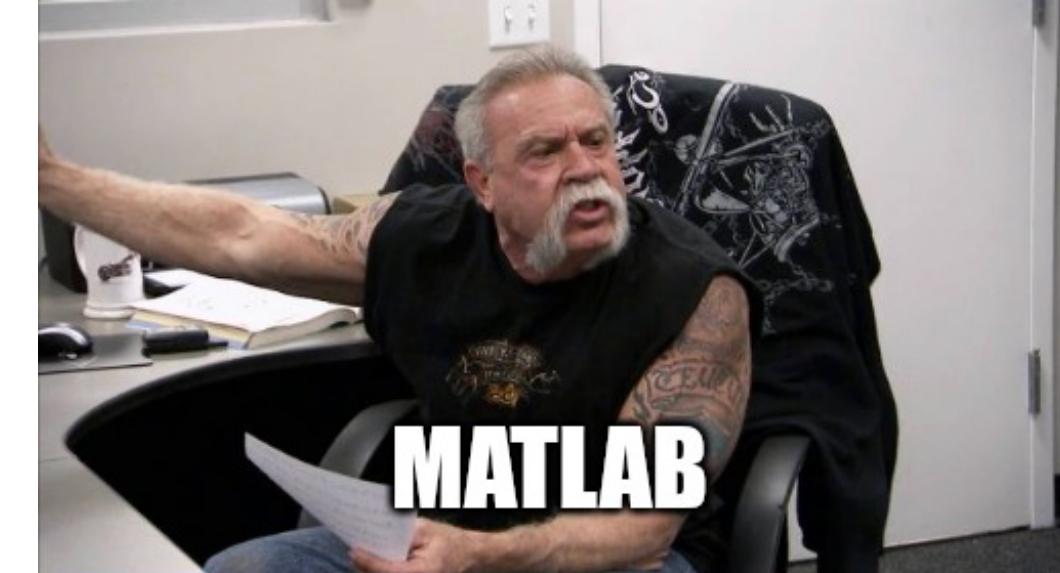
- Allen Institute for Brain Science brain-map.org
- DABI Data Archive BRAIN Initiative <https://dabi.loni.usc.edu/home>

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 circuit) 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



imgflip.com

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. Definitely your science.

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Ask questions!



Goals of this course

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

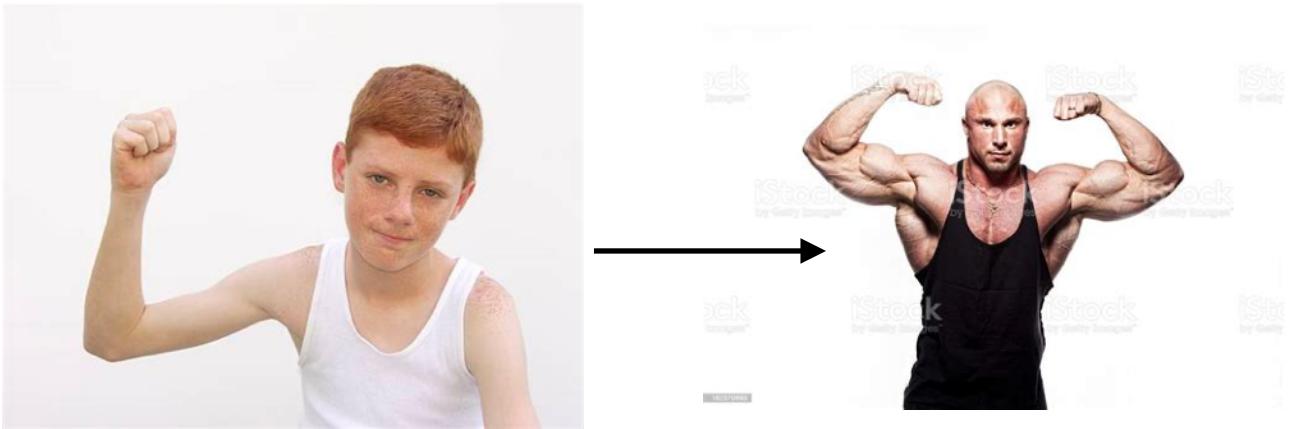
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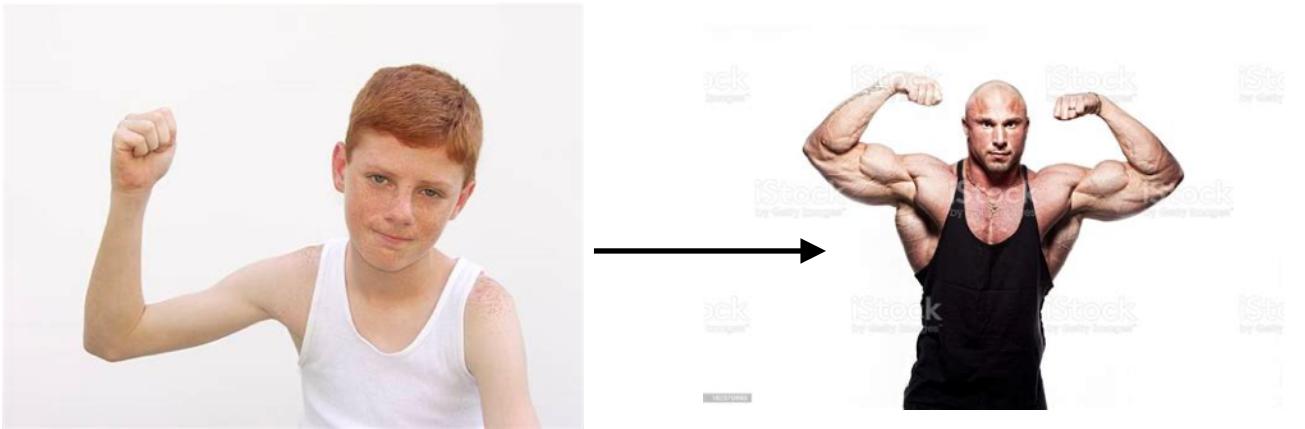


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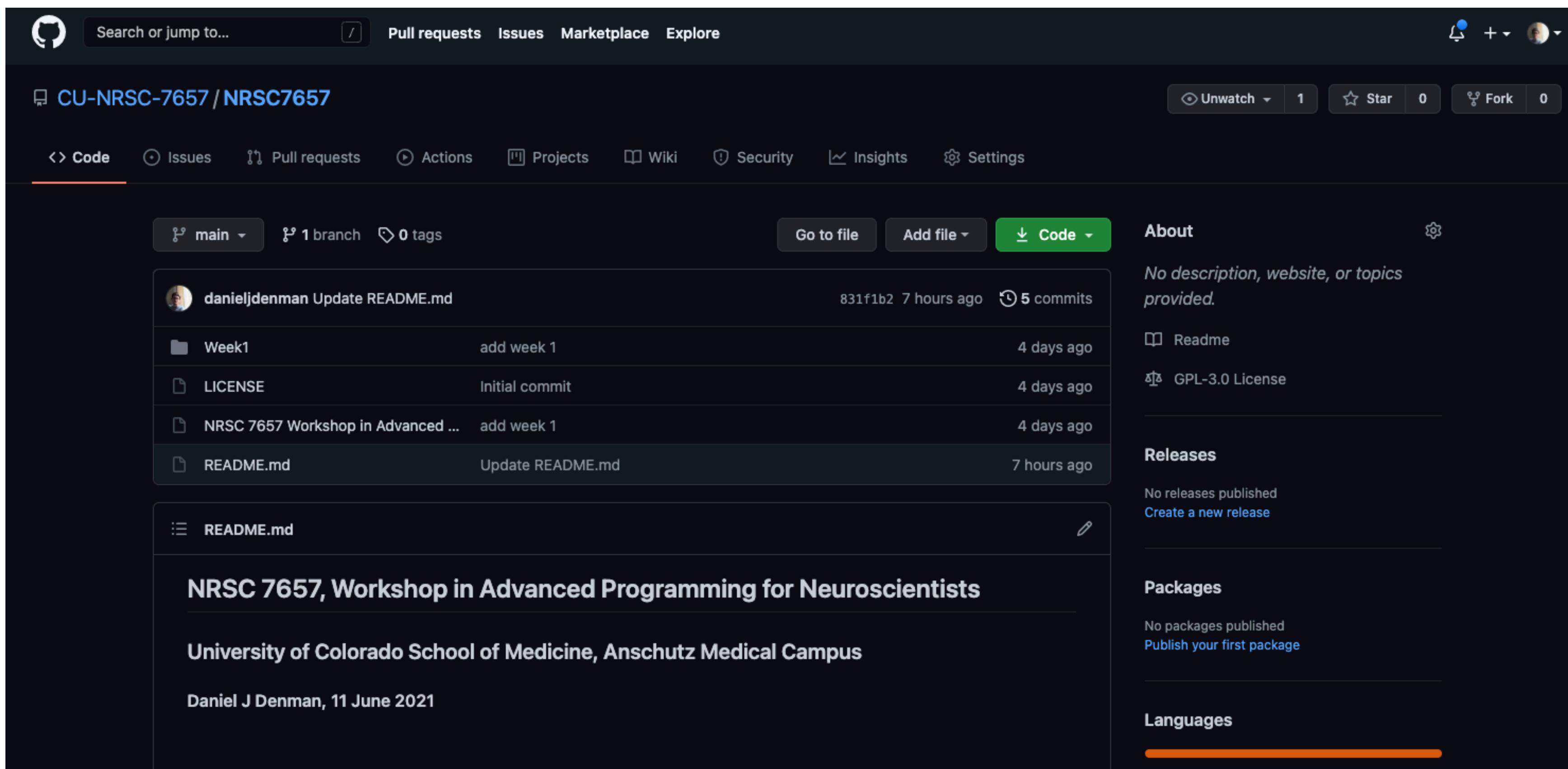


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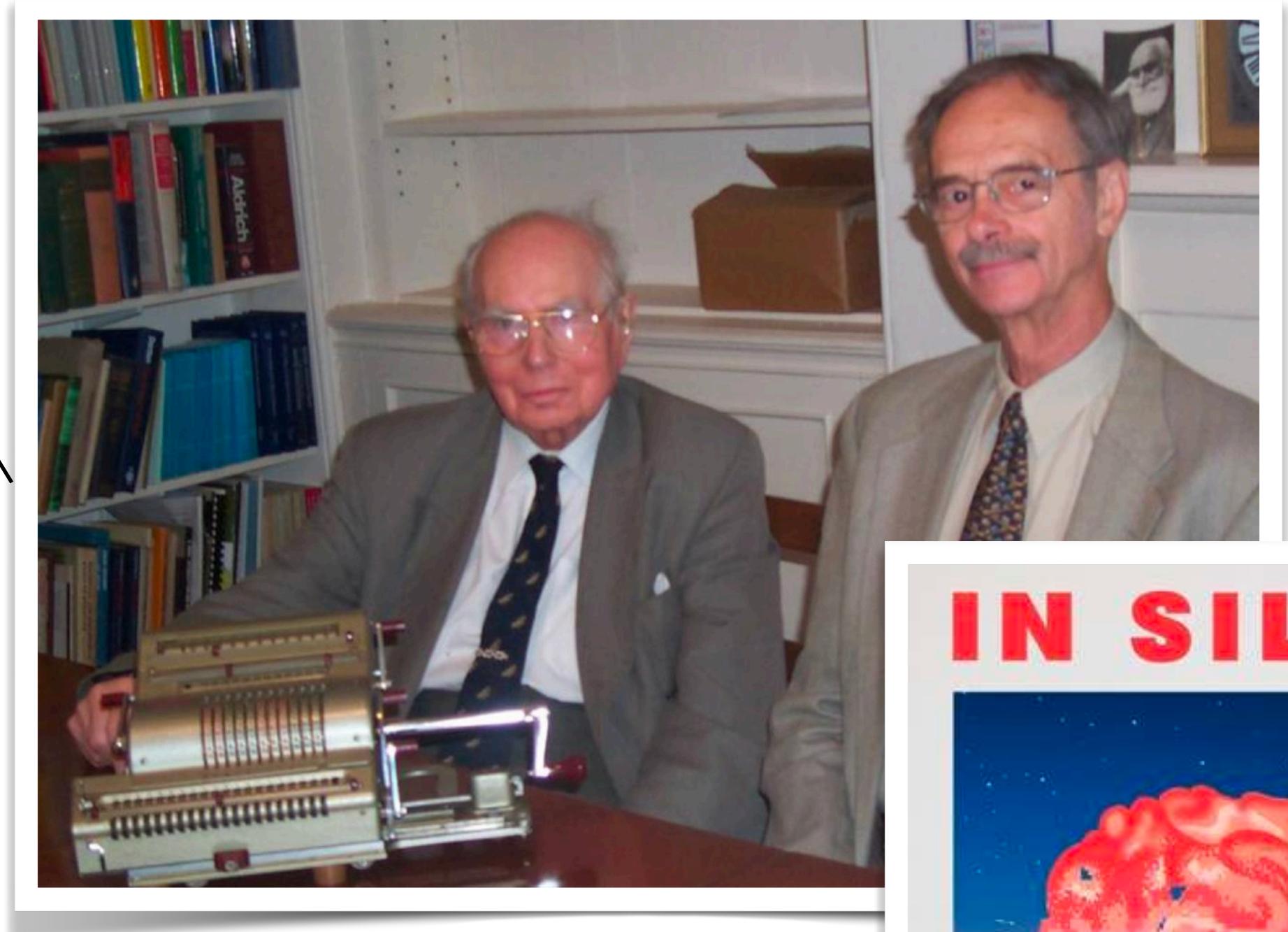
Final practicalities

- GitHub: <https://github.com/CU-NRSC-7657/NRSC7657>

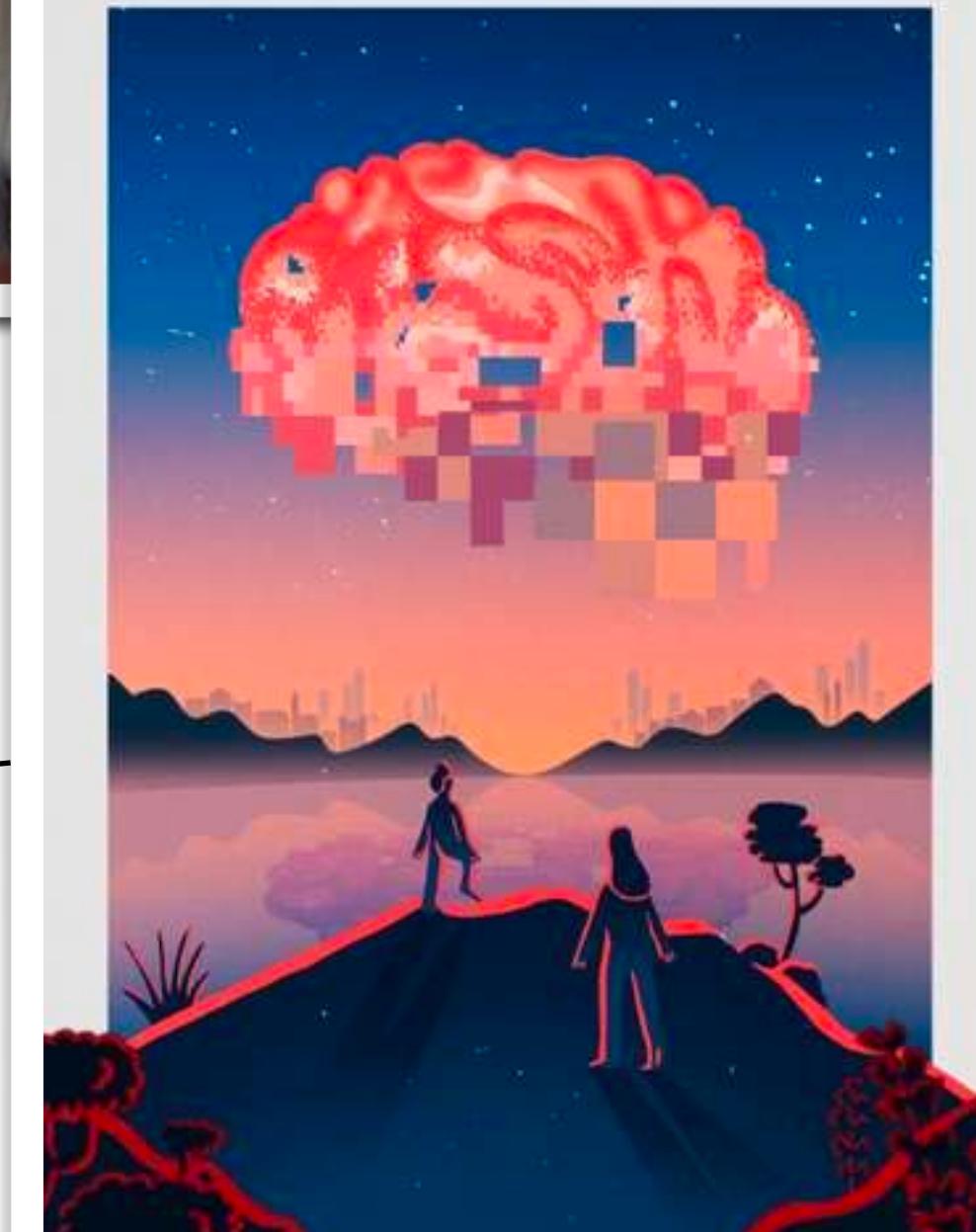


Computing in neuroscience

- 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

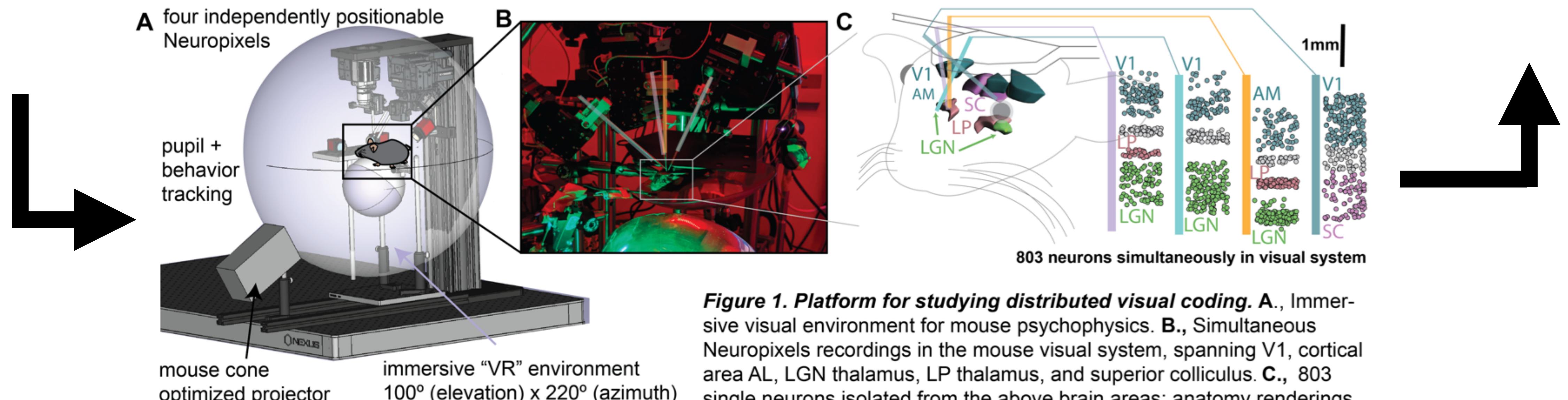


Figure 1. Platform for studying distributed visual coding. **A.**, Immersive visual environment for mouse psychophysics. **B.**, Simultaneous Neuropixels recordings in the mouse visual system, spanning V1, cortical area AL, LGN thalamus, LP thalamus, and superior colliculus. **C.**, 803 single neurons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

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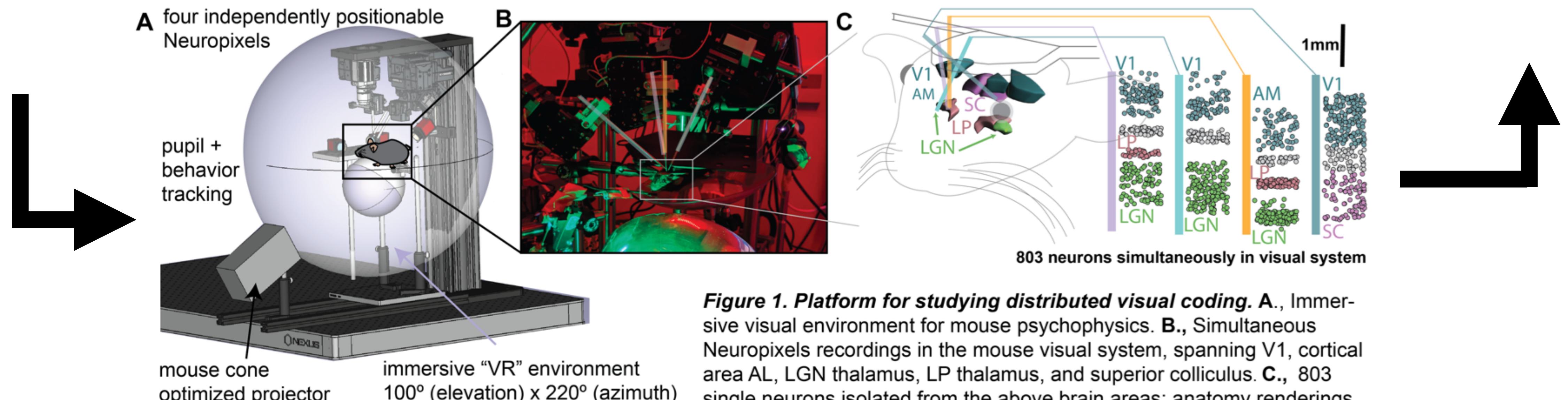


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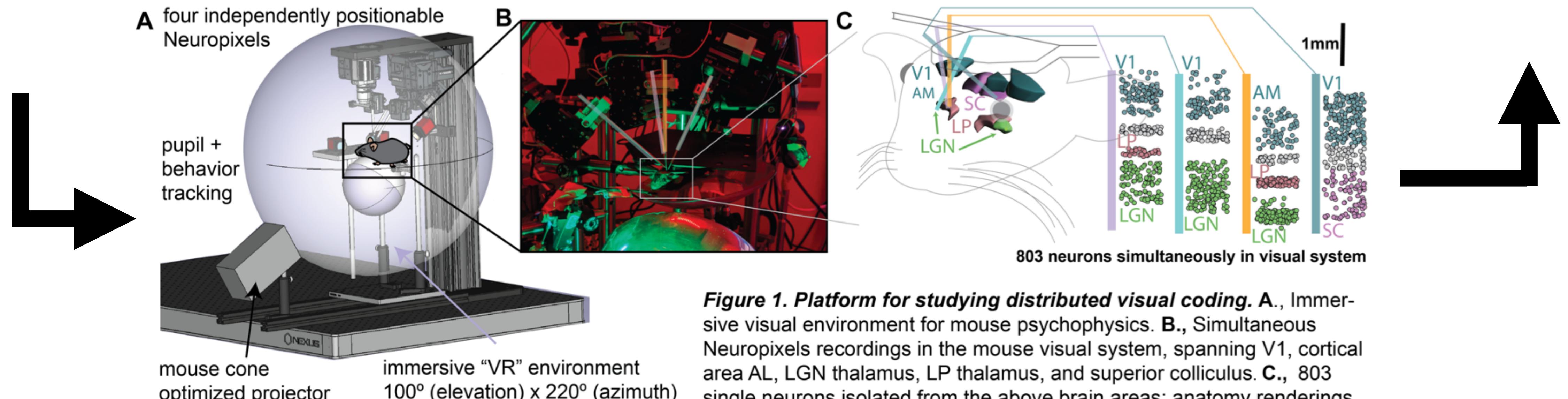
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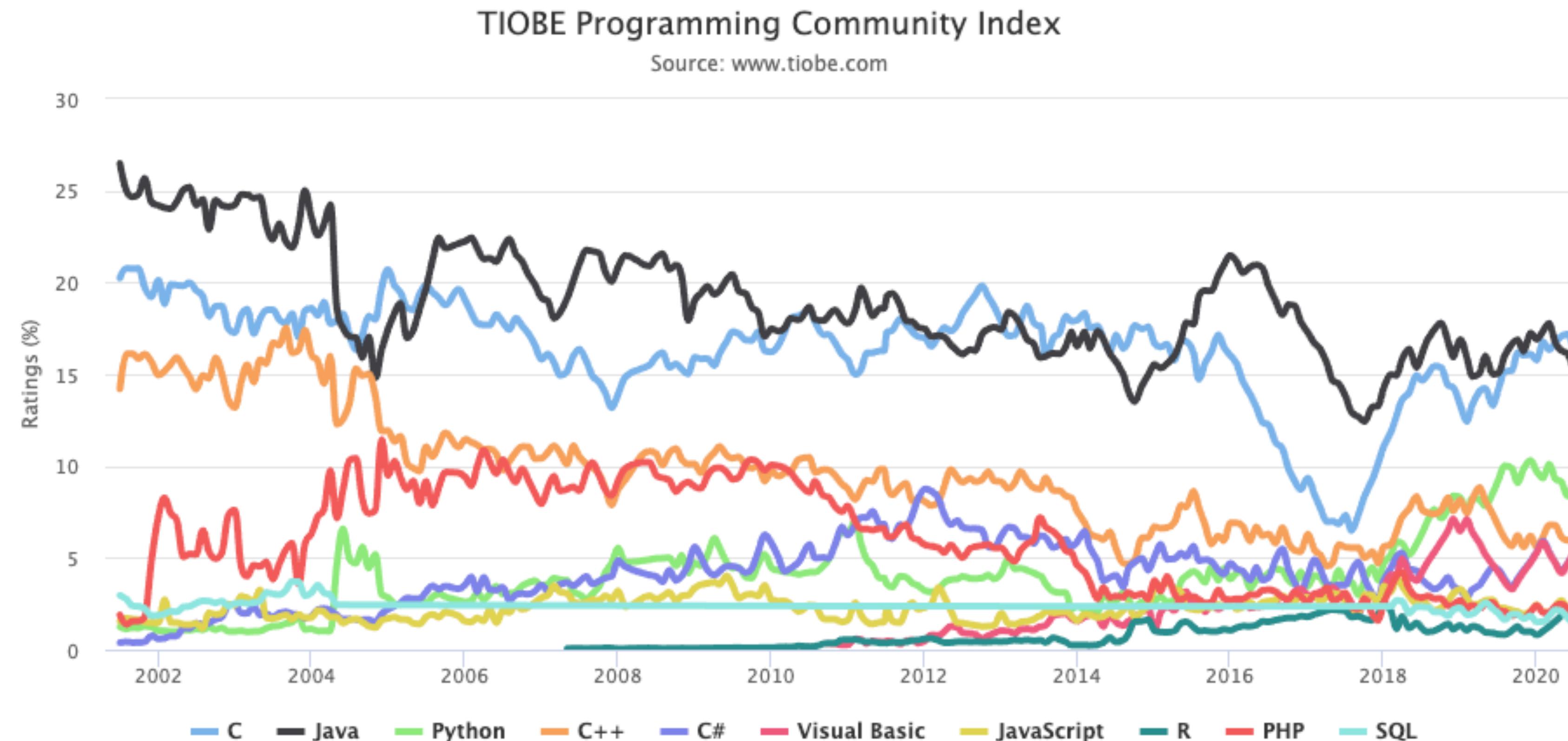
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Stimulus responses: python

Population statistics: **MATLAB and python**



history: languages used for neuroscience



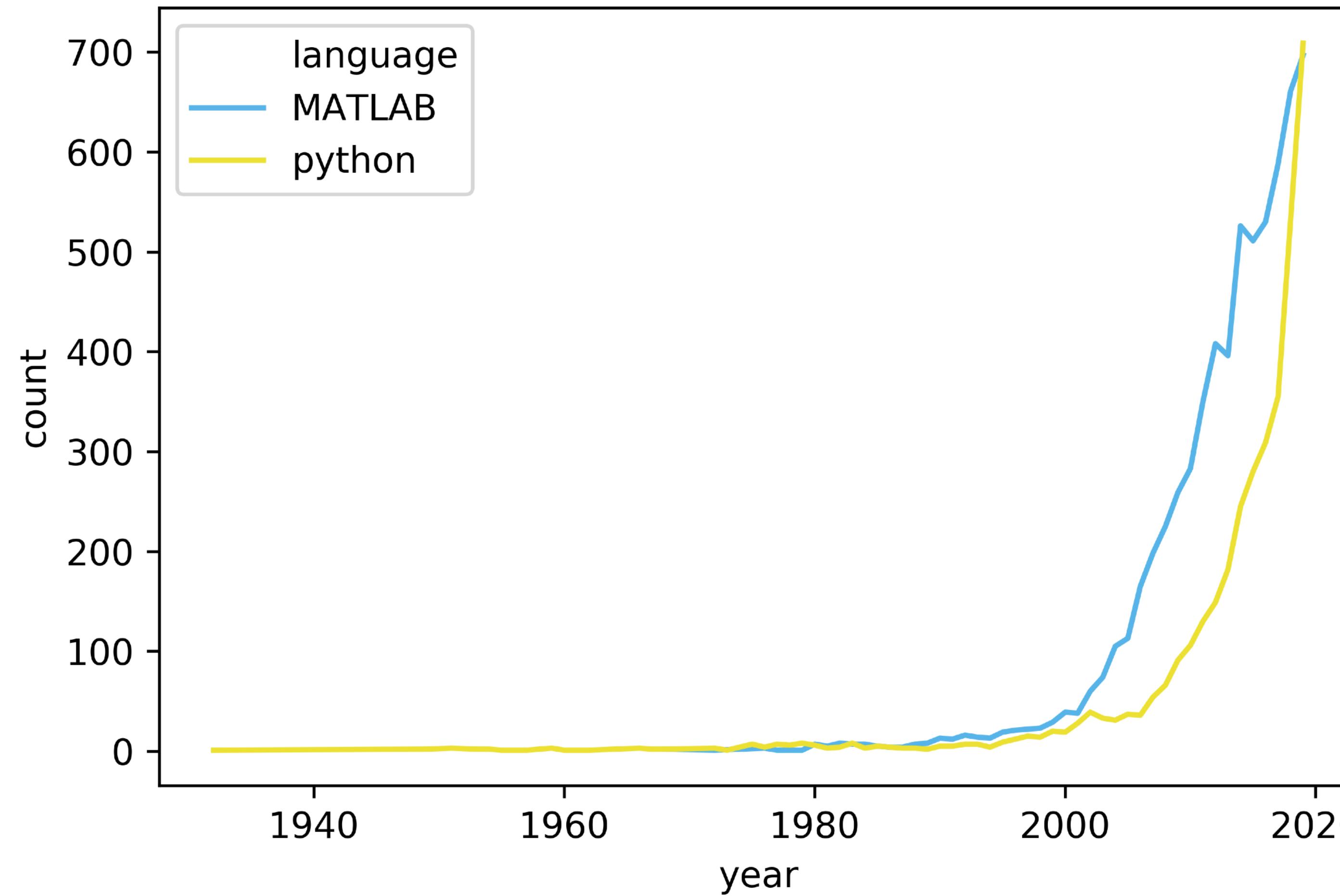
history: languages used for neuroscience

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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



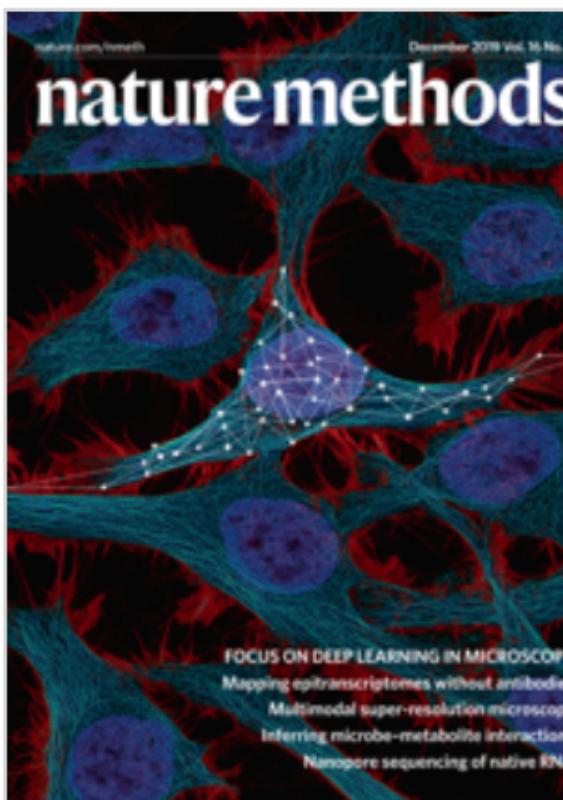
Focus on Deep Learning in Microscopy

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



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

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- 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”
- Support for Python2.7 ended Jan 1, 2020



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If there is something you are doing over and over again, especially in your analysis, script it!

overview

Some plusses

Some minuses

overview

Some plusses

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

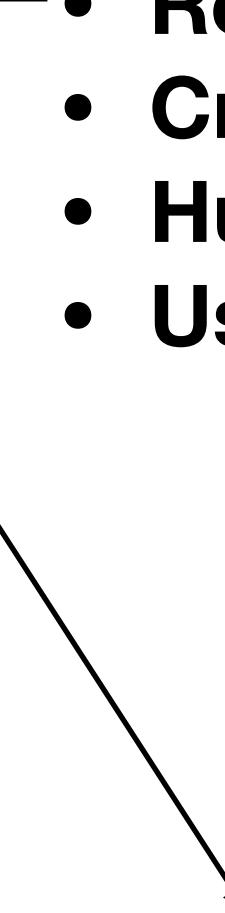
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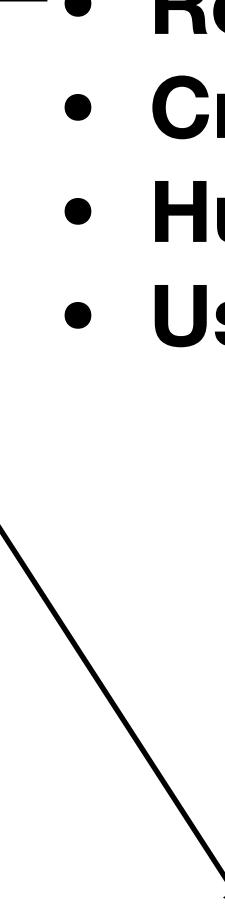
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amazon



aws



NETFLIX



You Tube

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overview: packages

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

Search projects



Or [browse projects](#)

381,490 projects

3,536,531 releases

6,207,207 files

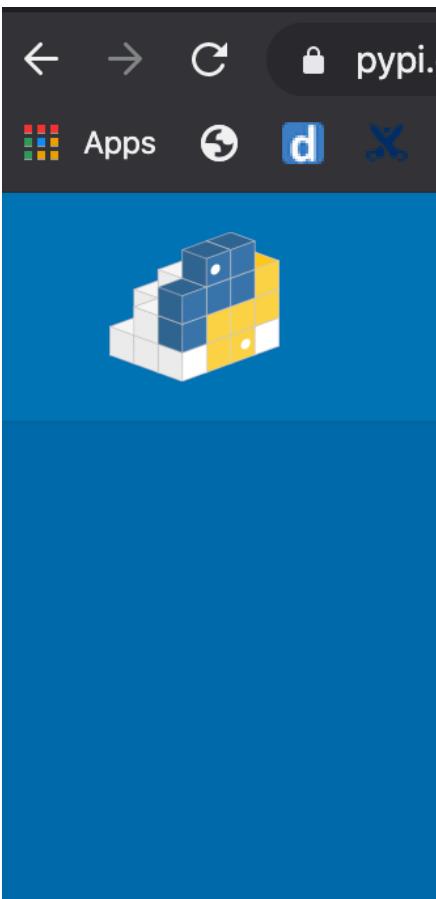
600,160 users

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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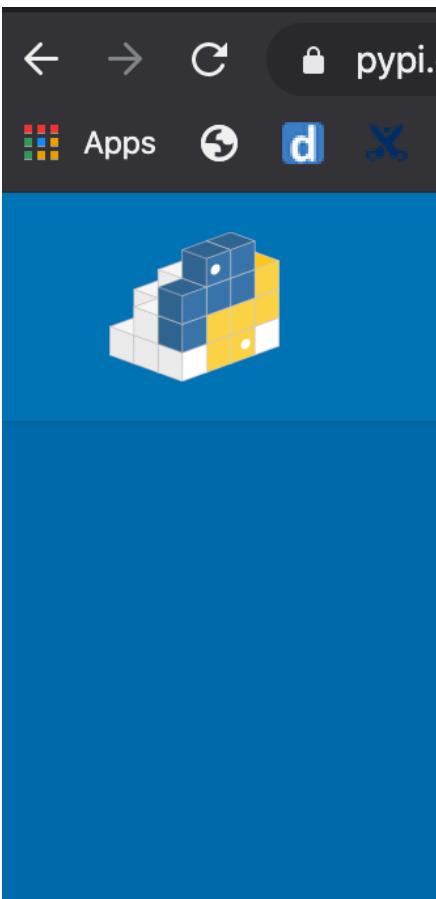
A screenshot of the Python Package Index (PyPI) homepage. At the top, there is a search bar with the placeholder "Search projects" and a magnifying glass icon. Below the search bar, the text "Or [browse projects](#)" is displayed. At the bottom of the page, there is a summary of statistics: "381,490 projects" (which is highlighted with an orange border), "3,536,531 releases", "6,207,207 files", and "600,160 users".

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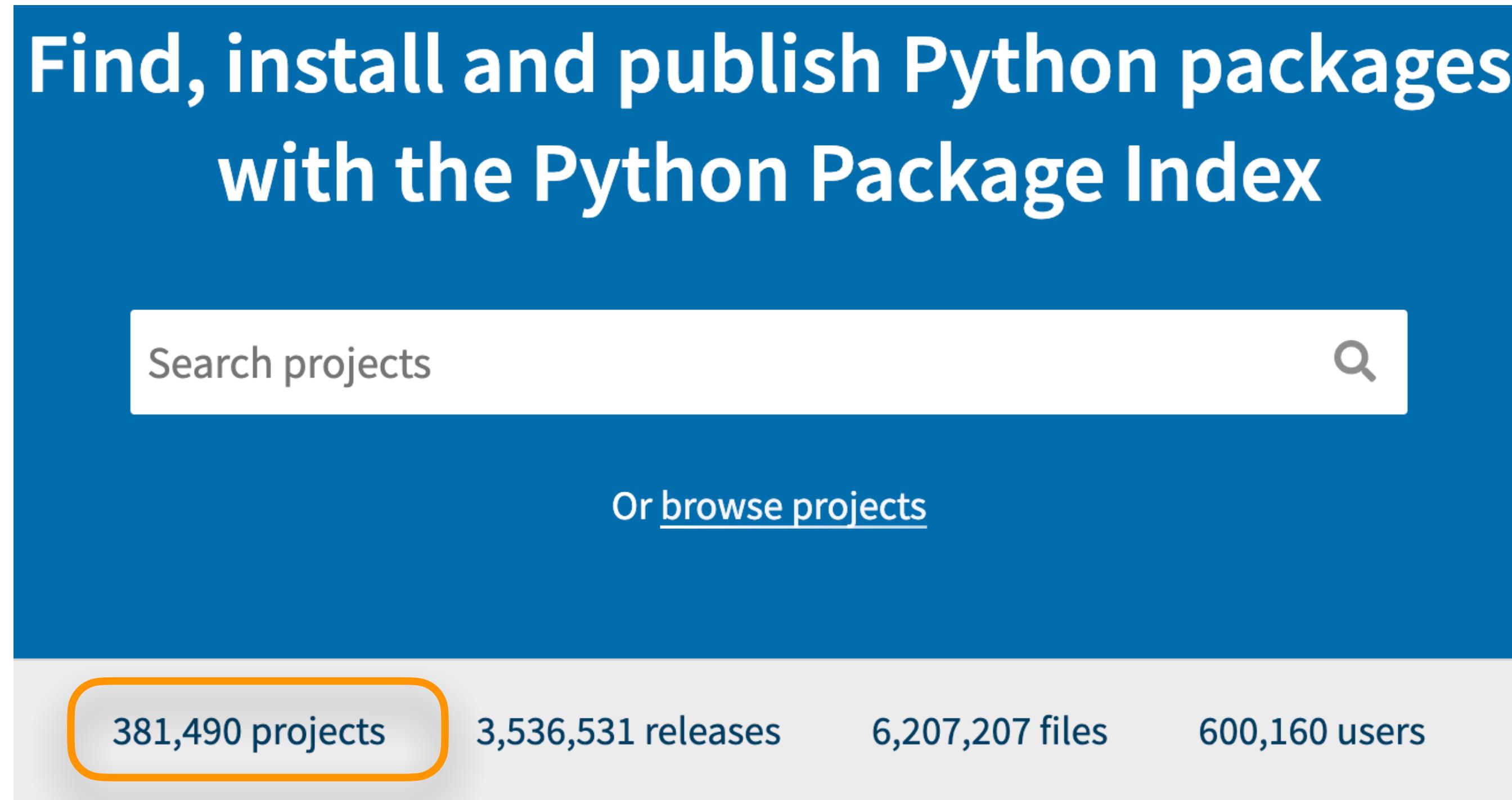
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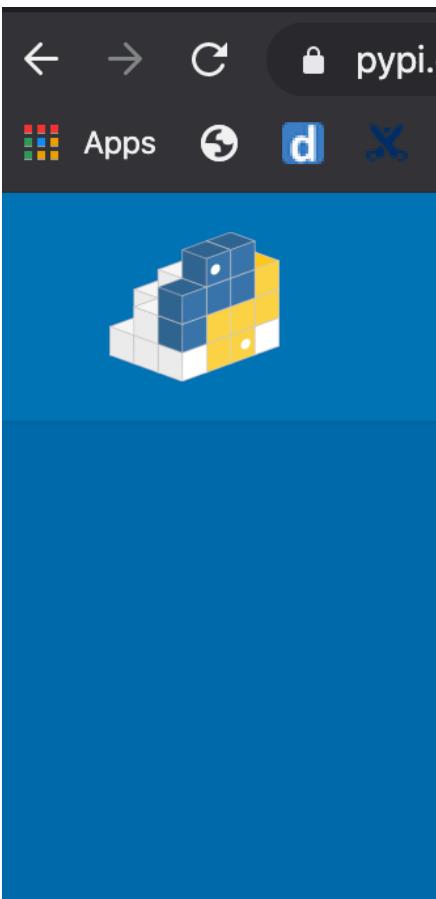


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overview: levels



overview: levels

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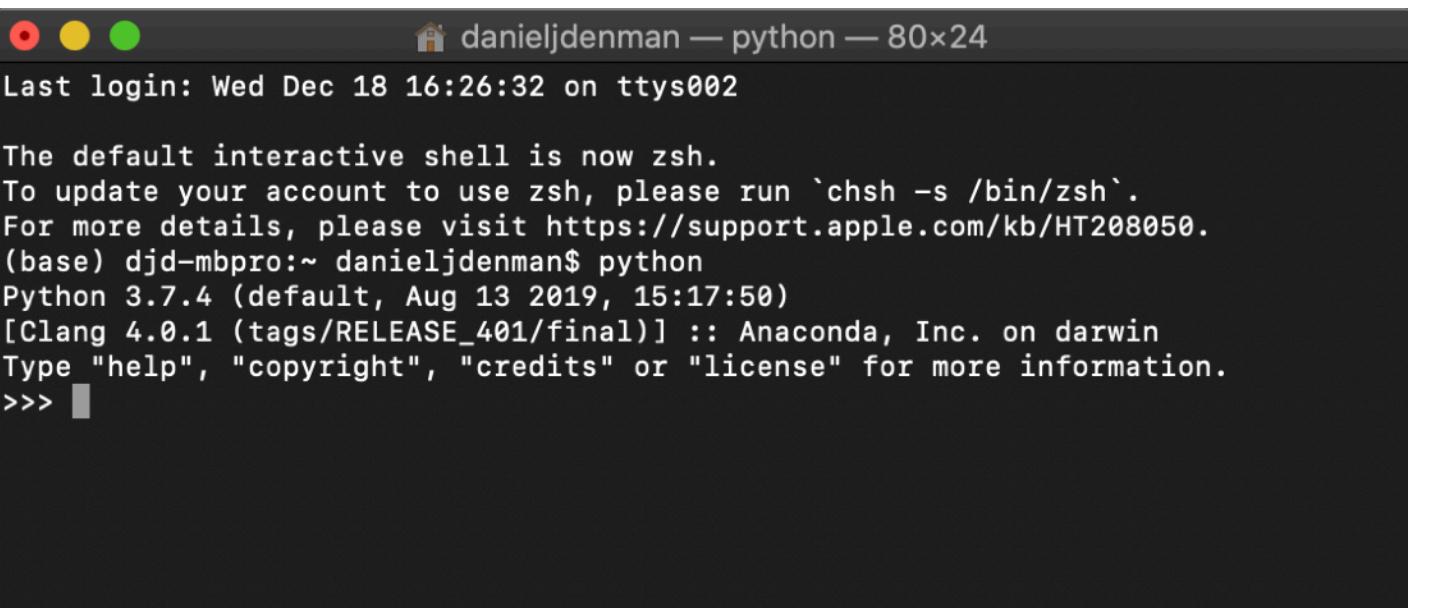
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The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
(base) djd-mbpro:~ danieljdenman$ python
Python 3.7.4 (default, Aug 13 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)



overview: levels

System



A screenshot of a Mac OS X terminal window titled "danieljdenman — python — 80x24". The window shows the following text:

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Package Managers Environments





overview: levels

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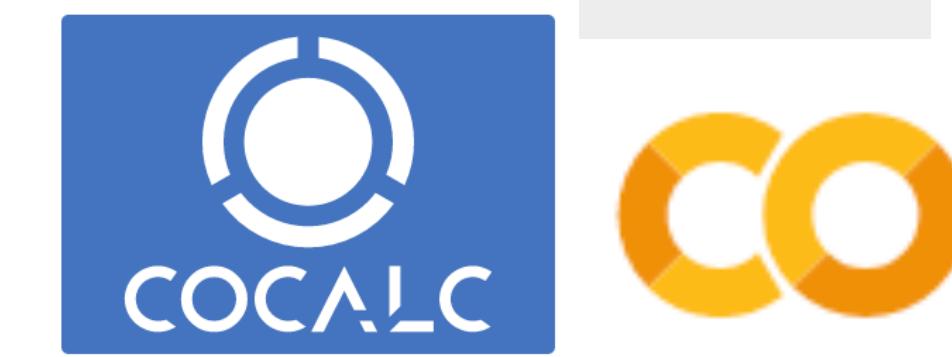
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Package Managers Environments



Containerized





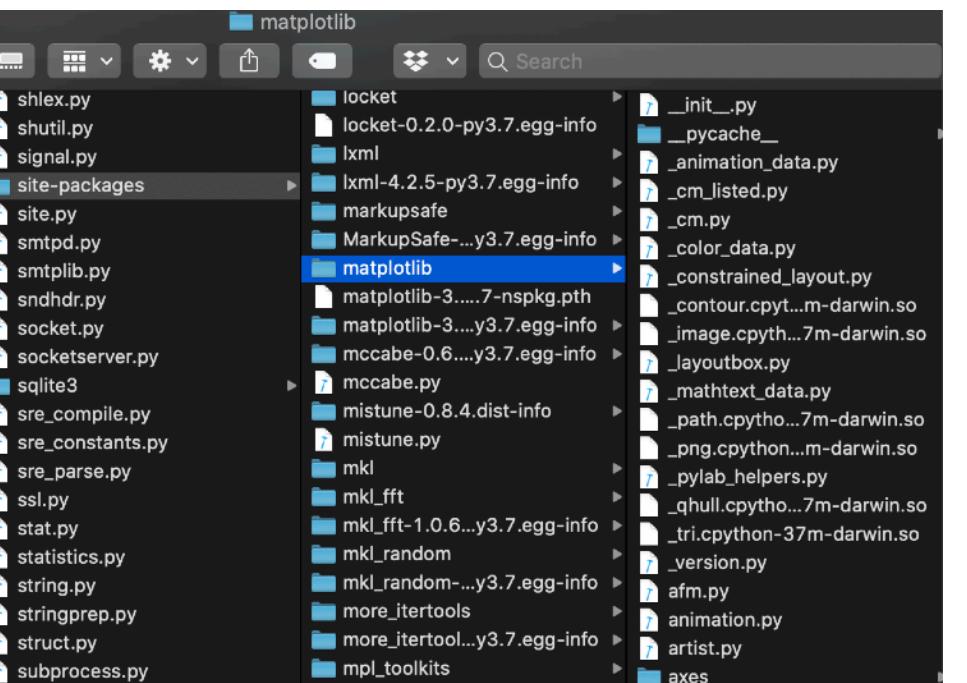
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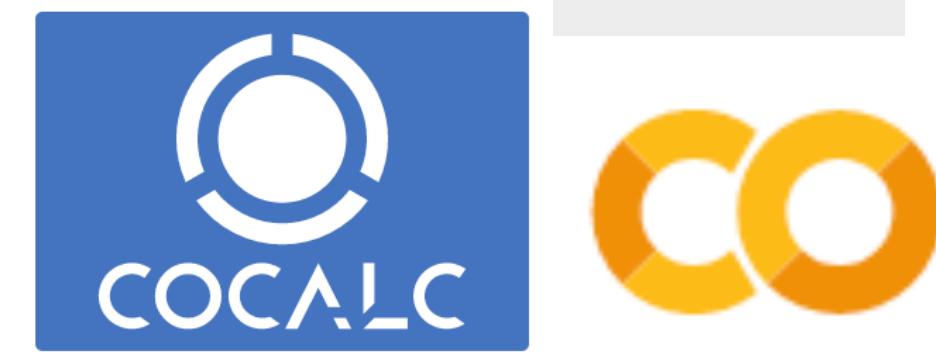
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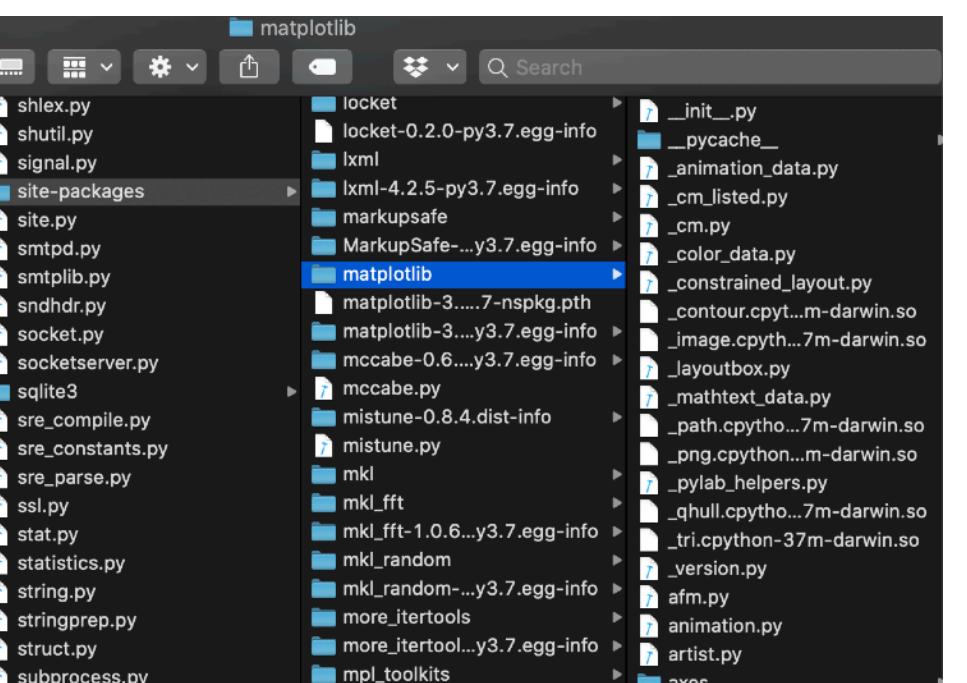
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Scripts

```
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
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```

Packages

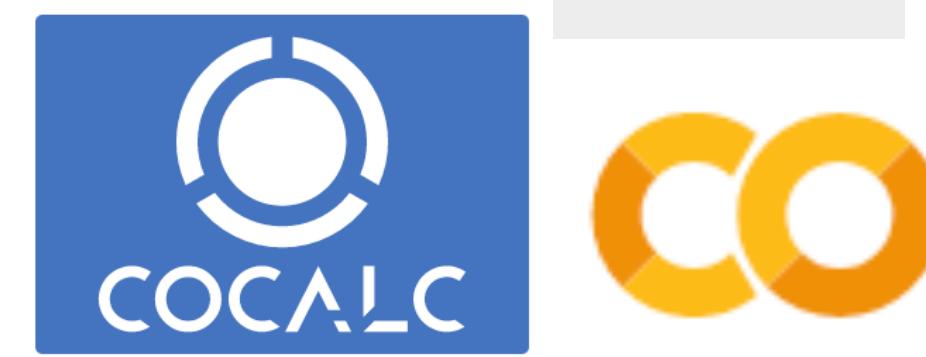


overview: levels

Package Managers Environments



Containerized





System

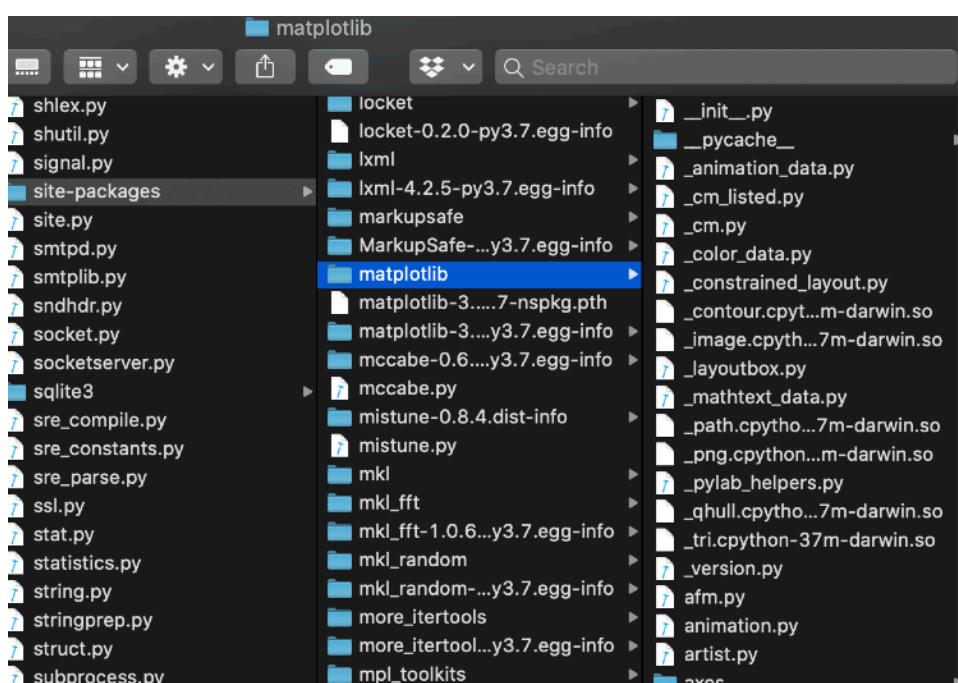
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Last login: Wed Dec 18 16:26:32 on ttys002
The default interactive shell is now zsh.
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(base) djd-mbpro:~ danieljdenman$ python
Python 3.7.4 (default, Aug 13 2019, 15:17:50)
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Type "help", "copyright", "credits" or "license" for more information.
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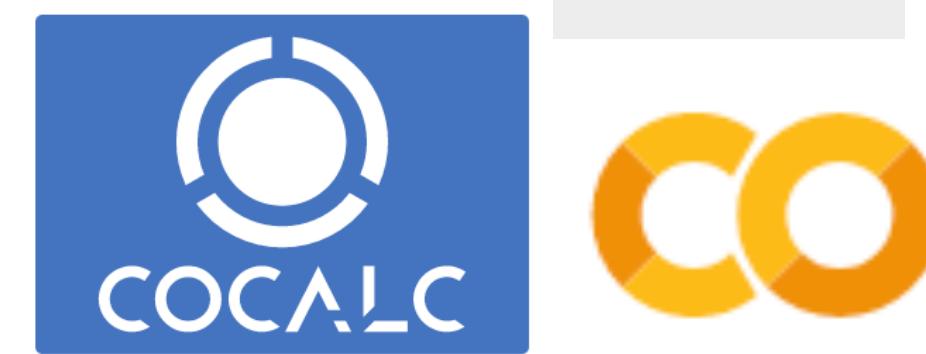


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Package Managers Environments



Notebooks (IPython, Jupyter, Jupyter Lab)

A screenshot of a Jupyter Notebook interface running in a web browser (Chrome). The browser title bar says 'JupyterLab' and the address bar shows 'localhost:8888/lab'. The main content area displays a notebook titled 'NRC7601_intro.ipynb'. The notebook contains a single code cell with the following Python code:

```
print("Hello world! time to do some science")
```

The output of the cell is:

```
Hello world! time to do some science
```

Below the code cell, there is 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.'

Further down, there is a section titled 'Introduction to Python (for Neuroscientists)' with a subtitle 'a guided tour of data analysis with python'. It includes a timestamp '10 Jan 2019' and author information 'NRSC 7601 Systems Neuroscience, Daniel J Denman, University of Colorado Anschutz'.

At the bottom of the notebook, there is a note: 'Here, we are using a Jupyter notebook environment to run a Python 3.7 kernel' and 'In a Jupyter notebook, we can iteratively explore data, do computations, make plots, and define functions and objects.'



System

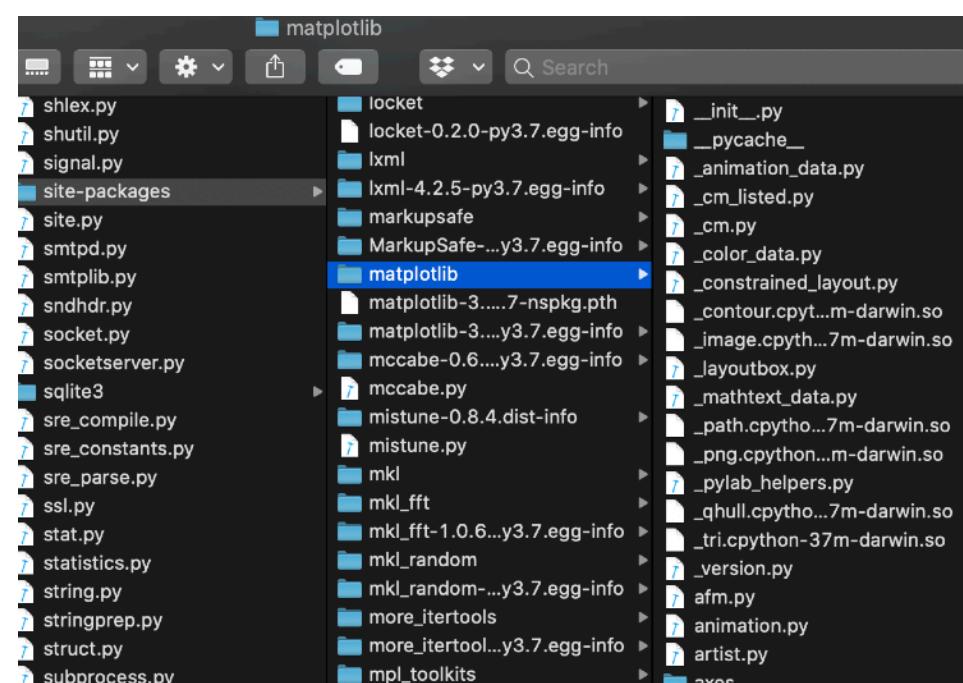
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(base) djd-mbpro:~ danieljdenman$ python
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Type "help", "copyright", "credits" or "license" for more information.
>>> 
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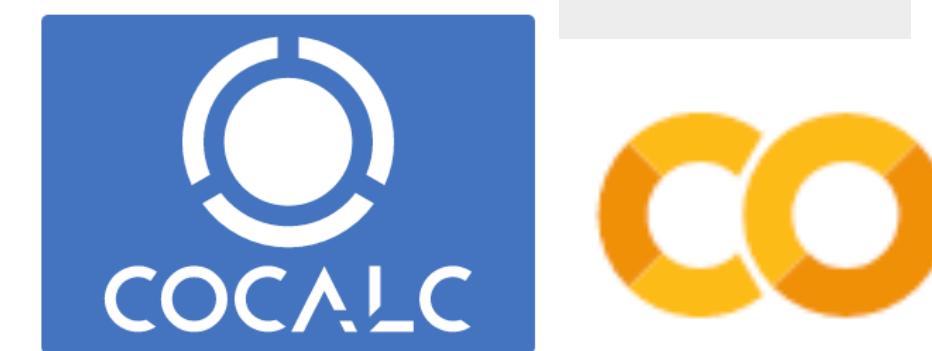


overview: levels

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Package Managers Environments



Week 1

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 code cell with the following content:

```
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:
```

The code cell contains the following Python code:

```
[1]: 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
```

Below the code cell, a note states: "The empty brackets on the left has 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



```
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```

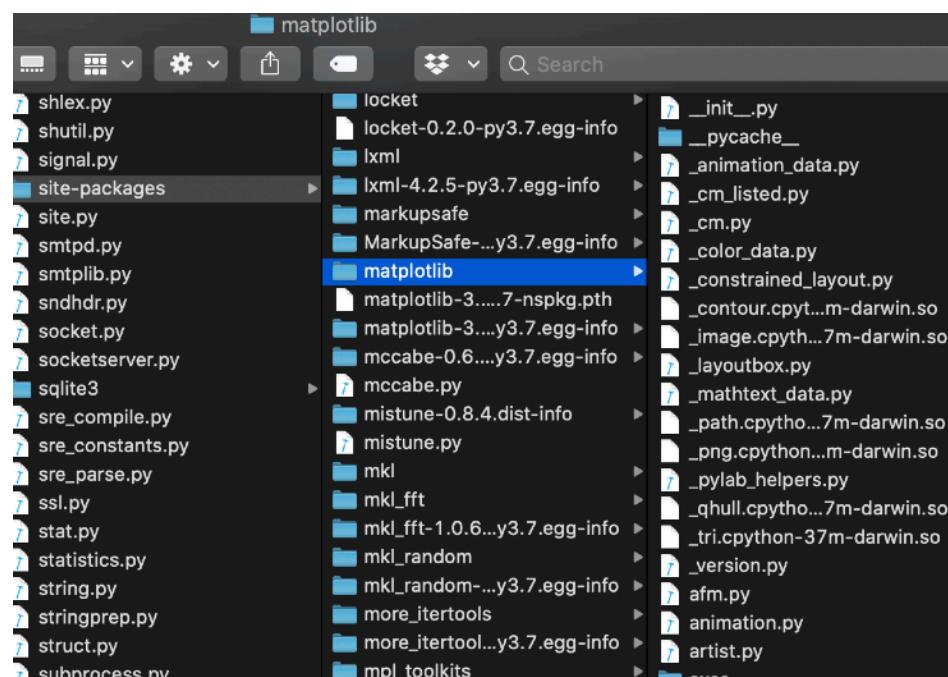
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Packages



overview: levels

Package Managers Environments

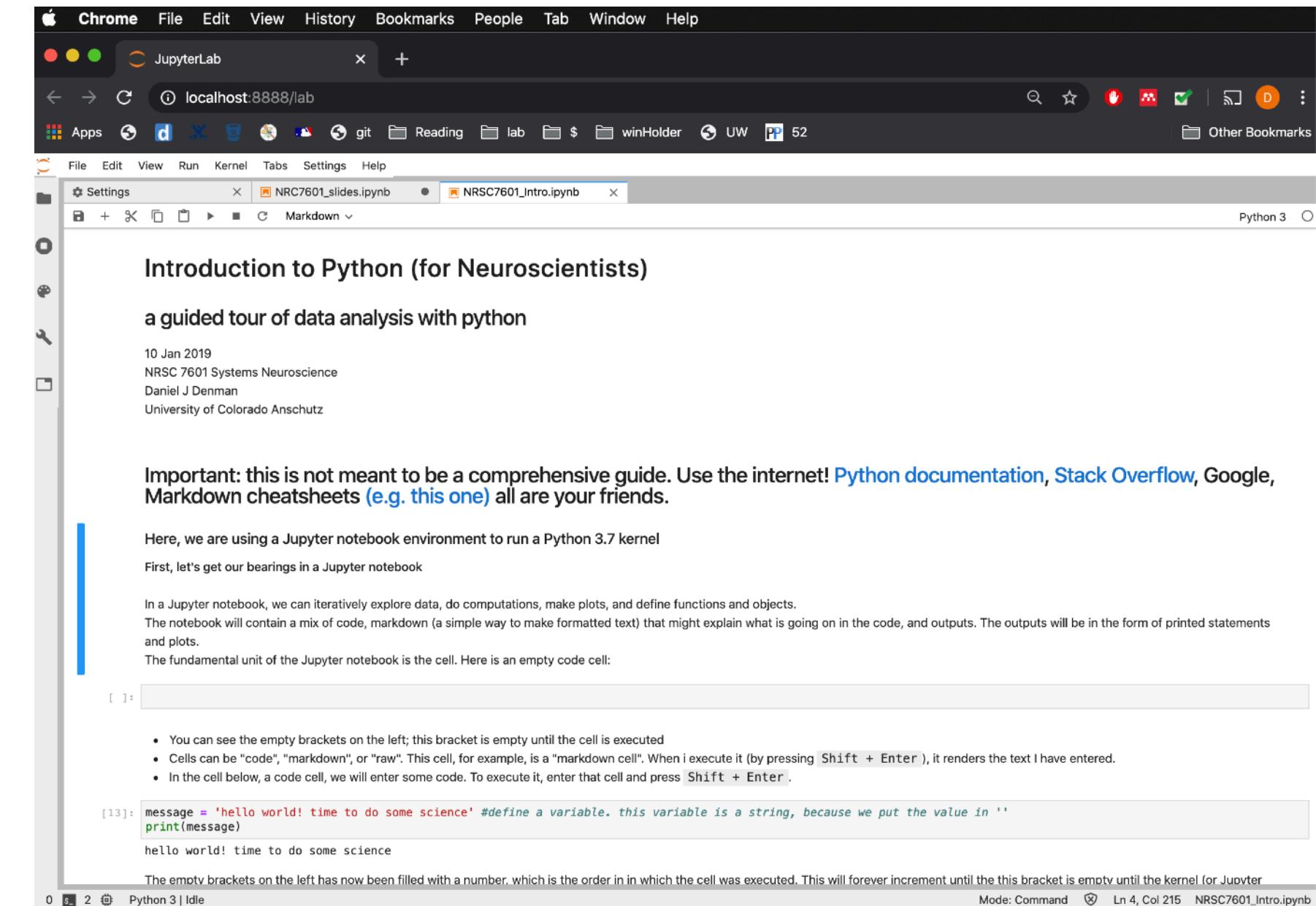


Containerized



Week 6

Notebooks (IPython, Jupyter, Jupyter Lab)



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10 Jan 2019
NRSC 7601 Systems Neuroscience
Daniel J Denman
University of Colorado Anschutz

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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:

```
[1]:
```

- 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



```
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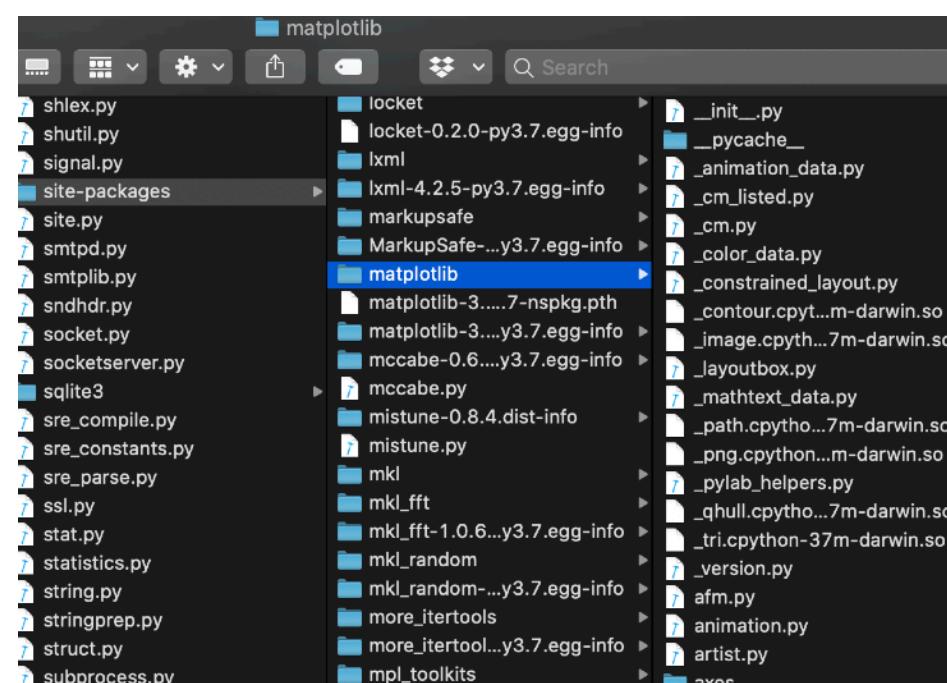
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Week 3

Packages



overview: levels

Package Managers Environments



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Week 6

Notebooks (IPython, Jupyter, Jupyter Lab)

A screenshot of a Jupyter Notebook interface in a web browser. The notebook title is "NRC7601_intro.ipynb". The first cell contains the text "Introduction to Python (for Neuroscientists)" and "a guided tour of data analysis with python". Below this, there is a note about the date (10 Jan 2019), the course (NRC7601 Systems Neuroscience), and the author (Daniel J Denman, University of Colorado Anschutz). The notebook then provides a guide to using Jupyter, mentioning the Python 3.7 kernel and the use of code cells. It includes a note about Markdown and a warning that the notebook is not meant to be comprehensive. The code cell at the bottom shows a simple print statement: "message = 'Hello world! time to do some science' #define a variable. this variable is a string, because we put the value in ''", followed by the output "Hello world! time to do some science".

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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Stack Overflow <— not cheating!

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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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Hardware control

RaspberryPi

Arduino

PyDAQMX

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...many APIs...

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Ca2+ analysis: Suite2P, AQUA
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Expression Analysis: scanpy
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Google Colab
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Week 2

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Week 2

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Week 2

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Week 5

why is it good for doing neuroscience?

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packages

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Week 2

Sharing
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Week 5
Week 6

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Week 2
packages

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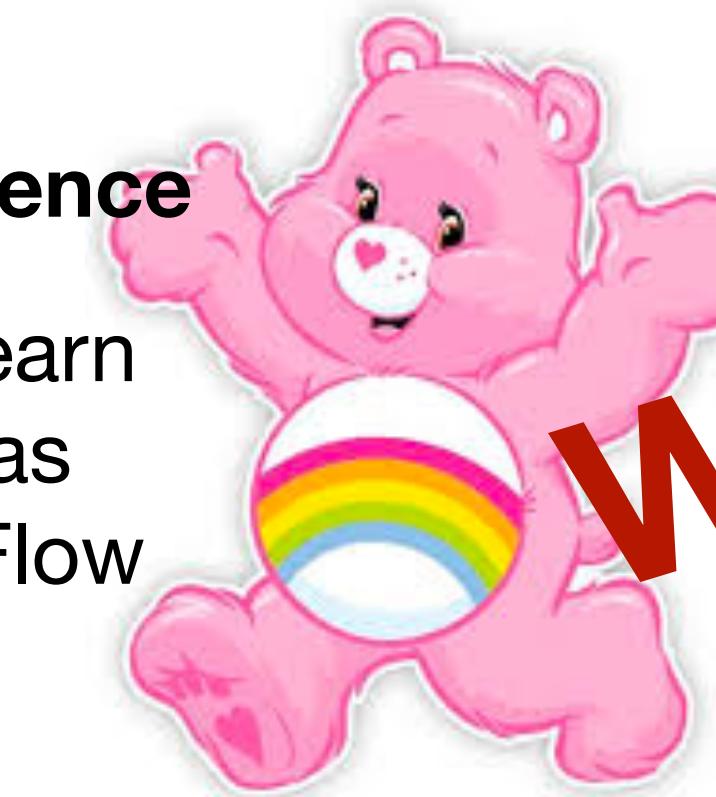
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Weeks 7-9



Sharing

Docker
Google Colab
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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
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MATLAB

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Week 1

- **Anaconda environments and where python is on your computer**
- **VS Code, starting a jupyter notebook, running a script**
- **Basics and syntax review**

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

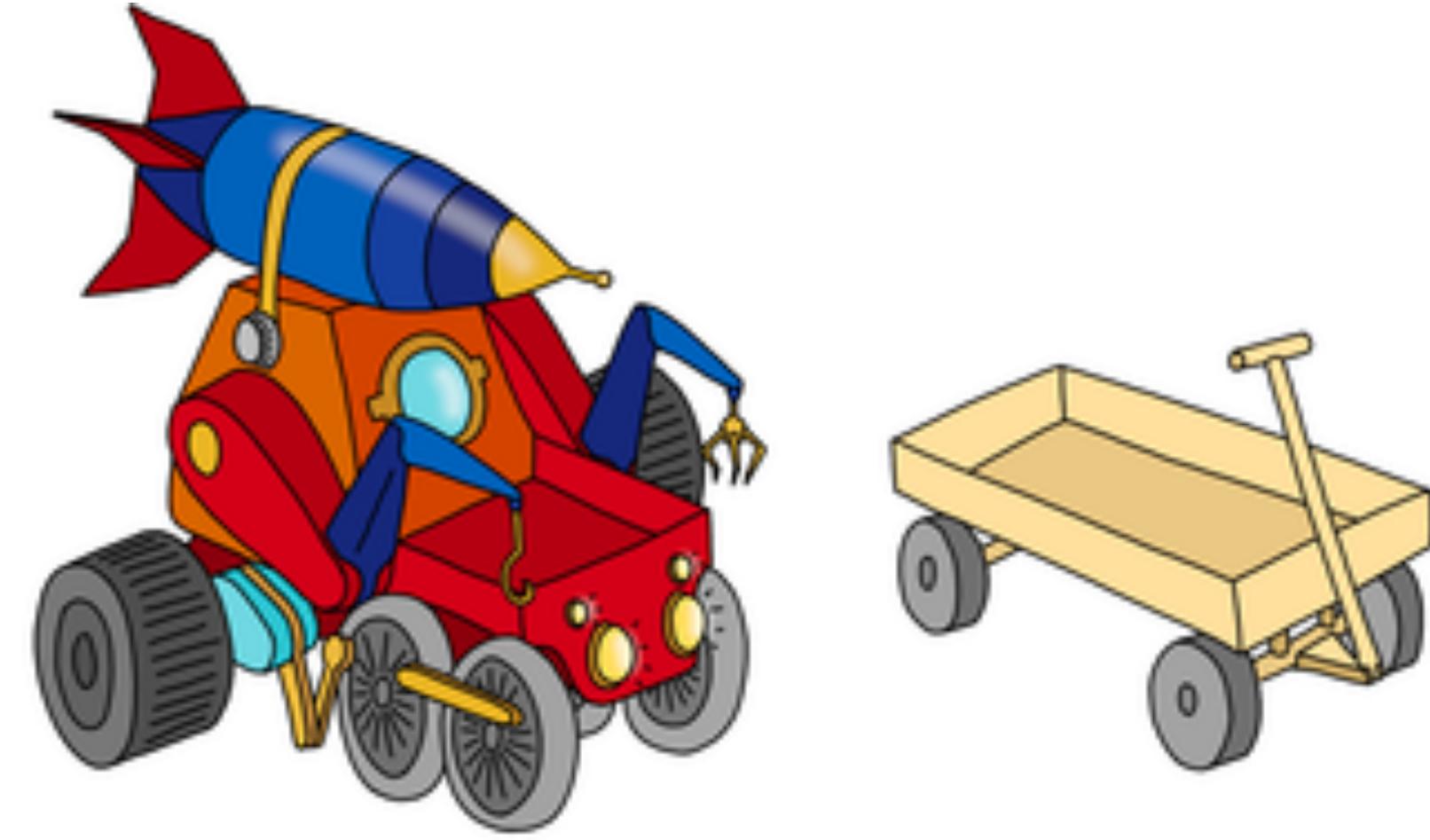
OPEN ACCESS

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)

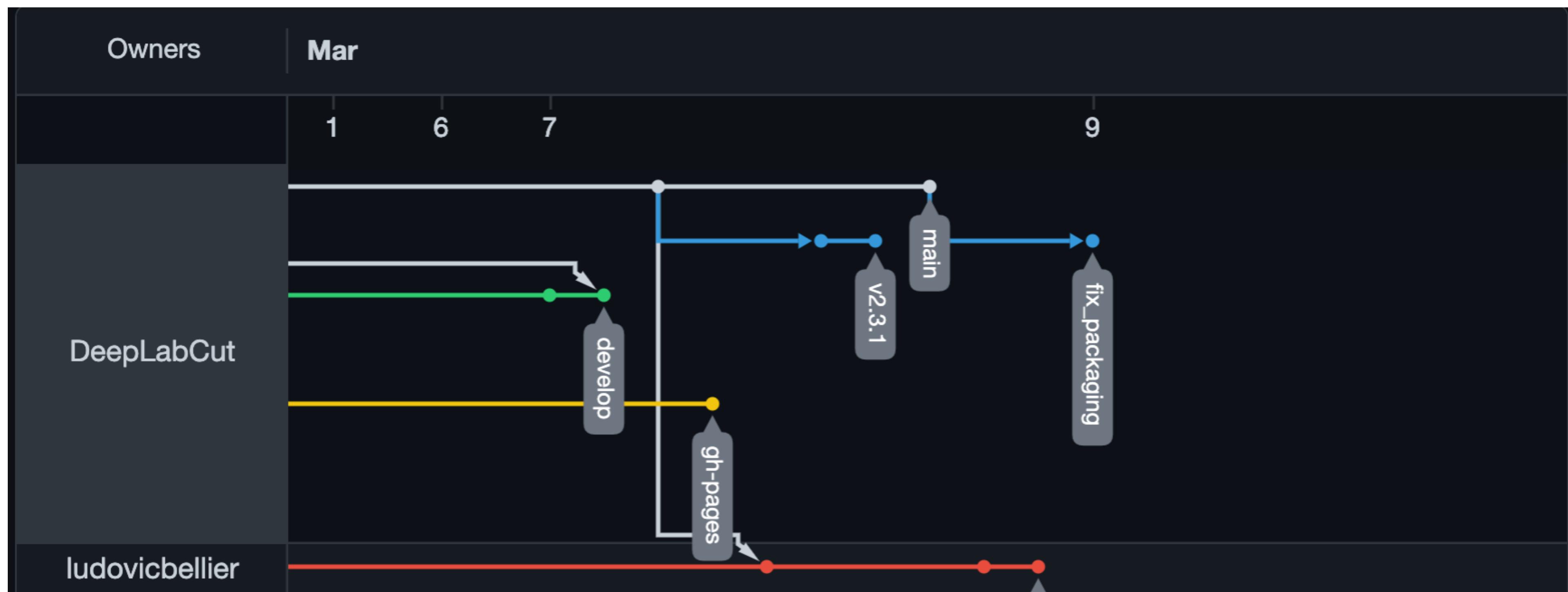
git

...and GitHub, are **version control**

- This is important. And not intuitive. It will likely make you frustrated and/or confused at some point.
- Version control is not optional; if you don't use git for version control, you are going to use something else (e.g.,: 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 git a part of your workflow can simplify and provide redundancy and flexibility; more advanced features also makes sharing simpler. Evaluation.
- git has to be installed, which we can use Anaconda to do (even if you are using MATLAB only for your project)
- Command-line is great, but if you are new to git we recommend using [GitHub Desktop](#)
- **We're going to go over some git interactively to get course materials today.**

git

Conceptually



GitHub

Conceptually

Remote



Local

A screenshot of a code editor (VS Code) showing a Python script named `squirrel_2AFC_gratings.py`. The script imports various modules like `glob`, `time`, `numpy`, `pyfimata`, and `pyglet`. It sets up a game window, defines a sprite, and handles events. A terminal tab at the bottom shows command-line output related to the script's execution.

```
import glob, time
from numpy import random
from pyfimata import ArduinoMega, util

#set up image and gameplay resources=====
import pyglet
pyglet.resource.path = ['./models']
pyglet.resource.reindex()
game_window = pyglet.window.Window(800, 600)
grating_image = pyglet.resource.image('grating.jpg')
grating_image.anchor_x = grating_image.width // 2 #center image
sprite = pyglet.sprite.Sprite(grating_image, x = 100, y = 300)
#=====

# set up simple class that does nothing but hold parameter states
> class Params():
    params = Params()
#=====

# set up global timer for session. simply starts right before the game loop starts and runs up forever.
# access using `timer.time`
> class Timer():
    timer = Timer()
    timer.start()
#=====

# on draw event. this is the main game loop=====
@game_window.event
def on_draw():
    game_window.clear()      # clear the window

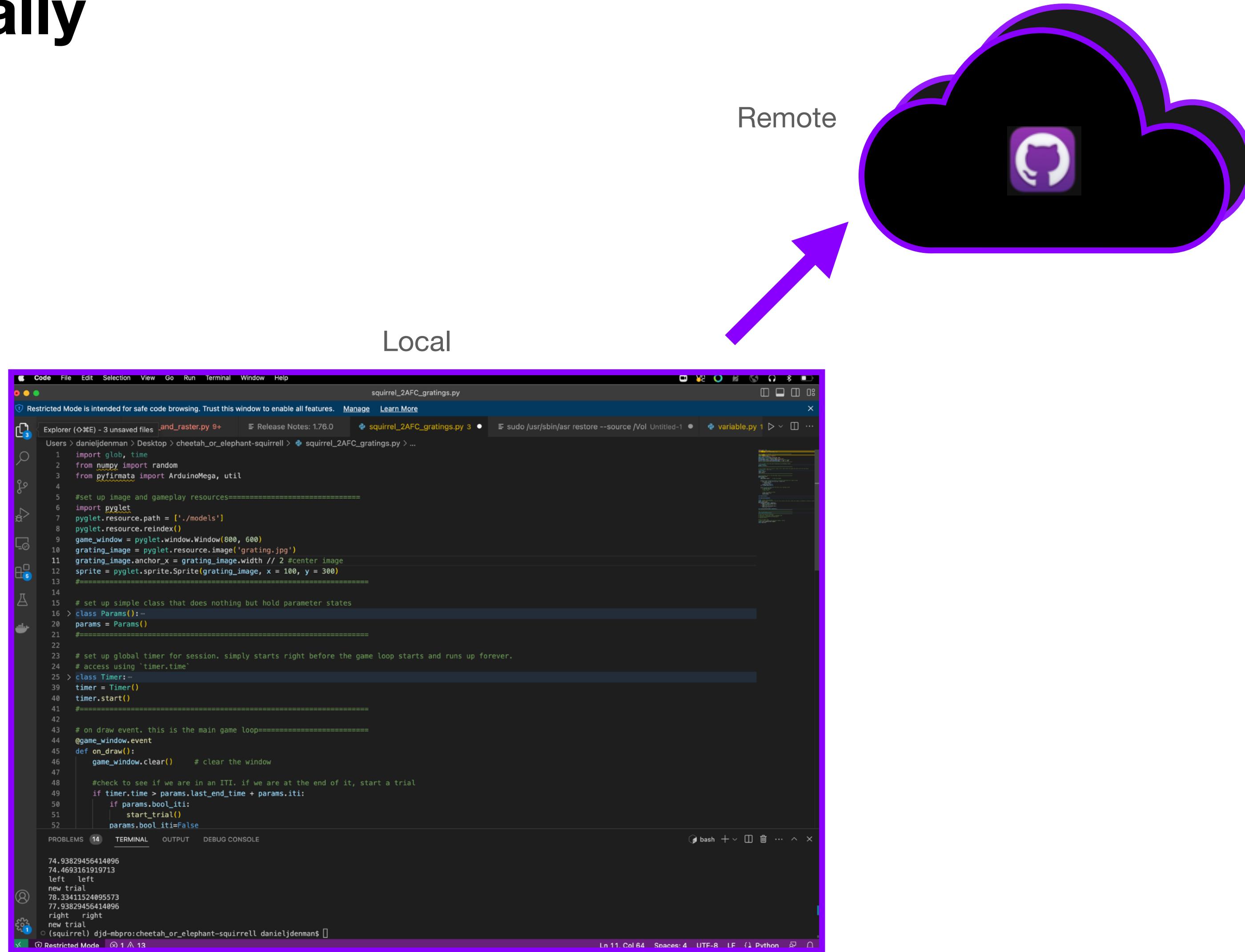
#check to see if we are in an ITI. if we are at the end of it, start a trial
if timer.time > params.last_end_time + params.iti:
    if params.bool_iti:
        start_trial()
    params.bool_iti=False

PROBLEMS 14 TERMINAL OUTPUT DEBUG CONSOLE bash + ... ^ x

74.93829456414896
74.4693161919713
left left
new_trial
78.3341524095573
77.93829456414096
right right
new_trial
(squirrel) djd-mbpro:cheetah_or_elephant-squirrell danieljdenman$
```

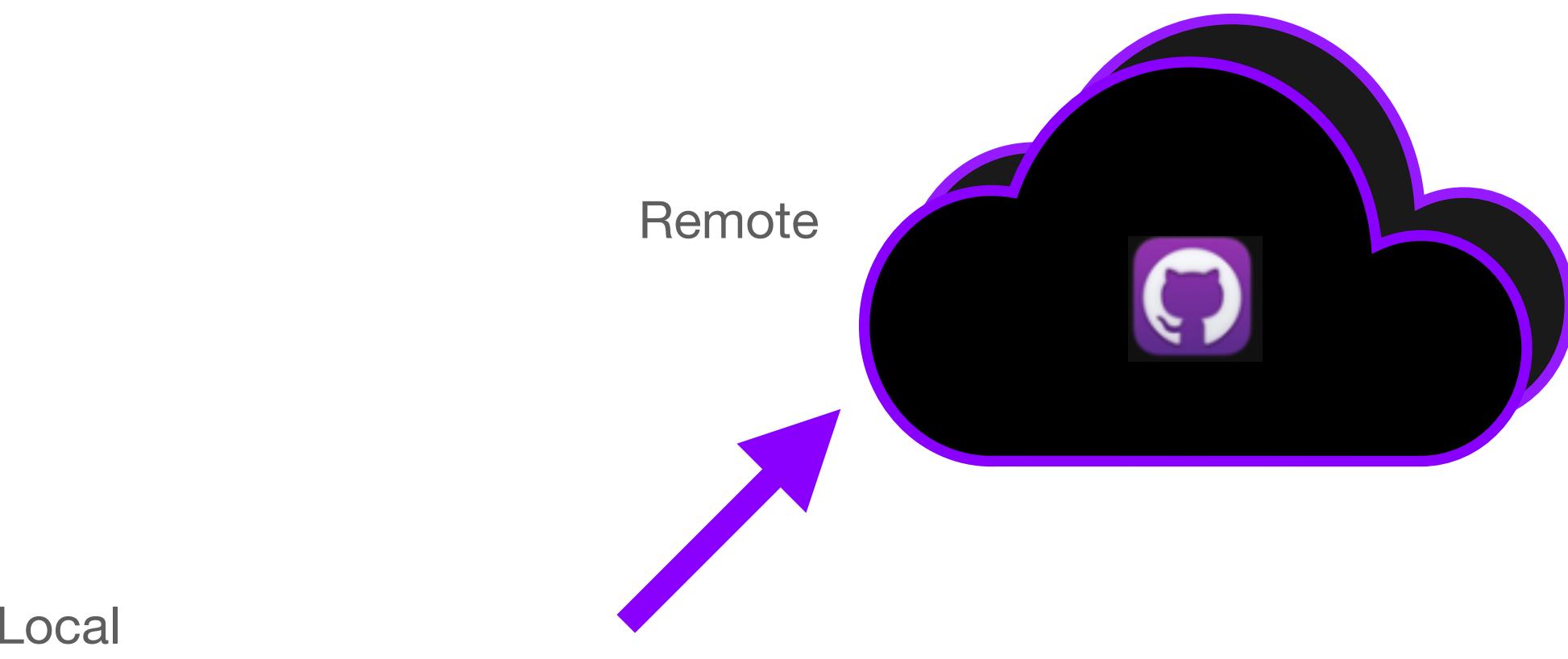
GitHub

Conceptually



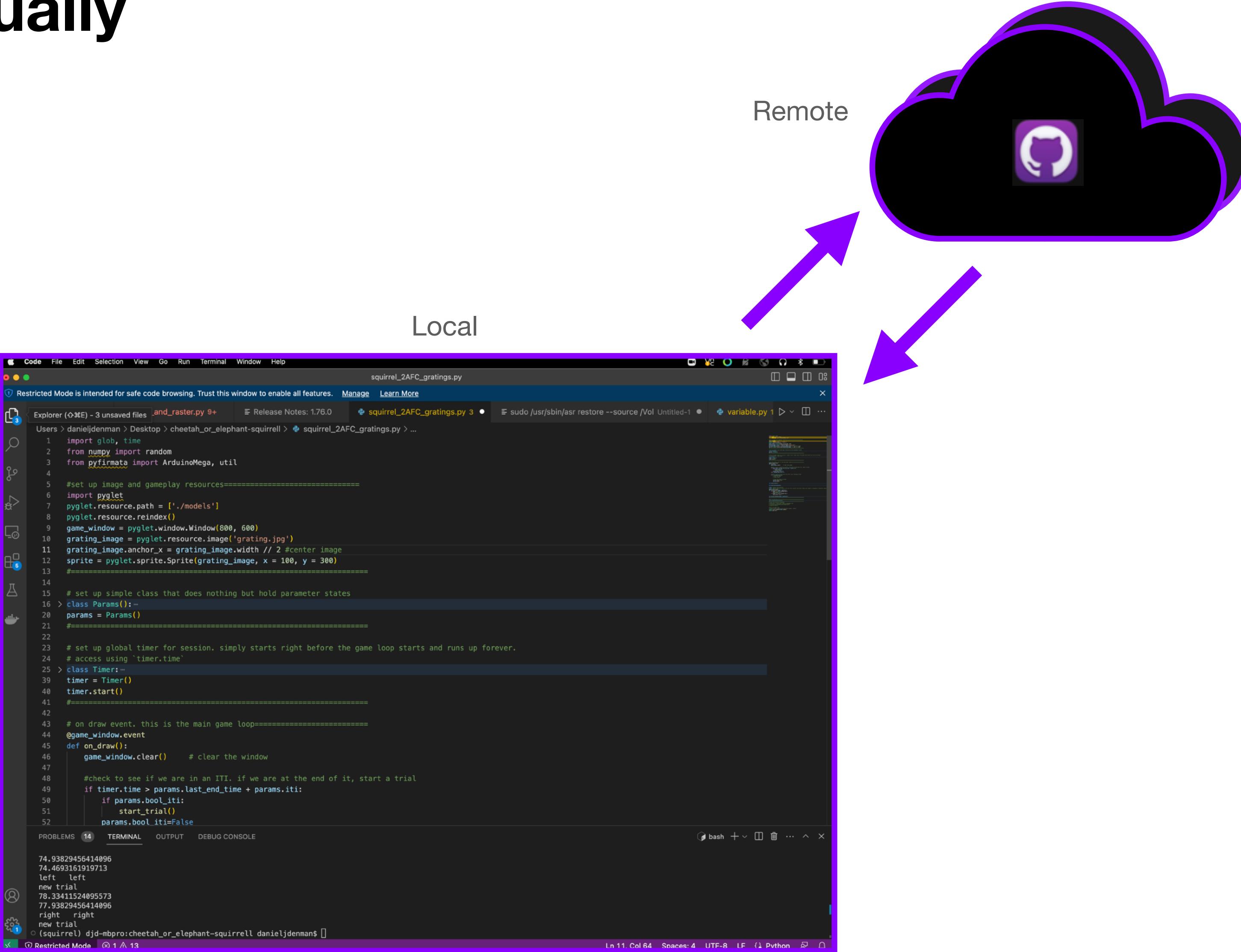
GitHub

Conceptually



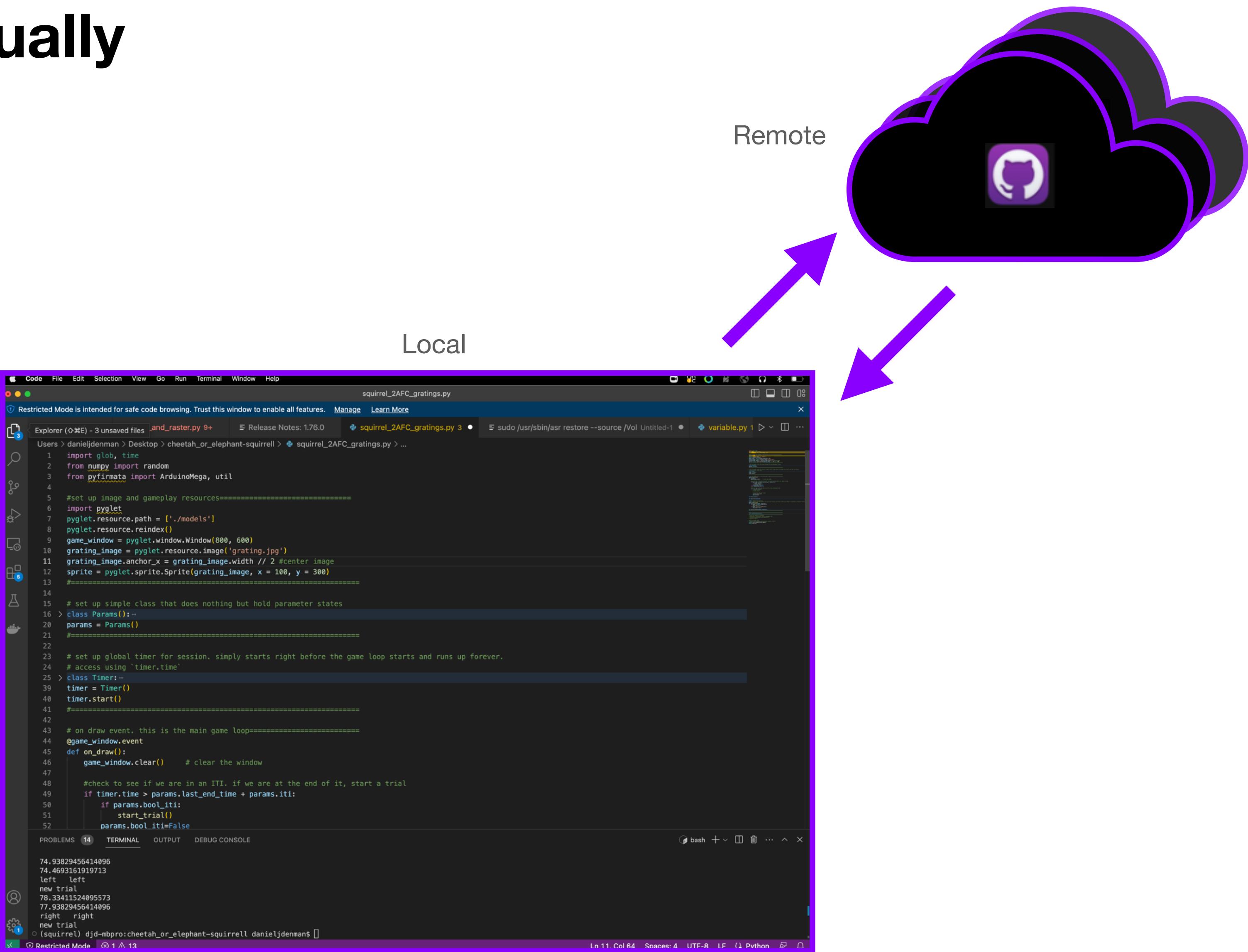
GitHub

Conceptually



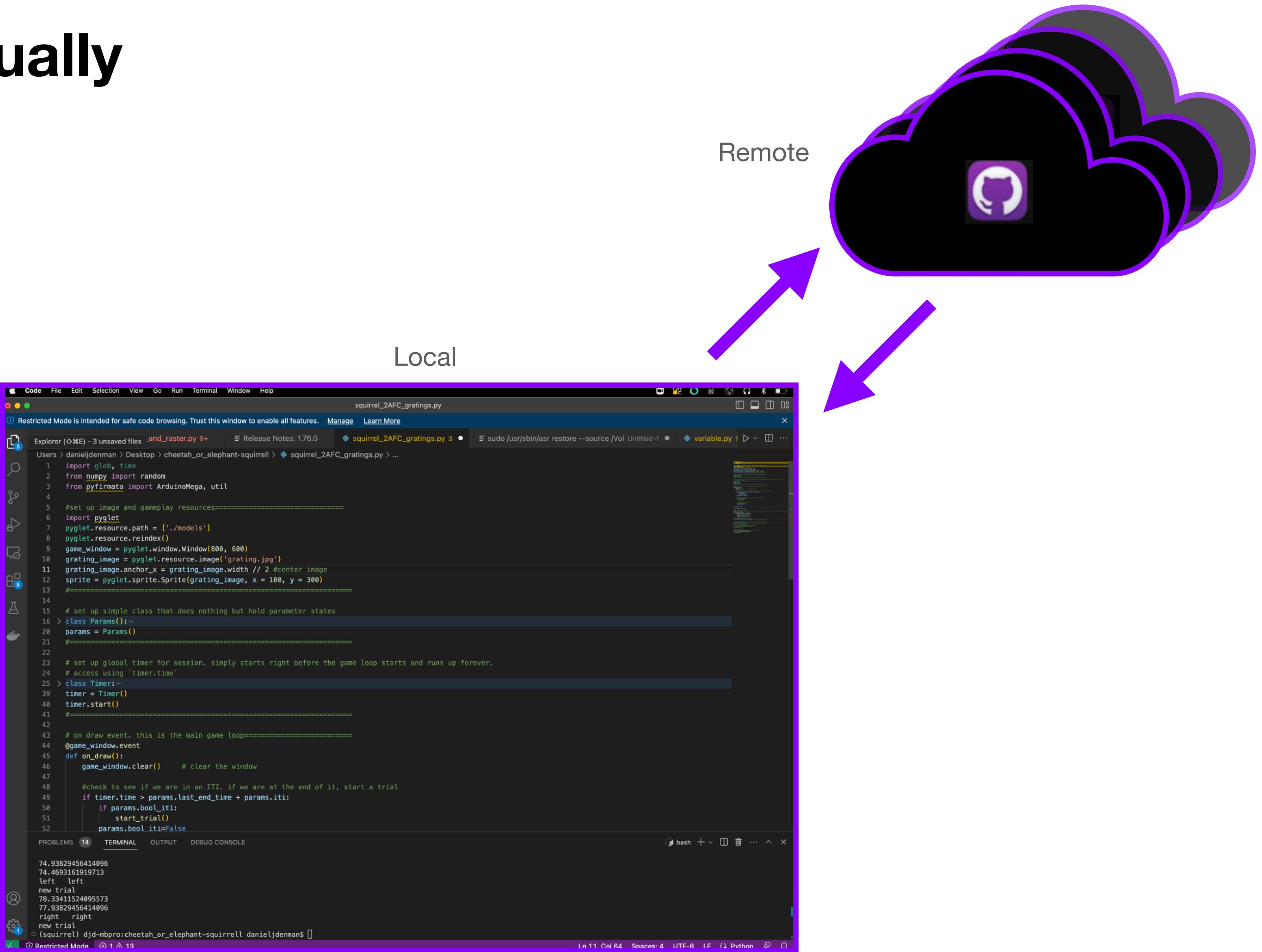
GitHub

Conceptually

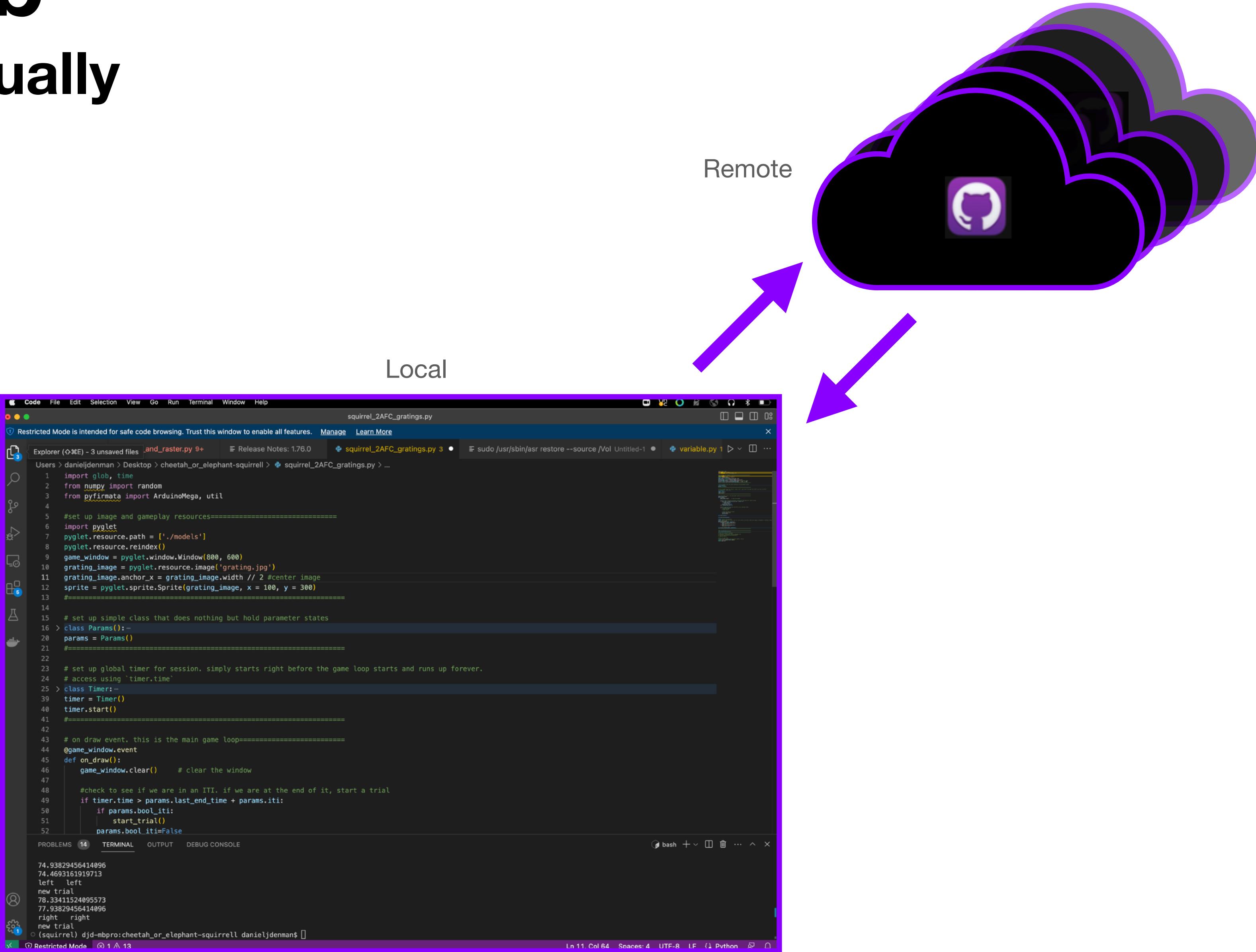


GitHub

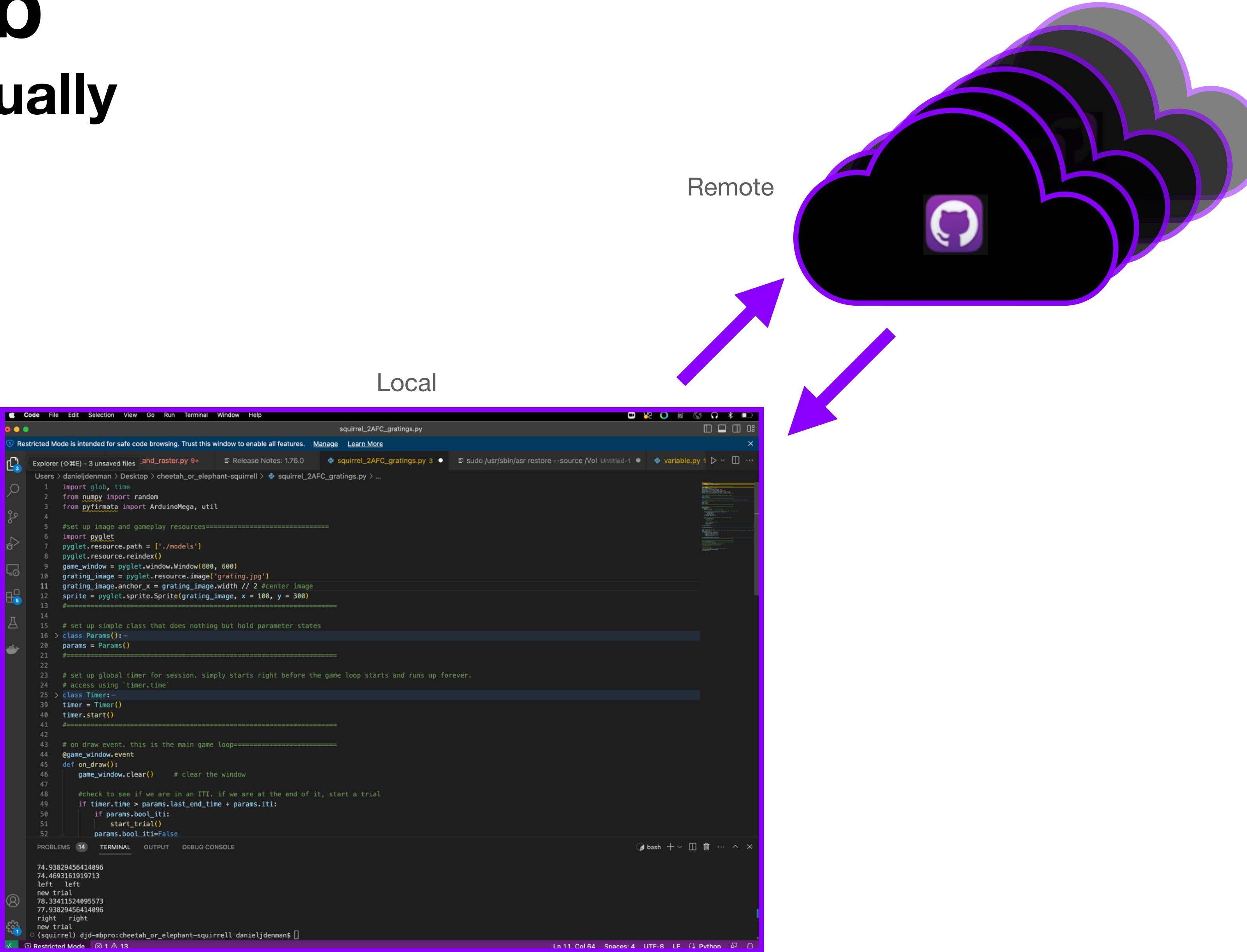
Conceptually



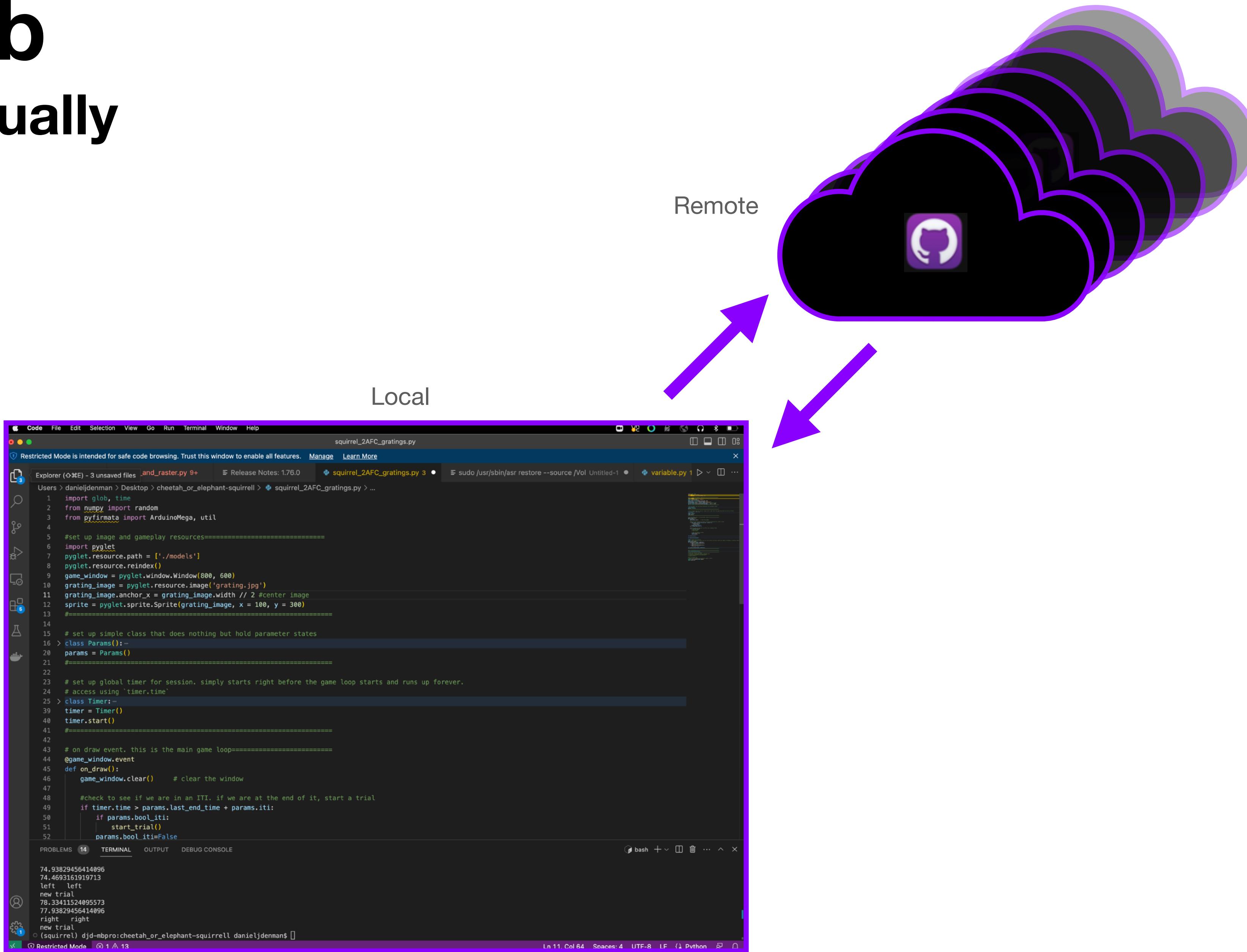
GitHub Conceptually



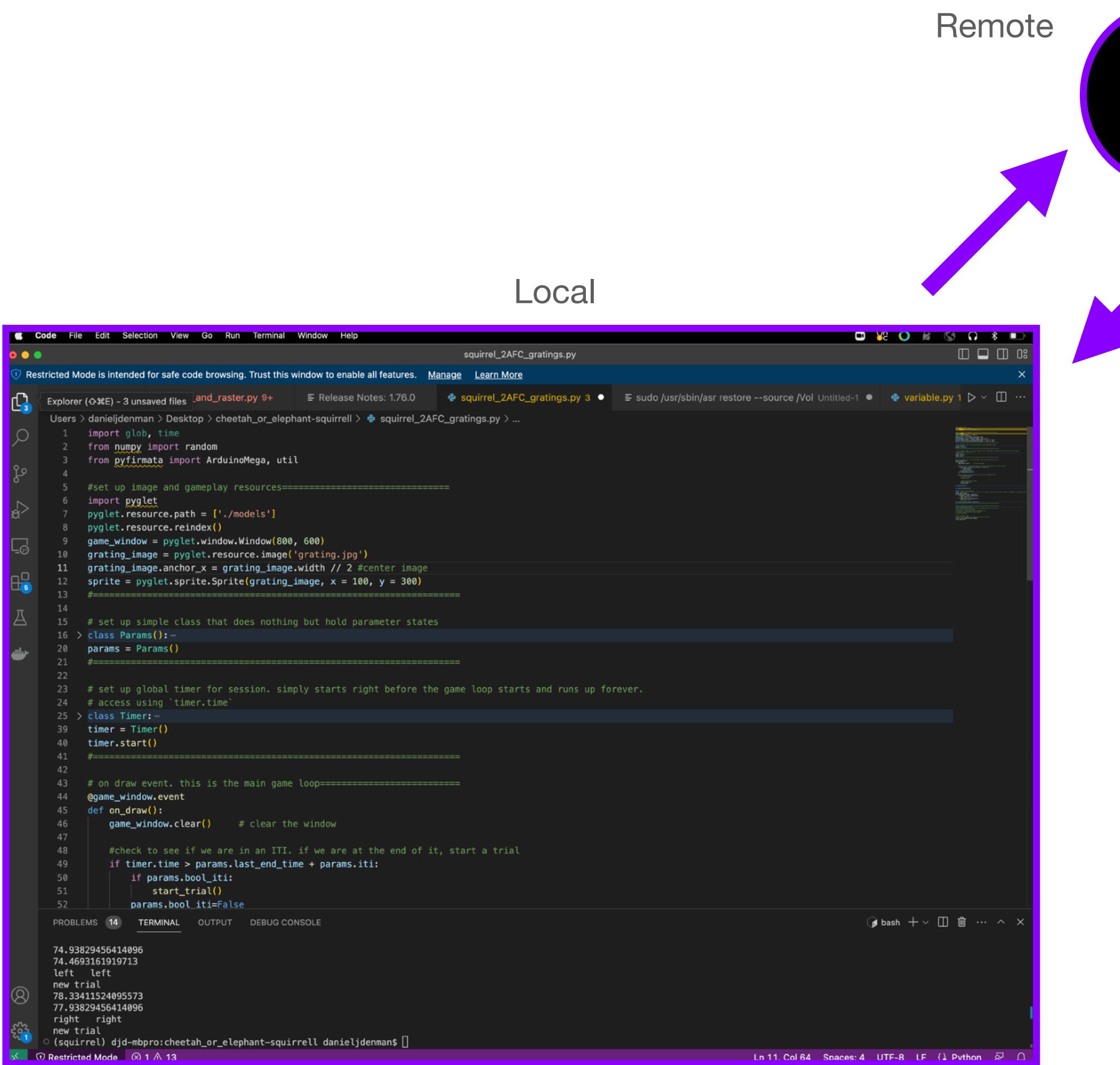
GitHub Conceptually



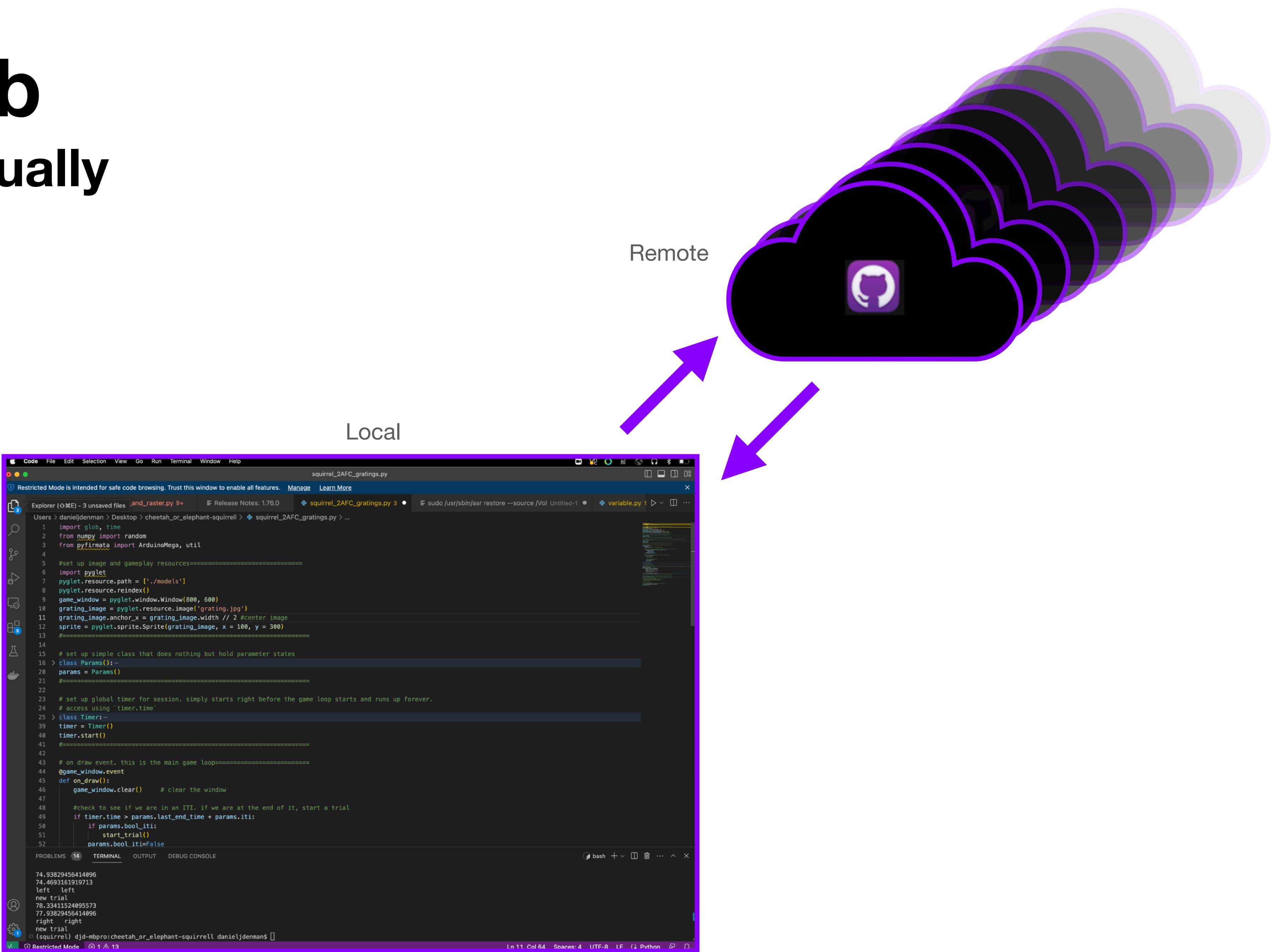
GitHub Conceptually



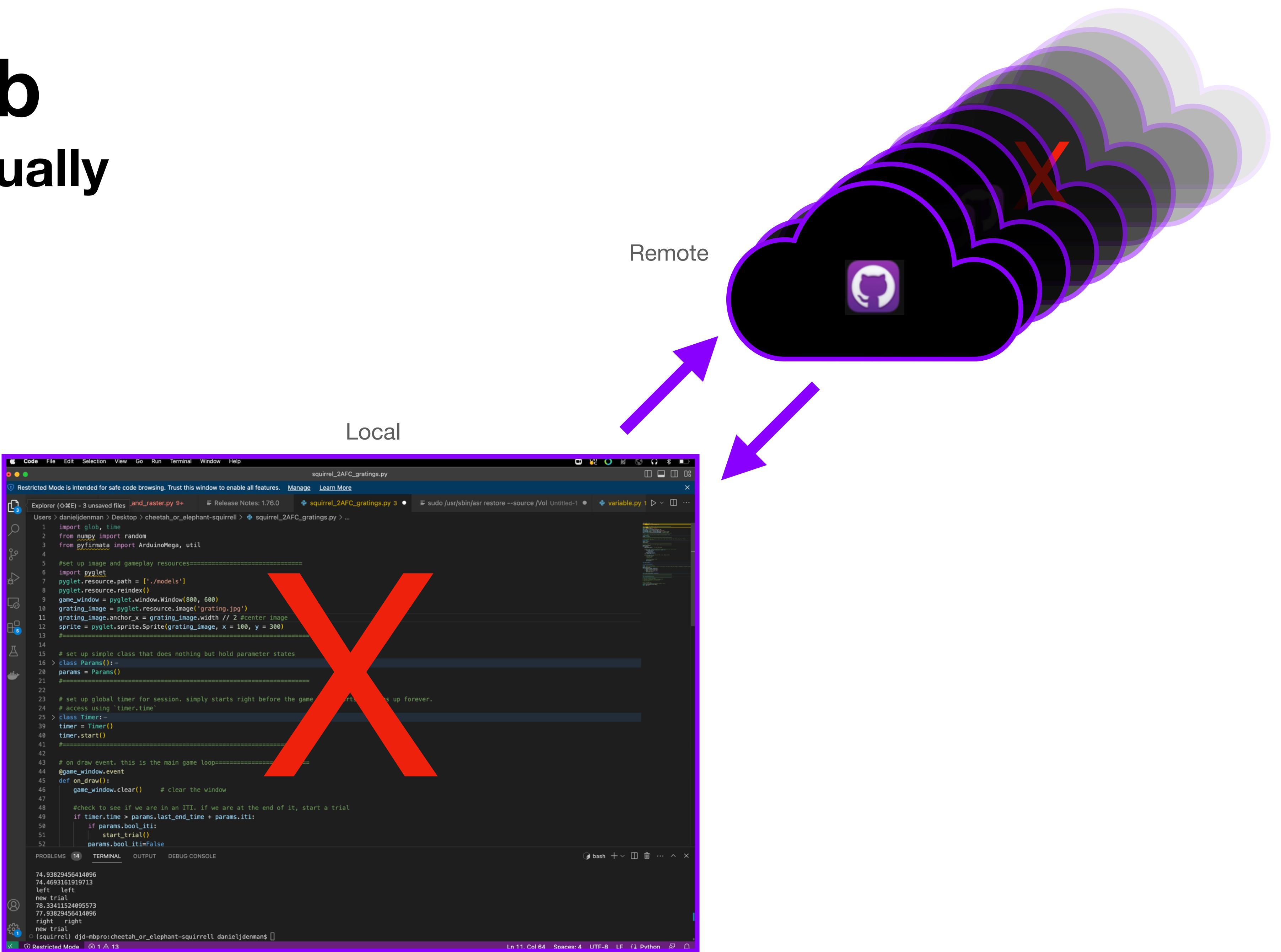
GitHub Conceptually



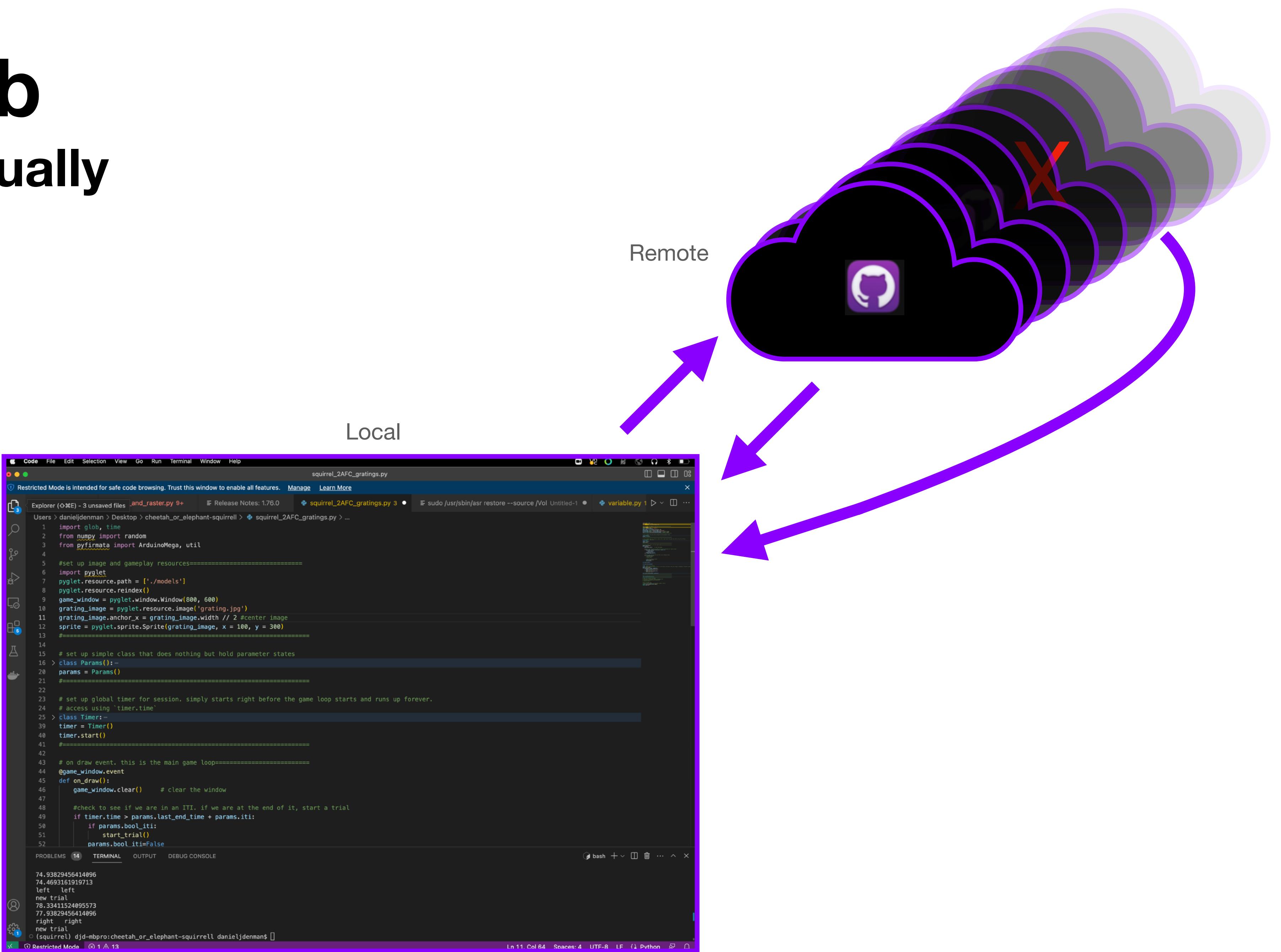
GitHub Conceptually



GitHub Conceptually

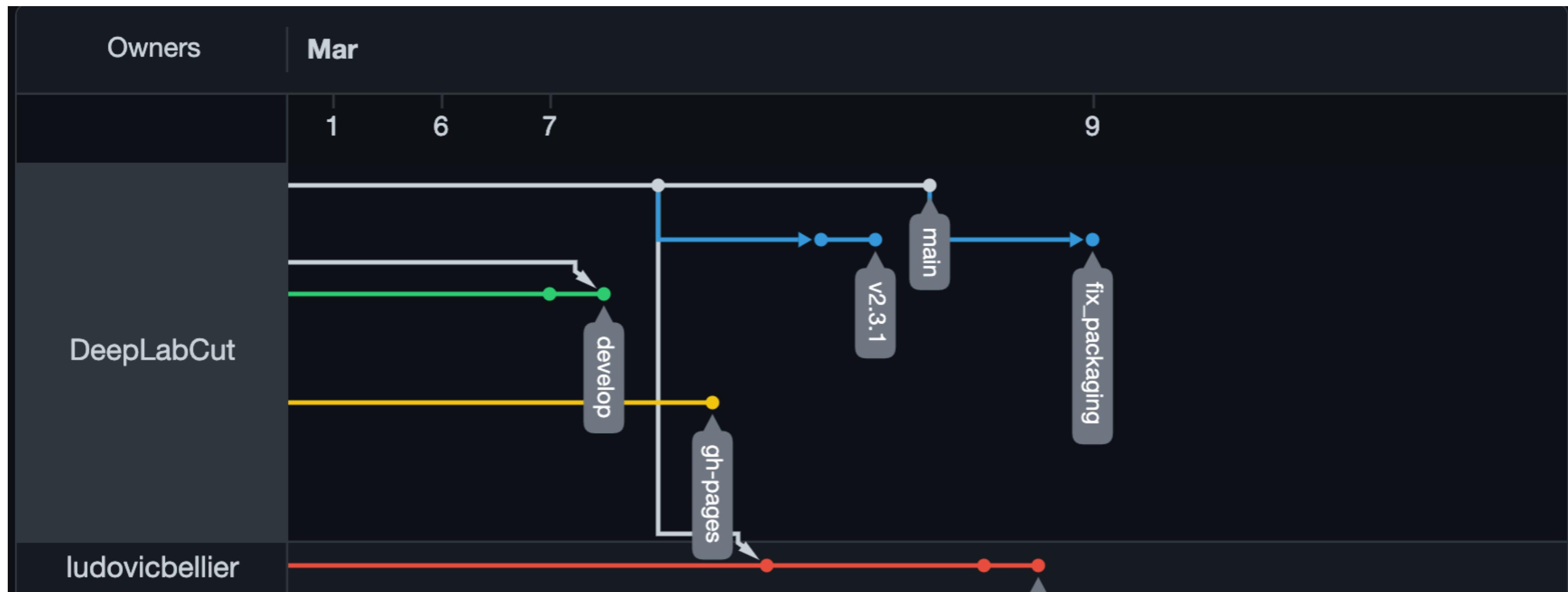


GitHub Conceptually



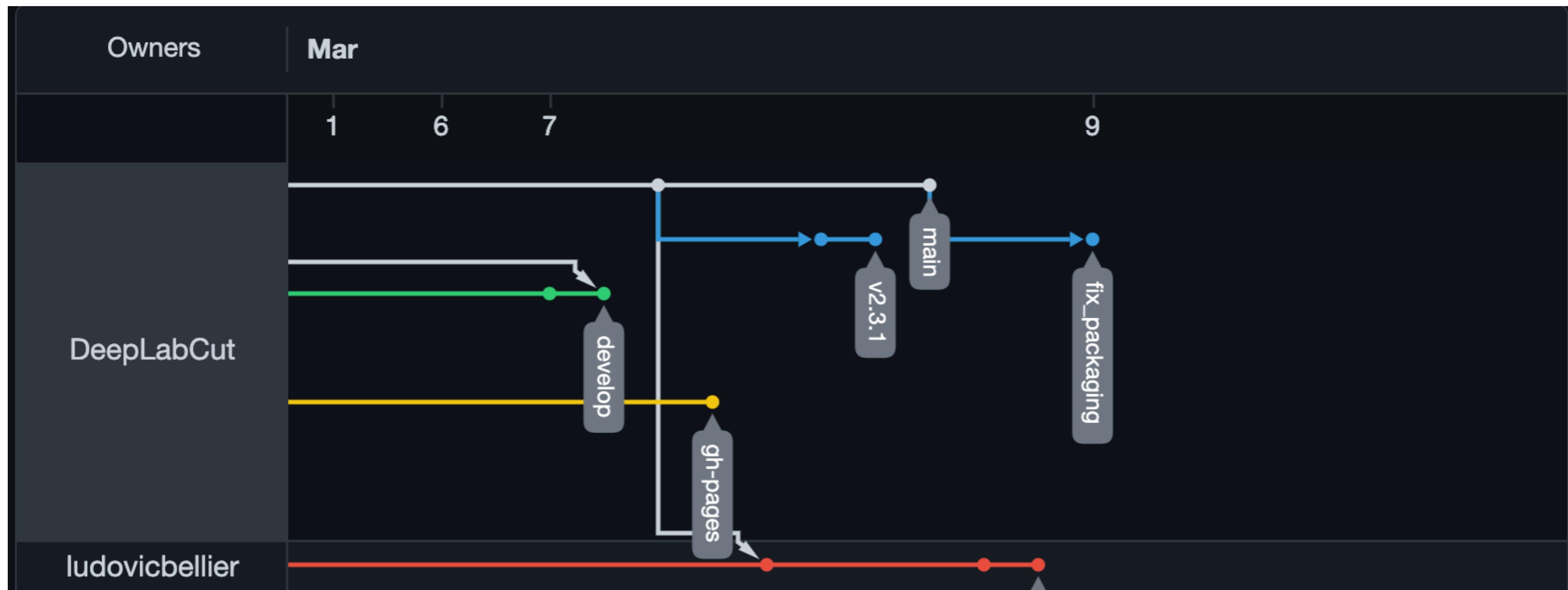
Github Desktop

Branching / Forking



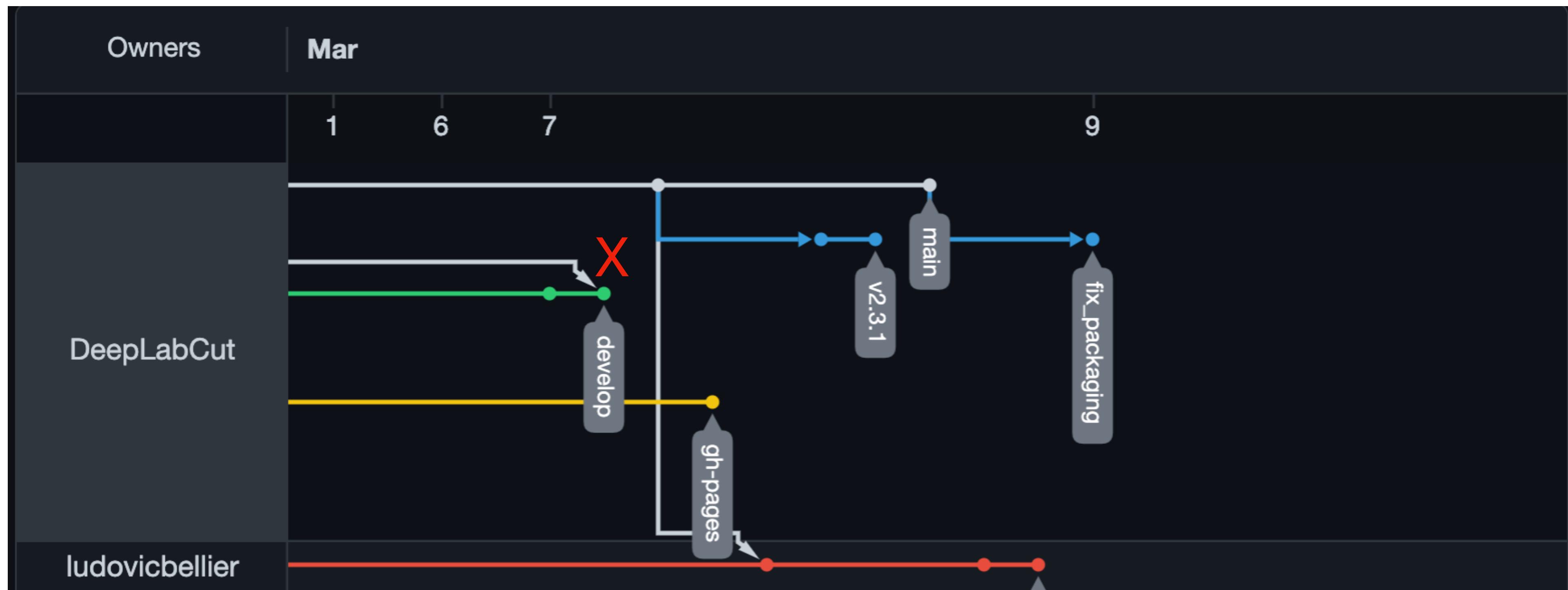
Github Desktop

Merging



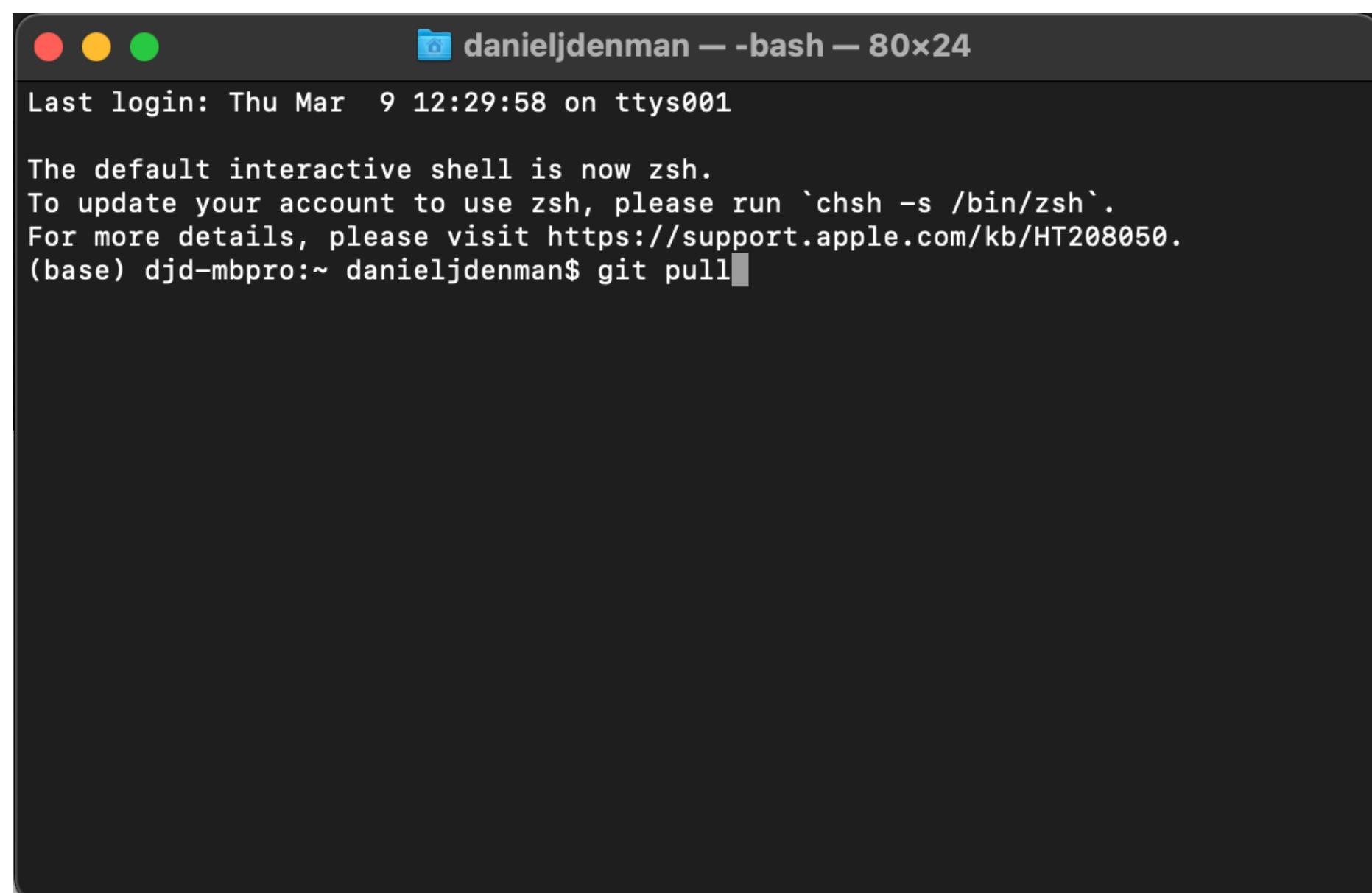
Github Desktop

Conflicts

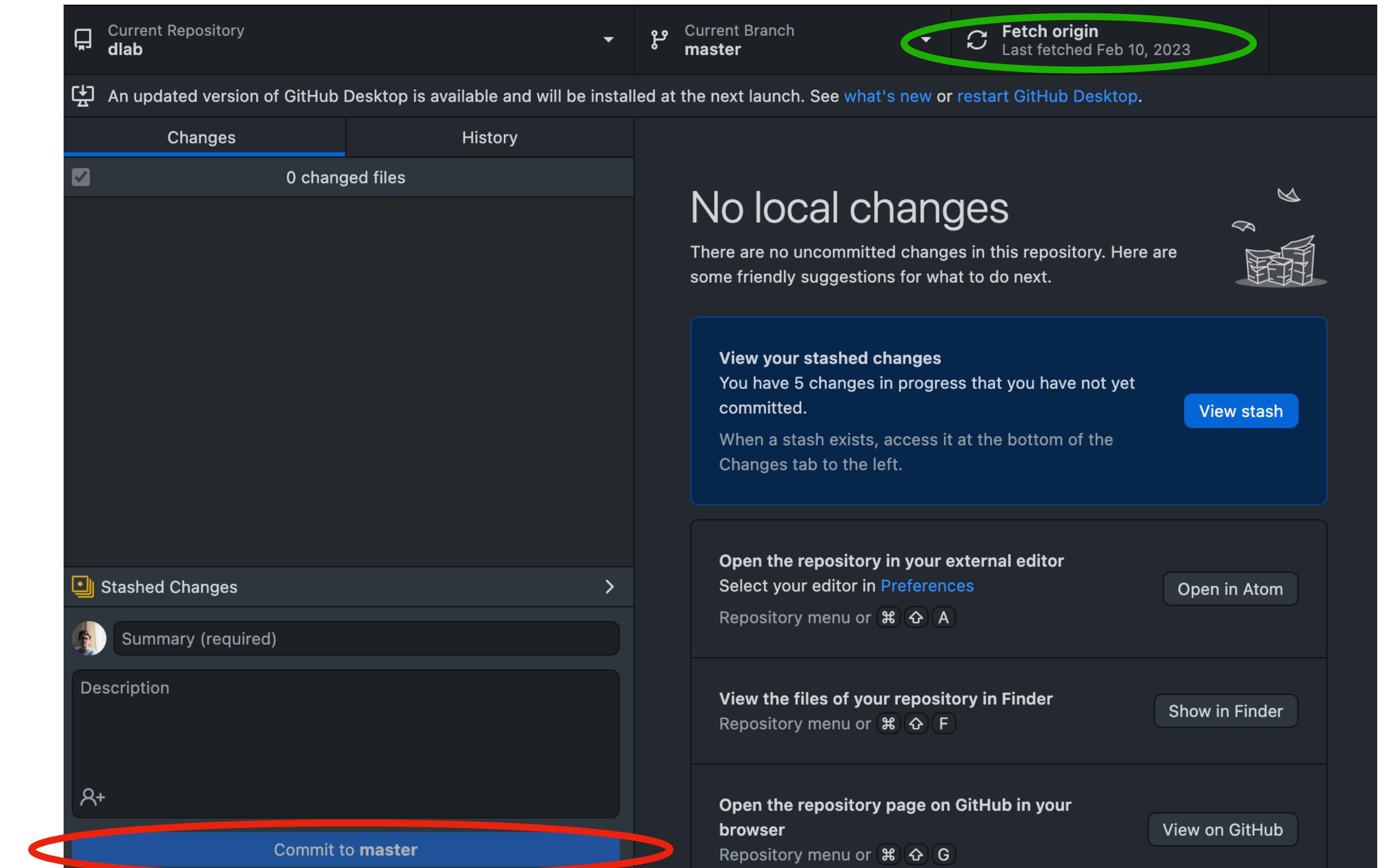


GitHub

CLI vs. GUI



```
Last login: Thu Mar  9 12:29:58 on ttys001
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.
(base) djd-mbpro:~ danieljdenman$ git pull
```



Current Repository **dlab**

Current Branch **master**

Fetch origin
Last fetched Feb 10, 2023

An updated version of GitHub Desktop is available and will be installed at the next launch. See [what's new](#) or restart GitHub Desktop.

Changes History

0 changed files

No local changes

There are no uncommitted changes in this repository. Here are some friendly suggestions for what to do next.

View your stashed changes

You have 5 changes in progress that you have not yet committed.

When a stash exists, access it at the bottom of the Changes tab to the left.

View stash

Stashed Changes

Summary (required)

Description

Commit to master

Open the repository in your external editor

Select your editor in [Preferences](#)

Repository menu or ⌘ ⌘ A

Open in Atom

Show in Finder

View the files of your repository in Finder

Repository menu or ⌘ ⌘ F

Open the repository page on GitHub in your browser

Repository menu or ⌘ ⌘ G

View on GitHub



git fetch origin
git reset --hard origin/master



git push --force